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COMMISSION STAFF WORKING DOCUMENT

5G Global Developments

Accompanying the document

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

5G for Europe: An Action Plan

{COM(2016) 588 final}

STAFF WORKING DOCUMENT

5G Global Developments

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1. Preamble

This Staff Working Document presents a short summary of 5G developments worldwide and of the main issues currently at stake which impact the anticipated deployment of 5G networks. It accompanies the Communication "*5G for Europe: An Action Plan*" with the aim of providing background information explaining the context within which the 5G Action Plan is being presented by the European Commission.

It draws on multiple consultations, events[1] with stakeholders, several studies[2], numerous input from Industry[3], early results[4] of the 5G-PPP and the results obtained through a targeted consultation that took place from 13 June 2016 to 11 July 2016[5].

2. 5G Early Context

Public reflections on a new generation of 5G communications technologies started in 2011, based on the prospects for new markets, new usages and advanced technologies which could not be considered during the time frame of development of the 4G/LTE standards (current generation of mobile communications systems)previous generation (4G).

This triggered European 5G related R&D projects under the EU 7th Framework Programme, which acted as technological pathfinders for the core 5G technological options[6]. The 5G Public Private Partnership (5G PPP) was then created in 2013 under the Horizon 2020 Research & Innovation programme by the European Commission with the objective of fostering European 5G industrial leadership. Today, the 5G PPP implements a set of strategic industry-led projects[7] with a total of 166 stakeholders. An EU funding of €700 million is planned for the initiative, leveraging at least €3.5 billion from the private sector between 2014 and 2020.

At the global level, several prominent 5G industrial public private partnerships have been launched between 2013 and 2015 involving leading operators, vendors, universities, and research institutes in the field of mobile communications:

- The **IMT-2020 (5G) Promotion Group** in **China** (2013), the major platform to promote the research of 5G in China including deployment aspects.
- The **5G Forum** in the Republic of **Korea** (2013), with a budget of $ 1.4 billion (2/3rd private, 1/3rd public), leading work on technologies and infrastructures for early 5G deployment in Korea in 2018 at the winter Olympic games.
- The **5G Mobile Communication Promotion Forum** (5G MF) in **Japan** (2014), a promotional organization for R&D and standardization collaborative activities. It leads

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1 See: e.g. https://5g-ppp.eu/event-calendar/
2 See footnotes 4 and 5 above.
3 Notably the *5G Manifesto for timely deployment of 5G in Europe*, 7 July 2016: http://ec.europa.eu/newsroom/dae/document.cfm?action=display&doc_id=16579;
4 White paper "5G Empowering Vertical Industries": https://5g-ppp.eu/roadmaps/
5 https://ec.europa.eu/digital-single-market/en/news/targeted-consultation-co-ordinated-introduction-5g-networks-europe
Please see respondent profile in annex. It is planned to publish shortly a public summary report of the results of the targeted consultation.
6 https://5g-ppp.eu/projects/
7 <web link Cordis to list of projects H2020>

the preparation of the 5G deployments in Japan for the Tokyo Olympic Games of 2020.

- Furthermore, in 2015 the **5G Americas** industry association was reshaped to focus on industry preparation towards 5G migration in the US and in South America.

These activities with governmental support have generated a global momentum, which has significantly accelerated the pace of 5G developments over the last 18 months. In that context, the European Commission DG CONNECT has signed Joint Declarations of co-operation with its counterparts in South Korea, Japan, China and Brazil to foster alignment of 5G global visions and approaches towards standards and radio spectrum[8]. A closer cooperation is also being established with key US organisations.

3. What is 5G?

The concept of very high performance 5G networks results from a combination of different factors.

From the service and business perspective:

- **A significant increase in mobile video consumption** will drive around six times higher traffic volumes per device in North America and Europe after 2020. The popularization of cloud-delivered Media and Social Media content to smart devices puts additional constraints on the intermediate communication links, whilst ever richer content calls for significant capacity increase. Virtual reality applications are expected to require gigabit/s capability whilst the generalization of 8K Ultra High Definition Televisions[9] and UHDTV streaming should require capacities of more than 100Mb/s for a single user.

  From the 5G perspective, the corresponding services are called "enhanced Mobile Broadband", also referred to as eMBB in the following text, and target applications with aggregated speeds higher than 10 Gb/s.

- **The advent of Machine to Machine communication,** with large numbers of connected devices (massive IoT) used in professional and industrial applications or in smart cities deploying large populations of sensors, calls for highly efficient radio networks and very low energy consumption.

  From the 5G perspective, the corresponding services are called "massive Machine to Machine Communication", also refered to as mMTC in the following text, and target applications with millions of devices/km².

- **New time-demanding applications** requiring instant reaction, i.e. very low latency in the order of 1ms, cannot be served by today's existing technology with the required guarantee of performance[10]. Typical applications include remote surgery, connected cars (mainly for safety services and fast prediction of surrounding conditions), smart factories and robotics, or detection of faults in energy grids. These time critical applications will, in most cases, have to combine 5G connectivity with distributed (mobile) cloud technology in order to meet the required end-to-end response times.

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[8] https://ec.europa.eu/digital-single-market/en/5G-international-cooperation

[9] 8K refers to the number of "pixels" (picture elements) with 4 times better horizontal and vertical definition of an image compared to traditional High Definition TV standards (2K pixels for horizontal definition)

[10] Typical LTE latency is today at about 10ms.

From the 5G perspective, the corresponding services are called "Ultra Reliable Low Latency" also refered to as URLL in the following text, and target applications with very low latency requirements.

From the technological perspective:

Several disruptive technologies are expected to act as game changers:

- **The prospect of economic fibre-like radio access** with data rates beyond 10 Gb/s is within reach, notably through the usage of higher frequency bands above 6 GHz and related technologies. Today, spectrum allocations for wireless broadband are situated below 6GHz. Higher frequency bands will offer larger capacities for disruptive capabilities, such as a large number of simultaneous communications with users/devices, and open the prospect for user data rates meeting the International Telecommunication Union (ITU) requirements for 5G (i.e. exceeding 10 Gb/s). Multiple trials performed by industry in 2016 showed that speeds higher than 10 Gb/s and up to 70 Gb/s can be achieved using spectrum above 6 GHz. A vast majority of vendors and operators aim at using spectrum around 30 GHz (25-32 GHz) for early 5G trials at high speeds, where commercial implementation may be feasible in the short term.
- **Network Function Virtualisation** (NFV) offers the prospect of implementing specific network functions (e.g. Content Delivery Network, Customer Premises Equipment management etc.) in software running on generic hardware, without the need for costly hardware-specific machines. The expected impacts are i) a drastic reduction in capital expenditure (capex) and network management costs – operational expenditure (opex); ii) reuse and sharing of the same functionality between several customers; iii) higher innovation capability through easy introduction of new software functionalities and creation of a "network app" market place. The trend towards virtualisation is profound in the industry. For instance, Telefonica plans to virtualise at least 30% of its network in the short term; AT&T plans to virtualise 75% of its network by 2020 to cope with mobile traffic explosion. More than 250 companies support the ETSI-NFV Industry Specification Group (ISG) which is one of the leading bodies for NFV functional specifications.
- **Software Defined Networking** (SDN) is a complementary trend to NFV that allows the control of network resources to be opened to third parties, with the possibility for these third parties to manage their own physical or virtual resources individually, as needed, with the required level of performance tailored to actual needs. This possibility goes much beyond the management capabilities offered to today's MVNO's[11].

  In the context of 5G developments, and in view of supporting ad-hoc digital business models of industrial users, SDN and NFV are seen as key components to enable these specific categories of professional users to control their network capabilities dynamically according to their needs. As network resources are potentially available to third parties through open interfaces, they also open the possibility for smaller players

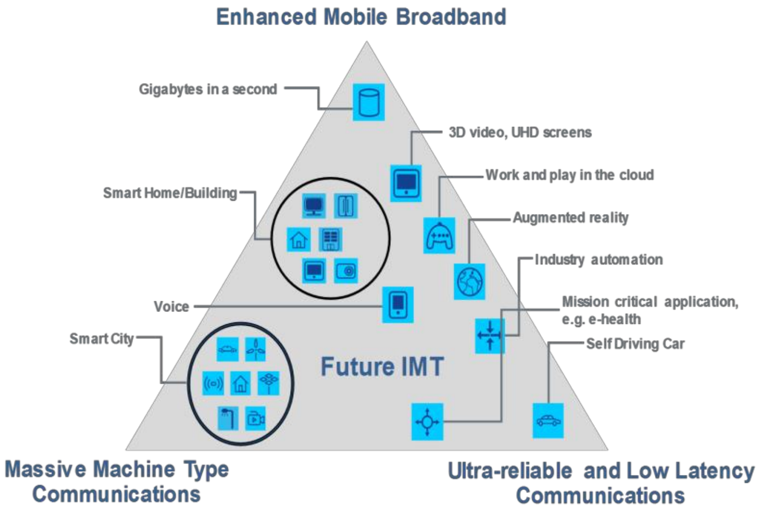
[11] A Mobile Virtual Network Operator operates resources contracted from a network operator owning physical and logical network infrastructure.

to innovate through development of specific service offers building on network resources made available for third party access and programmability.

The core capabilities outlined above go much beyond the current and future 4G/LTE capabilities in the following ways:

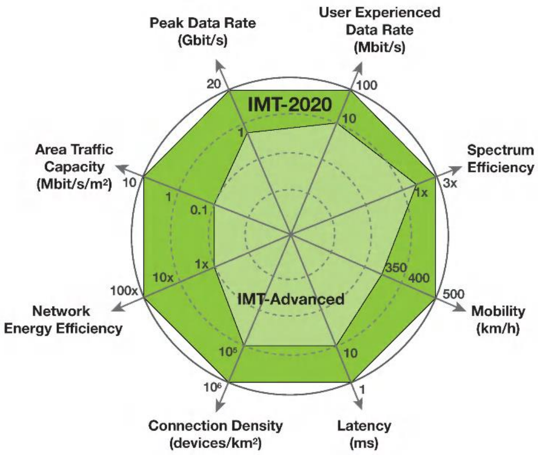
- **Speed**: Today, 4G data rates (accessible to multiple users) are at about 500 Mb/s, which enables in average a maximum data rate of 50 Mb/s per user. Evolution scenarios contemplated by standardisation organisations like 3G PP[12] target a maximum capability for 4G up to 3Gb/s[13].
- **Flexibility to accommodate demanding professional-grade applications**: 4G core network architectures and capability do not widely implement SDN/NFV based functions. This does not allow the resource allocation flexibility that is needed in scenarios where a radio access has to serve applications with very different requirements (e.g. connected vehicle users with very low latency requirements or video streaming users with very high downlink speed requirements). The lack of open interfaces also pre-empts the emergence of innovative service offers in the new domains.
- **Instant response time**: Core 5G application requirements such as low latency of 1ms (10 to 20 ms for 4G), serving 1 million devices/km² (about 1000 device/km² for 4G) or fast deployment of new services in the order of 1 hour deployment time (measured in days with current technology) are not part of today's 4G technology.

Against this background, 5G definition and use cases have been developed by industry. The ITU recommendation ITU-R M.2083-0, approved in September 2015, defines the overall objectives of the future development of IMT for 2020 and beyond. It calls for 5G system improvements that cover three generic classes of services, based on anticipated market developments. These are outlined in the "ITU triangle" below:



[12] 3G partnership Project, the lead global standardisation body for mobile Communications created in the late 90s to address 3G Global standards
[13] LTE-A-PRO version

The ITU Vision document also characterises the increased performance level needed to achieve the 5G (IMT 2020) vision, as outlined in the figure below (IMT advanced refers to 4G)



The 5G PPP Vision document summarises well these objectives (extract below):

> "*5G will not only be an evolution of mobile broadband networks. It will bring new unique network and service capabilities. Firstly, it will ensure user experience continuity in challenging situations such as high mobility (e.g. in trains), very dense or sparsely populated areas, and journeys covered by heterogeneous technologies. In addition, 5G will be a key enabler for the Internet of Things by providing a platform to connect a massive number of sensors, rendering devices and actuators with stringent energy and transmission constraints. Furthermore, mission critical services requiring very high reliability, global coverage and/or very low latency, which are up to now handled by specific networks, typically public safety, will become natively supported by the 5G infrastructure. 5G will integrate networking, computing and storage resources into one programmable and unified infrastructure*[14]*. This unification will allow for an optimized and more dynamic usage of all distributed resources, and the convergence of fixed, mobile and broadcast services. In addition, 5G will support multi tenancy models, enabling operators and other players to collaborate in new ways*."

Similar considerations can be found in other industry publications, e.g. the white paper developed by the Next Generation Mobile Network Alliance (NGMN)[15].

Relevant results of the targeted survey:

There is a widely shared understanding that **5G will be of a disruptive nature**, **a key infrastructure for Europe** and a **core asset to support competitiveness**. This view is expressed by about 70% of respondents, and opposed by only 10%. In the same context, 63% of the respondents agreed with the view that **5G will be a strategic infrastructure in Europe** for the telecom industry, the industries that use connectivity and society in general. **These views are well shared across all categories of respondents,** with some marginal disagreements.

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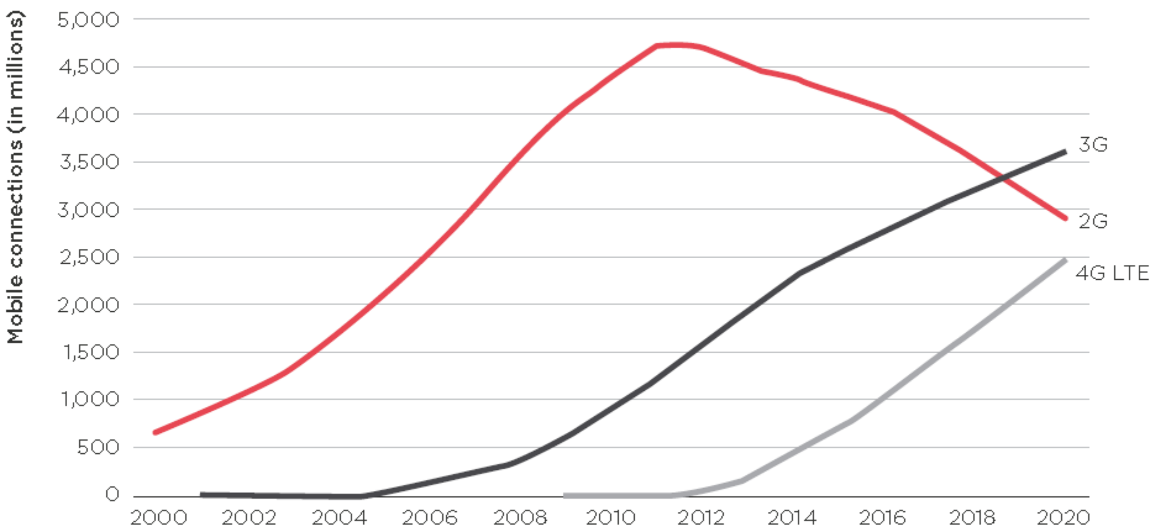
[14] This does not refer to a single physical infrastructure, nor to a single ownership structure.
[15] NGMN 5G White Paper (2015): http://www.ngmn.org/fileadmin/ngmn/content/images/news/ngmn_news/NGMN_5G_White_Paper_V1_0.pdf

4. Migration and co-existence aspects

Evolution from 4G: within the overall 5G development time frame, it is important to note that 4G will continue to be developed and enhanced, and also to be deployed. 5G is not conceived as a technology replacing 4G, but rather enhancing it and complementing it with new service capabilities. At this time, it is considered that the usage of 4G will continue for many years, before eventually 5G takes over completely. A valid similarity can be found with the current 4G introduction pattern, with 4G ramping up whilst earlier 3G/2G are still in use in other frequency bands and still growing globally in the case of 3G. See example graph of technology co-existence below[16].



Therefore, 5G will be designed to co-exist with 4G, and is expected to support the advent of multi technology operations, with terminals having the capability to connect to the best available network, as a function of the service requirements of the application. Each radio access being introduced in a different frequency band, the terminal may eventually dynamically select the best radio access for the considered application. This also encapsulates the usage of WiFi and unlicensed bands, which should be much more tightly integrated into the connectivity offer portfolio of a service provider, and will help to provide "tailor made" connectivity to users as part of their application requirements. The industry is currently working on the required functionality that makes this multi radio convergence possible already partially in a 4G/LTE context. This evolutionary perspective is a key aspect to support gradual investments in 5G, offering an introduction perspective designed to gradually complement the 4G offer.

Considering that 5G will "piggyback" on 4G and thus enhances it, the deployment of 4G is considered as a pre-requisite for a successful introduction of 5G. 4G will ensure the continuity of service when and where 5G functionalities are not fully available in some parts of the infrastructure. This is also reflected by responses to the targeted survey from mobile operators stating that mobile operators are expected to spend USD 1.7 trillion worldwide on their

[16] GSMA report: Understanding 5G: Perspectives on future technological advancements in mobile

network equipment between 2014 and 2020, much of it to upgrading to 4G architecture. That is almost double the USD 878 billion spent from 2009 to 2013 at the time when 3G was being built.

Typical example of a foreseen evolution strategy towards 5G, the case of "connected vehicles" application: a typical upgrading strategy is being pursued in the area of connected vehicles, as outlined below. It is to a large extent also relevant to other specific industry sector applications.

In the case of connected vehicles, it is not envisaged that 5G would simply supersede earlier investments in **ITS-G5**[17] technology, as currently deployed in Europe and in other regions of the world. This technology is based on an evolution of the WiFi standard (802.11.P) and is recognised as a technology of choice for early ITS deployment in Europe, as outlined in the C-ITS platform final report[18], targeting primarily road safety services in the first instance.

The main scenario contemplated for the introduction of 5G functionalities is for the provision of additional services compared to the earlier rolled out technologies, following a **hybrid communication** approach.

As identified in the C-ITS platform report, the main set of agreed services is for the Day 1 level, and covers:

- Hazardous location notifications:
    - Slow or stationary vehicle(s) & Traffic ahead warning
    - Road works warning
    - Weather conditions
    - Emergency brake light
    - Emergency vehicle approaching
    - Other hazardous notifications
- Signage applications:
    - In-vehicle signage
    - In-vehicle speed limits
    - Signal violation / Intersection Safety
    - Traffic signal priority request by designated vehicles
    - Green Light Optimal Speed Advisory (GLOSA)
    - Probe vehicle data
    - Shockwave Damping (falls under ETSI Category “local hazard warning”)

In addition, the C-ITS platform of the Commission has already identified a set of "Day 1.5" services and is working on higher levels of vehicle automation.

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[17] "ITS" is the acronym for Intelligent Transport System. "G5" is a standard for car-to-car communications and should not be confused with "5G".

[18] http://ec.europa.eu/transport/themes/its/doc/c-its-platform-final-report-january-2016.pdf

From a technological point of view the automotive sector works against "Phases"[19], each with a greater service capability.

Phase 1

Generally, the Day 1 applications of the C-ITS platform can be considered as ‘awareness driving’, e.g. the traffic participants share status information, to allow others to understand the current status of conditions around them.

Phase 2

For the next phase, it is expected that the participants will also share the observations, e.g. the data from their sensors, in addition to status data. This can be envisaged to allow provision of information about traffic participants that are not themselves able to provide status information, e. g. because they are not C-ITS equipped. This second phase is often called ‘sensing driving’.

Phase 3

Again building on top of the information provided in the first two phases, a third phase is envisaged to enable ‘cooperative driving’. To allow that, it will be necessary to share intentions, e. g. the participants will inform the others about their intentions, such as lane changes, planned trajectories etc.

Phase 4

The third phase will most likely be followed by a fourth phase that will allow the participants to make coordinated actions, e. g., forming platoons, coordinating lane merging etc. This phase is often called ‘synchronised cooperative driving’.

Phase 5

The next and major step after the above phases will be moving towards an "accident-free" driving system, based on automated driving with optimised traffic flows. The 5G technology is expected to play a growing role in the set of technologies (some of which are likely to be duplicated to provide redundancy and security) which will be required to reach the goals of an "accident free" environment.

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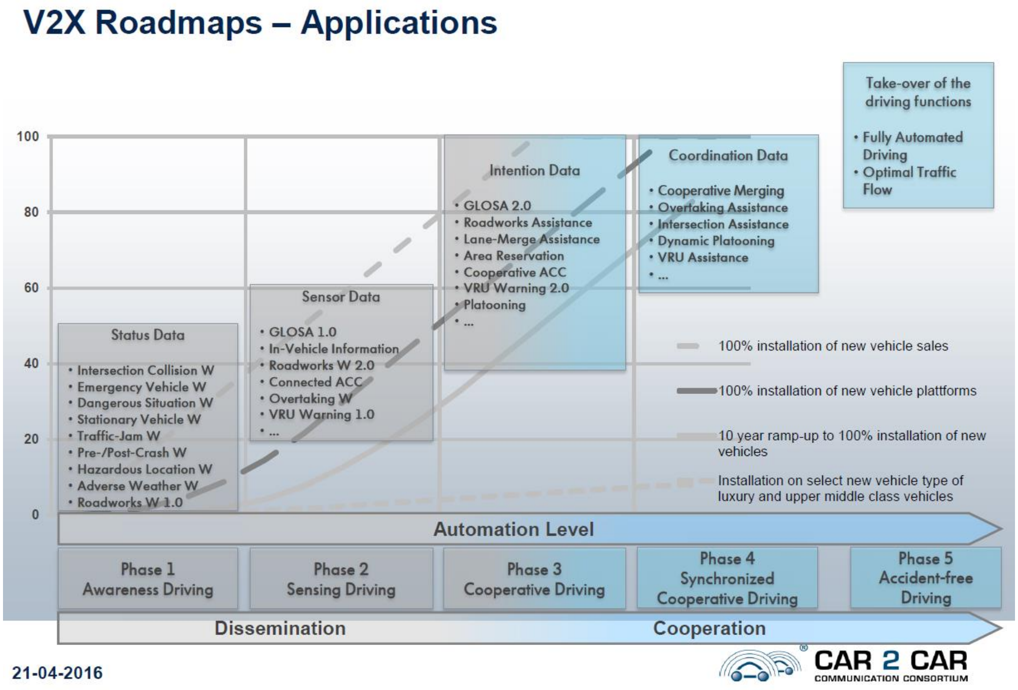
19 http://www.codecs-project.eu/fileadmin/user_upload/pdfs/D3.1_653339_CODECS_Workshop_Perspectives_In_Functional_Roadmapping_Summary_V1.0_c.pdf

The overall evolution is summarised below:



According to the Car 2 Car consortium[20], the use cases for 5G in vehicles are:

- Map update for highly automatic driving - Instantly update the map of a vehicle's surrounding.
- Precise Positioning - support for vehicles without high precision location tracking like cars.
- Audio / Video Streaming (Entertainment), Online Gaming.
- Sensor and State Map Sharing (Sensor Raw Data) -Transmit raw sensor data such that others can use their own classifiers to infer decisions.

The above 5G introduction scenarios for the automotive sector take into account the view of the C-ITS platform report, namely: "*... a hybrid communication concept is therefore needed in order to* ***take advantage of complementary technologies.*** *It is therefore essential to ensure that C-ITS messages can be transmitted independently from the underlying communications technology (access-layer agnostic) wherever possible*[21]".

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20 ETSI 5G Summit, "From Myth to reality", 21 April 2016, Towards accident-free driving, https://docbox.etsi.org/Workshop/2016/20160421_5G_FROM_MYTH_TO_REALITY/SESSION_C_MASSIVE_M2M/TOWARDS_ACCIDENT_FREE_DRIVING_ANDERSEN_CAR_COM_CONSORTIUM.pdf

21 The C-ITS Platform recommends that for short-range communications in the 5.9 GHz band initially the communication system to be used is IEEE802.11p/ETSI ITS-G5, and to study whether geographical coverage obligations can be introduced to increase coverage of C-ITS services through existing cellular communications infrastructure, and therefore foster uptake of C-ITS services.

5. 5G opportunities

From a market perspective, it is predicted that 5G revenues may reach US$250 billion in 2025, with North America, Asia-Pacific, and Western Europe being the top markets[22], based on clear prospects that critical and massive "Machine to Machine" communications will generate substantially higher revenues in addition to enhanced Mobile Broadband services. A study carried out for the Commission[23] indicates that the benefits of 5G introduction across four industrial sectors may reach €113 billion per annum. In 2025 it is expected that €62.5 billion will be generated from first order benefits in the four key industrial sectors examined in the study.

Leading market actors also predict that 5G will already represent more than 150 million connections in 2021[24] globally, more than the number of current 4G/LTE subscriptions in Europe (147 million). The study mentioned above, carried out for the European Commission, identifies several "first order" benefits for 5G introduction in 4 sectors: automotive, healthcare, transport, utilities:

"First order" benefits focus on the more direct benefits to the producers of goods and services. These benefits predominantly fall into three categories:

1. Industries will exploit 5G capabilities to obtain benefits in three key areas of their activity:-

- ***Strategic benefits*** will arise from greater access to information about the supply chain, internal operations, market characteristics and consumer utilisation of goods and services.
- ***Operational benefits*** and enhanced productivity will arise from increased real-time access to information about operations (inside/outside the workplaces and throughout the supply chain).
- ***Direct User benefits*** should arise for consumers from access to 'improved' goods or services. Improvements could include cost, quality, usability, reliability and longevity.

2. Data and information for administrators and third parties: Enhanced access to 5G capabilities and information, including real-time data, will help administrators and other third parties to enhance the provision of services (to private and public sectors) including traffic management, security and data for pupic healthcare management.

3. New business models will utilise 5G capabilities to enable new business models to develop and new goods and services to be provided

[22] ABI research: https://www.abiresearch.com/press/expanding-beyond-mobility-management-enterprise-mo/
[23] Study SMART 2014/0008: "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe", addressing mainly 4 sectors: the automotive, health, transport and energy sectors.
[24] Ericsson Mobility Report 2016.

These benefits are quantified in the table below:

industrial sectors benefits	**Automotive (€ mn)**	**Healthcare (€ mn)**	**Transport (€ mn)**	**Utilities (€ mn)**	**Total (€ mn)**
Strategic	13,800	1,100	5,100	775	**19,770**
Operational	1,800	4,150	3,200	2,700	**11,850**
Consumer	13,900	207	-	3,000	**17,110**
Third Party	13,700	72	-	-	**13,770**
Total	**42,200**	**5,530**	**8,300**	**6,470**	**62,500**

There are also significant "second order" benefits, estimated at €50 billion in the year 2025, based on the "knock-on" impacts resulting from the use of goods and services. They generally concern more indirect benefits to society.

The above results provide some guidance for the industry related trials that are likely to be supported in Europe to test the introduction of the new 5G services.

These data also indicate that fast-paced digitalisation of key industrial sectors (such as transport, logistics, automotive, manufacturing, media, entertainment) and the public sector (including smart cities, public safety, health and education) provides ample opportunities for Europe's information and communication technologies (ICT) industry to bring to market new and innovative solutions whilst positively contributing to societal requirements.

Despite this availability of early data, the business opportunities still require further investigation because the digitalization of the many industries in transformation will significantly disrupt the current business models. A particularly relevant example is the transformative effect and economic shift towards new service delivery models (e.g. where "on demand" approaches will replace long term planned contracts) for which the expected significant redistribution of revenues streams cannot yet be fully assessed. **This implies the need for increased cooperation between the various communities of stakeholders to be able to assess more precisely the evolution of the value chain.**

Relevant results of the EC targeted survey:

- **The importance of the 5G "holistic" perspective**, encompassing the widest possible range of 5G use cases from the beginning, is well reflected in the survey results: 50% of respondents agree that 5G European deployment should target as a priority from the start the services that enable the creation of ecosystems with key industries, namely mMTC and URLLC classes of use cases. This holistic apptroach is massively supported by the ICT industry and SMEs whilst 20% disagree. Within this latter group can be found individuals, small players in specific markets like content production, and a few academics and research centres. Only two large operators disagree with the view of the core ICT community.
- There are also differences of view with regard to the market prospects. 78% of the respondents believe that by 2020, roughly at the time of 5G commercial introduction, eMBB will be the dominant market application.
- This is however modulated by the facts that in 2025, 5 years after 5G introduction, 42% of the respondents also believe that mMTC will be the largest market, ahead of eMBB. The dividing line is between the IT industries outside of the telecom sector, potential 5G users, which place mMTC and URLL ahead, whilst the classical telecom actors tend to have higher expectations for eMBB.

6. Coordinated market deployment, learning our lessons from 4G

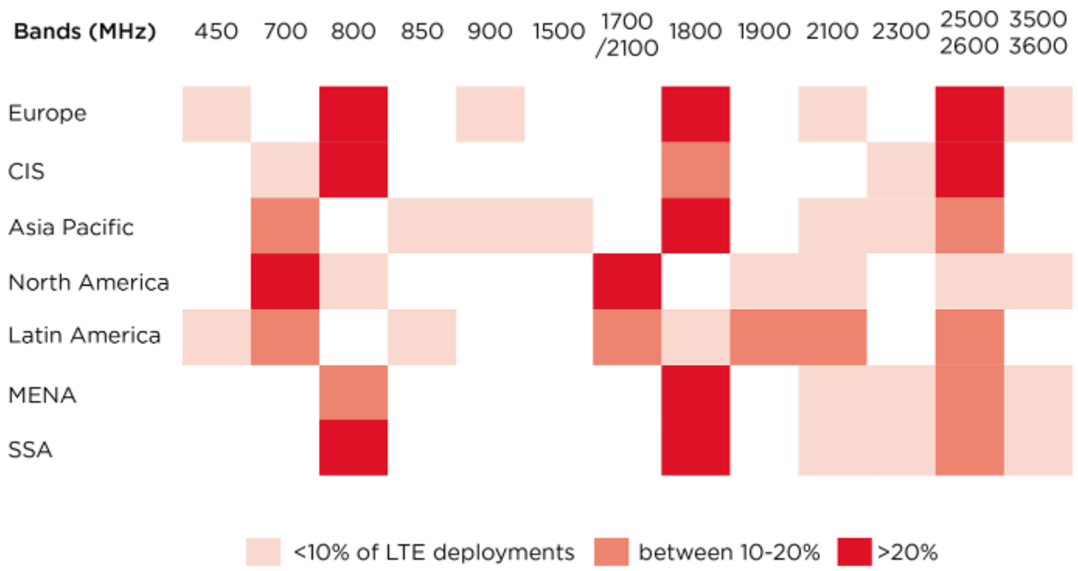
Today, the proportion of 4G/LTE subscriptions measured against the total population is 75% in the US, 82% in the Republic of Korea, 65% in Japan, and 28 % in the European Union[25]. These figures suggest a delay in market deployment of 4G in Europe that many attribute to a lack of a coordinated approach within the single market, in particular with regards the time table for the release of the radio spectrum frequencies to operators, as well as the initial unavailability of 4G devices in the EU [26].

International comparisons show that there is an objective correlation between early availability of spectrum and fast market take up. In the US auctions of the 700 MHz band were held as early as 2008. Subsequently, Verizon launched its LTE network in 2010 and by July 2012 had more than 304 cities covered with LTE, about 75% of the US population. AT&T launched its network in 2012, and had more than 47 city markets with LTE by July of that year. In comparison, Europe organized its auctions significantly later, and in a somewhat dispersed order. Auctions of suitable LTE spectrum (mainly 800 MHz and 2600 MHz bands) occurred over a wider time span in Europe: in 2010 in Germany, in 2011 and 2012 in France, in 2011 in Italy and Spain, and 2013 in UK and Poland[27]. This has led to a corresponding "lag time" for actual network deployment and commercial pan-European 4G operations. It is interesting to note that in spite of early auctions in Europe over the last 2 years, the 700 MHz band will not be fully available on an EU-wide scale before 2020, 12 years after its US-wide availability. This interdependency also highlights the strategic importance of making the 700

[25] Source: Idate, figures of 2015.
[26] See e.g. Mobile Wireless Performance in the EU & US, May 2013, GSMA and Navigant economics
[27] This was the planned date for Poland; the actual auction was further delayed to 2015

MHz band available for mobile wireless applications as quickly as possible, especially for the purpose of reaching appropriate coverage objectives in due time[28].

The early identification of suitable and harmonised frequency bands is also an important factor. The figure below outlines the different regional approaches towards 4G spectrum availability, illustrating the current difficulty in achieving global harmonization, a risk that is likely to arise also with 5G. Despite the size of the country, Verizon in the US was able to reach 97% population coverage within three years of launch, due to its initial assignment of low frequency, high propagation "coverage band" spectrum in the 700 MHz range. On the other hand, later regional choices of spectrum not massively adopted by lead markets may have slowed down the speed for local availability of suitable terminals. This demonstrates once again that late adoption and lack of global spectrum harmonization have an adverse impact on the take-up of services and on the pan-European footprint that can be achieved by those services.



Share of LTE deployments by frequency band, by region (January 2015). *Source: GSMA Intelligence*

[28] The Commission's proposal for a Decision of the European Parliament and of the Council on the use of the 470 – 790 MHz frequency bands in the Union, COM(2016) 43 final, provides that the relevant spectrum be made available across the EU by 2020.

Relevant results of the EC targeted survey:

The issues raised by the delayed 4G licensing is well reflected in the results of the targeted survey. As regards the best introduction model for a new network technology (taking 2G, 3G, and 4G as example scenarios), the model that was used for the introduction of 4G (absence of coordination besides the technical harmonisation of spectrum) gets the most negative assessment, with 40% of respondents considering the 4G introduction scenario as the model to exclude in the future, and only 27% rating it positively The model that gets the highest support is the 2G co-ordinated introduction model, with 40% of positive rating and only 21% considering this scenario as outdated. This is particularly clear in the responses of users of technologies and non-ICT industries. However, IT players in the telecom sector have more of a "neutral" position on average in the survey, albeit supporting the view that the 4G licensing model, complemented by a target time frame for making available 5G bands and licensing conditions, i.e. introducing some MS coordination, would be the best compromise.

7. Radio Spectrum Issues

From a spectrum availability perspective, the agenda is framed by the ITU process towards defining 5G bands above 6 GHz at the World Radio Conference 2019 (WRC-19). The WRC-15 decided to put on the agenda of WRC-19 a specific agenda item related to 5G frequency bands as follows:

- *WRC-19 Agenda Item 1.13: to consider identification of frequency bands for the future development of International Mobile Telecommunications (IMT) including possible additional allocations to the mobile service on a primary basis in accordance with resolution COM6/20 (WRC‑15)*
- *RESOLUTION COM6/20 (WRC-15) invites ITU-R to conduct and complete in time for WRC‑19 the appropriate sharing and compatibility studies for the frequency bands:*
- *24.25-27.5 GHz, 37-40.5 GHz, 42.5-43.5 GHz, 45.5-47 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz and 81-86 GHz (with allocations to the mobile service on a primary basis), and 31.8-33.4 GHz, 40.5-42.5 GHz and 47-47.2 GHz (which may require additional allocations to the mobile service on a primary basis)*

Several leading nations however clearly intend to accelerate the timing of 5G deployment through focusing on alternative spectrum ranges, both below and above 6 GHz. This is notably the case of:

- The Republic of Korea, which has already identified spectrum and assigned 3 blocks of 1 Ghz each to 3 operators at 28 GHz, and which is currently deploying infrastructure to be in time for the Olympic Games in Pyun Cheong in 2018, where early 5G introduction is planned. It may be noted that the deliberate choice of the 28 GHz frequency band does not conform to the ITU resolution above;
- Japan, is taking steps to introduce 5G in bands below 6 GHz in the context of the Tokyo Olympic Games in 2020, with the intention of designating 5G spectrum by the end of 2016;
- China, has started a comprehensive 5G trial programme, aiming at full testing of a complete 5G system before 2020. The programme runs over 3 phases: phase one, until end of 2018, is primarily R&D and validation of key technologies and

subsystems; phase two, from 2018 to 2020, is about system and products R&D trials; phase 3, post 2020, is about gradual commercial introduction and application trials, with a likely focus on industrial applications. Though China is not part of the nations willing to accelerate the pace of the International organisations, the intention of China is to be part of the leading nations for 5G introduction. To that end, CN has already selected the 3,4 -3,6 GHz band for early trials and later introduction.

- The USA is part of those nations willing to accelerate the pace of 5G introduction. Worth noting is the low reliance of the US administration on global standardisation bodies, and their paradigm that spectrum allocation is the decisive key to fast track 5G. This is well illustrated by the statement of FCC chairman Tom Wheeler[29]:

  "The United States approaches the kind of opportunity 5G presents somewhat differently from other countries. We do it by indicating which spectrum will be made available and then relying on a private sector-led process for producing technical standards best suited for those frequencies. We won't wait for the standards to be first developed in the sometimes arduous standards-setting process or in a government-led activity."

  In line with this approach, the FCC released on 14 July 2016 the "Spectrum Frontier" rulemaking, laying down a set of applicable 5G frequency bands in the US together with their conditions of use. Similarly to the Korean case, some of the frequency choices (28 GHz band) do not follow the above ITU Resolution. The fast track approach of the FCC is also mirrored by US operators' initiatives, targeting 5G introduction by 2018.

In February 2016, several operators, KT, NTT DoCoMo, SK Telecom and Verizon, agreed to form a new global initiative called the 5G Open Trial Specification Alliance[30]. In July 2016, major US operators also announced having already completed 5G specifications[31].

In Europe, and in view of the fast-track spectrum developments in key regions, the Radio Spectrum Policy Group (RSPG) has launched work to identify by the end of 2016[32] pioneer spectrum bands for Europe's early 5G launch as of 2018, in line with the ITU priorities and thus with a maximum potential for global harmonisation. Furthermore, the RSPG plans to deliver an Opinion on a 5G spectrum roadmap, including aspects of spectrum allocation and authorisation, by early 2018. To this end, the Commission is working with the Member States within the RSPG and also plans to initiate technical studies at EU level to enable timely harmonisation measures delivering 5G spectrum to market players.

[29] Remarks of FCC Chairman Tom Wheeler at March 8, 2016 Satellite Leadership Dinner.
[30] https://www.nttdocomo.co.jp/english/info/media_center/pr/2016/0222_02.html
[31] http://www.verizon.com/about/news/verizon-first-us-carrier-complete-5g-radio-specifications-pre-commercial-trials-continue-full; these specifications are focused on eMBB use case and seem limited to fixed wireless access.
[32] Document RSPG16-031Final, see http://rspg-spectrum.eu/public-consultations

In that context, and considering the importance of 2020 as a target date for roll-out of large scale commercial 5G networks, the following aspects are considered as the most important by the stakeholder community:

- Making the 700 MHz available, preferably Europe wide, to mobile services by 2020 as proposed in the relevant proposal for a Commission Decision addressing UHF bands (see section 6).

- Exploiting the opportunities offered by spectrum already harmonised in the EU for mobile broadband applications below 6GHz, more particularly the 3.4-3.8 GHz band.

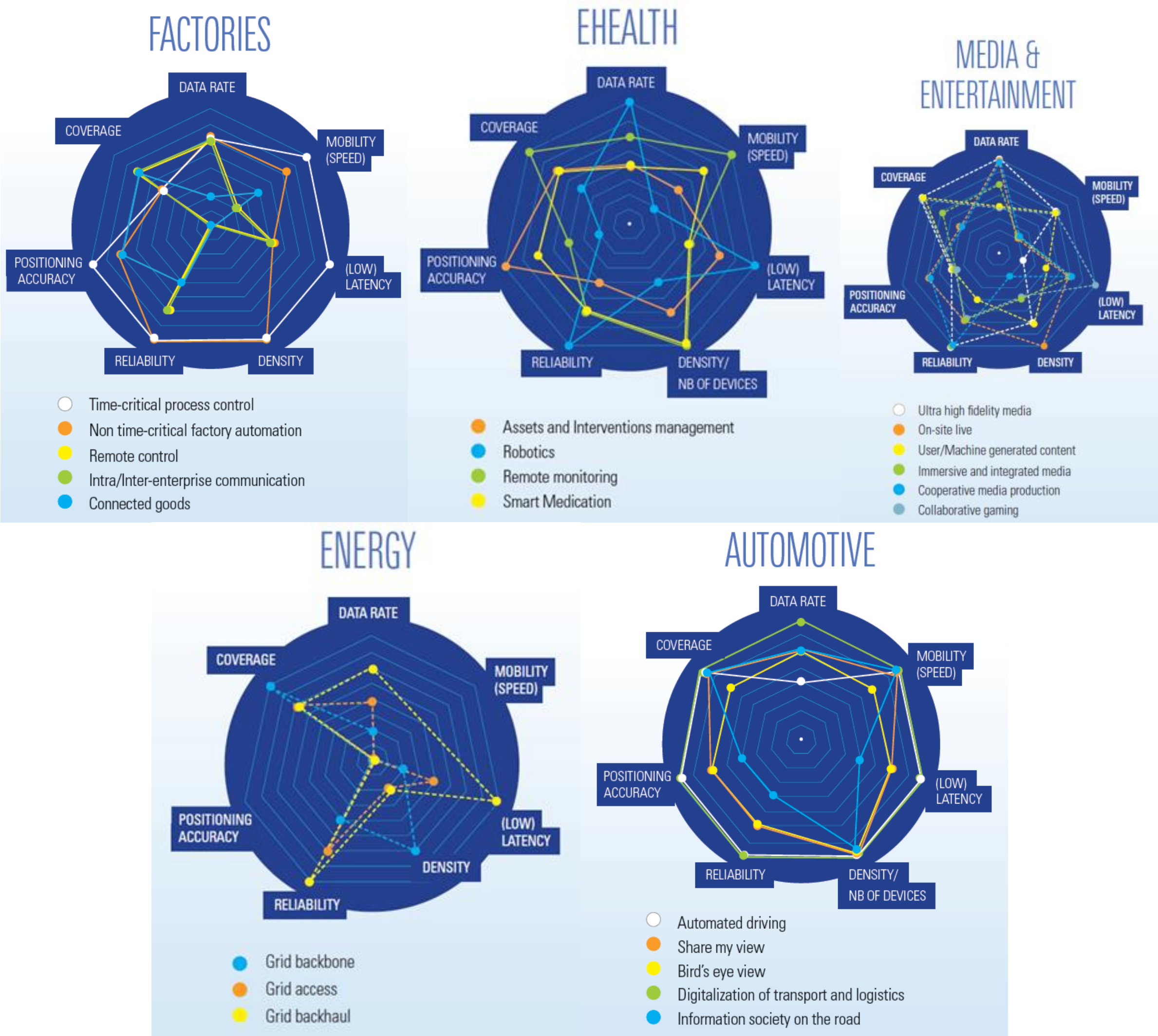
- Identifying before WRC-19 the applicable frequency bands above 6GHz having the widest possible harmonisation potential.

Relevant results of the EC targeted survey:

- **The central role of spectrum availability is well reflected** in the survey. Whilst 46% of respondents do not consider it necessary to already identify the 5G pioneer bands by the end of 2016, a majority of 63% consider that these bands need to be identified by the end of 2017. This includes the ICT industry, user industries and a number of SMEs. Only a limited share of respondents, 24%, believe that it would be acceptable to wait until the results of the next WRC conference in 2019 before allocating the spectrum, including one large operator, one vendor, and the satellite industry with a few individual respondents. Overall there is **strong support for early decisions on 5G pioneer bands in advance of WRC-19**.
- There is **large support for bands to be globally harmonised**: 73% find it is a must, only 9% disagree. Those who are neutral or disagree include mainly academics and industries in non-ICT domains, like banks or transport solution providers. There is a relative majority group of 40%, mainly composed of large industrial players, who disagree with the proposition that lack of harmonisation can be compensated by technology using a "tuning range" approach.
- Regarding the identification of pioneer bands, **3 spectrum bands gain most preference** for 5G introduction in Europe: the highest scores go to the **700 MHz, the 3.4-3.8 GHz band and the 24-27 GHz** frequency ranges. However, it is worth noting that 40% of the respondents place themselves in the category "do not know". It is also interesting to further underline that the 28-29 GHz option, contemplated in the US, has not much support whilst the 31-33 GHz option, seen as more appropriate in Europe, also gets limited support. There is a clear preference for the lowest possible spectrum bands, due to their propagation characteristics. The respondents most supportive of the 3 preferred pioneer bands mentioned above include network operators, ICT technology suppliers and a few industry users, e.g. from the energy and transport sectors.

8. Trials and early roll out

In addition to the trial directions mentioned in section 4 above, intensive cooperation between industries have taken place over the last year to define the core 5G characteristics needed to serve innovative business models (transport and especially the automotive sector, health, energy, smart factories, media and entertainment). This work was mainly conducted in the context of the 5G PPP[33] and allowed a number of business cases to be identified that would require availability of technologies beyond the capabilities of existing networks. The diagram below illustrates these requirements.



These figures illustrate the fact that automotive health and media and entertainment are potentially the most demanding use cases (applications) in terms of requirements that cannot be satisfied with existing technologies[34], which implies that industry needs further trials and joint work before validating new technologies and business models.

The European positioning of stakeholders vis-a-vis these developments is reflected in the box below.

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[33] White Paper: 5G empowering vertical industries.

[34] A "dot" on the outermost line of the spider diagrams below means that (part of) the requirement of the considered business model can not be met with today's networks

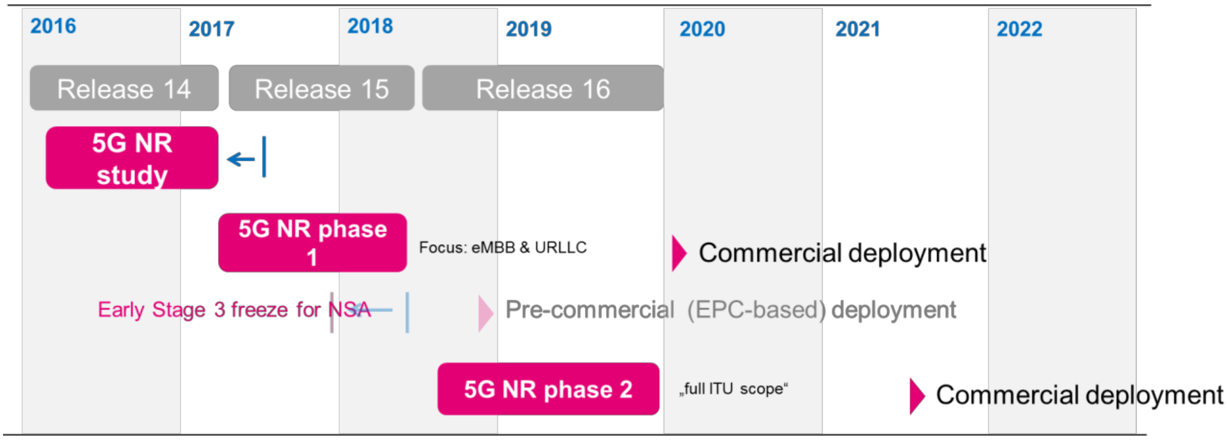
Relevant results of the EC targeted survey:

- Regarding the default 5G introduction date set by the standardisation organisations as 2020, the relative majority of respondents, 43%, support this as a target with only 18% disagreeing. It needs to be noted however that a part of the "neutral" and disagreeing respondents do actually **call for earlier introduction**. Altogether, more than **50% of respondents estimate that early trials and pilots are needed before 2020** i.e. that by 2018 cross-country trials and pilots should already be available on a large scale if Europe wants to achieve significant commercial deployments in 2020. This category includes basically all ICT solution providers and a significant proportion of operators. It also includes content companies and some non-ICT industry players, who state that in some cases the need is already there today (e.g. low latency communications). A limited number of respondents from large companies indicate that the timing of actual deployments, especially when they require large investments, should be decided by operators according to their business plans (1 operator).
- Regarding the need for showcasing events in Europe (e.g. mirroring the Olympic game 5G showcasing events in Asia) there is a **good support for such initiatives to "show" European leadership**, with 56% of the respondents agreeing, and massive support from large industrial (ICT or other industries) actors. Only 25% do not see the interest. Supporters include primarily larger companies and users, whilst disagreement comes mainly from SMEs, academics, a citizen association and individual responses. Three operators are also in that category, but no technology suppliers. Views vary on the date for such events: **2018 is proposed by half of the supporters whilst** 2017 and 2019 get about 25% each.
- Regarding trials and use cases that Europe should concentrate on, the picture is diverse, but the majority of respondents, about 60%, focus on **Automotive/Connected vehicles/Traffic management and media and entertainment**. These cases are also well flagged in the industry manifesto. The typology of these respondents is dominated by the ICT service and technology providers, with smaller content companies.

9. Standards

The main technical steps for the preparation of the commercial introduction of 5G are framed by the agenda of international standardisation bodies. 3GPP, the key global standardisation body in the area of mobile communication network standardisation, officially started the standardisation process in September 2015, with an inception workshop in Phoenix that gathered more than 500 participants. Since then, the standardisation agenda has been defined. 3GPP has planned to deliver a first release, release 15, (mainly focused on broadband with some complementary aspects related to low latency use cases) by mid 2018 whilst a second release covering the complementary use cases, related to industry applications, would be available by the end of 2019 under 3G PP release 16. There is still some uncertainty related to the exact content of the work item to be started in March 2017: the actual standard specification phase after the study item collecting the industrial requirements. A full agreement on this next phase has not yet been reached, in particular regarding the question whether the first phase should focus on eMBB only or already accommodate additional use case scenarios. The figure below shows the standardisation time line agreed at the last 3G PP

TSG RAN[35] plenary meeting in Busan, in June 2016. The next important decision point will take place in March (on the strategy for new radio interfaces).



Source, Deutsche Telekom, EUCNC 2016 conference

The timing outlined in the above figure relates mainly to new radio access and new radio access network architecture. In parallel, 3GPP is also actively working on standards to redefine the core network under the 3GPP "System Architecture" (SA) Group. This standardisation track, which eventually should support different industrial users with differentiated controls of their service requirements, is also key to support future network based innovation through SMEs and start-ups. However, due to the current focus on radio access, this part of the standardisation exercise attracts less attention from the stakeholder community

From a global (as well as European) perspective, these fast-track approaches focused on radio access raise a number of challenges:

- The risks that a parallel, potentially proprietary, specification develops outside of 3G PP, as was the case with WiMax – LTE parallel tracks, also limiting openness and innovation capabilities;
- The risk that the standardisation bodies accelerate their pace under commercial pressure, limiting the scope of the standard and its ability to evolve to cover a more holistic set of use cases;
- The risk that the core network standards get less attention, limiting the potential openness of future network platforms, hence limiting the prospects for developing an innovative community of third party developers;
- The risk that Europe lags behind, in spite of a globally recognised technological excellence.

[35] Technical Specification Group "Radio Access Network" of 3G PP.

Relevant results of the EC targeted survey:

Standards

- Regarding standards, the survey **results do not oppose an acceleration** of the pace of the standardisation process. However a number of respondents point to the **risk of limiting the scope of standards**. 64% of respondents agree that the standards should **not be limited in priority to the eMBB** use case but should rather include from the onset the other "industry" driven use cases such as **Machine to Machine communication and ultra-low latency** use cases. Virtually all operators and associations, with technology providers as part of that category, complemented by research institutes and SMEs in various sectors (content, transport), hold that view. Only 11% disagree, mainly individual respondents and a few SMEs.
- There is also strong support for standards that address both the radio access and the core network architecture, to support new business models. 60% of respondents agree that **the two issues should be tackled together**, i.e. radio should not be the only focus. This trend confirms the earlier public consultation on standards that took place under the DSM initiative. It includes most of the ICT service and technology providers with user companies in different sectors (transport, energy, bank, content). Those who did not support such a combined approach are mainly SMEs, individuals and national organisations.
- There is very good support for the principle whereby the European Commission should set out a strategy to ensure that appropriate standards can be developed and agreed in a timely manner in areas concerning the interface between communications functions and third party service providers (like industrial users). This role for the Commission is supported by 65% of the respondents (13% disagree). Those who did not support such combined approach are like under the previous topic mainly SMEs, individuals and some national organisations.

10. Investments Issues

The success of the commercial deployment of 5G will depend critically on the timeliness and intensity of investments in two key areas:

1. **Investments in infrastructure**: mainly to lay out a dense fibre network infrastructure to ensure the backhauling of 5G cells, as well as to finance the installation of the actual 5G cell equipment. The densification of cells is necessary to optimise both capacity and spectrum re-use between base stations.

2. **Investments in service innovation:** to stimulate the emergence of the new 5G-enabled services. This includes both the financing of pilot projects at the end of the research and development cycle and investment to support an ecosystem of innovative companies where the new services will be "discovered" and developed (ecosystem of both start-up companies and larger organisations).

Investment in infrastructure

Each successive generation of mobile infrastructure has cost more than previous generations. Every generation has required more spectrum and cells have got smaller, meaning there has generally been a linear increase in base station numbers, the costs of which have been reduced in a linear manner by more efficient technologies.

The actual prospect of such investments will be affected by multiple and complex factors including regulation, market readiness, interest rates, etc.. 5G being a new technology in sight with disruptive effects, work is still needed to understand how European conditions by 2020 can be made most conducive to investment in 5G. However, the survey results, as outlined below, confirmed within a larger stakeholder base a number of issues which were already addressed during the preparatory steps of the 5G Action Plan in the context of the high level industry reflection group launched by Commissioner Oettinger at the last Mobile World Congress in Barcelona.

Relevant results of the targeted survey:

- 57% of the respondents are of the opinion that the telecom **operators can finance the deployment of 5G** in Europe. This is supported by academics, SMEs, national organisations and one OTT. The disagreements come from all operators and operators associations, from technology suppliers and a number of user industries across sectors. This is to be modulated by the fact that a relative majority of 45% believe that **co-investments with other industrial sectors represent a realistic scenario** for industry driven use cases. This is supported by all ICT players but also by a number of industries in user sectors and SMEs. It is to be noted that, at the moment, most key players in the field believe that the level of investments required for the 5G deployment across Europe is hard to estimate, given the different strategies each operator will decide to follow and the scenarios and use cases initially considered.
- A sizeable share of respondents (45%) consider that **public funding is necessary for full deployment of 5G** networks across the EU, notably through the European Fund for Strategic Investment, the European Investment Bank, national or regional funds. This trend is very visible among replies from large industry players. Infrastructure support is the main target (see below).
- A clear majority of 63% of respondents agree that Infrastructure **funding should be focused on backbone fibre networks**, and facilitate competition in the development of 5G . Only 12% disagree.
- 54% support the idea that **5G deployment would be facilitated through specific measures reducing the cost of deployment of access facilities**. The main identified issues include: i) addressing issues related to building permits and rights of way (in line with other major infrastructure projects, such as electricity pylons, and their low rents/legal protection); ii) planning restrictions on small cells; iii) harmonizing radiation limitations at a European level so as to avoid some countries and regions having significantly more severe rules than the harmonised norm; iv) taxes on sites and administrative fees.

Investment in service innovation activities

5G will also require substantial investment in more downstream innovation than previous generations of communications systems. In fact, the integration of the future advanced "5G connectivity" in applications across key industry sectors will follow innovation models close to the "Internet innovation" process, where experiments and trials take a larger role in comparison to the linear R&D approach that has prevailed in network innovation so far. New business ecosystems will emerge in which a multiplicity of players will meet, compete and work together. This will open opportunities to start-ups and smaller players, which will eventually profit from the innovation capabilities offered by networks providing open interfaces to develop network "apps" and services, similarly to "app" developments already taking place through cloud computing platforms.

To address this challenge, industry suggested setting up a 5G Venture Fund[36] to accompany the European innovative start-up companies aiming at developing 5G technologies and applications across industrial sectors. This could eventually become a catalyst for substantial digital innovation at European scale, beyond connectivity, and accelerate the ultimate digitisation of a larger number of industries and sectors.

The proposed approach under consideration is to set up a mechanism combining several sources of equity financing from both corporations and public authorities through a shared EU decision platform that would reflect a common strategy and provide consistency in co-investment decision making (a targeted venture financing facility).

Under this possible arrangement, companies could bring together some part of their corporate venture capital investment leveraged by public funding resources tentatively related to EU Financial Instruments such as the "Single EU Equity Financial Instrument", as a typical example. The synergies between such an initiative and similar investment activities in the digital sector would deserve to be explored as to avoid overlap with existing financing opportunities. It would also be relevant to ensure an adequate coordination with the main infrastructure investments and with the trial projects financed from other sources.

11. Conclusions

5G developments world-wide are accelerating and deployment has now become part of the 5G agenda of leading regions. The European Commission has a significant role to play in promoting 5G deployment, as clearly shown in the targeted survey, with 73% of the respondents agreeing with this assumption. The present Staff Working paper outlines a number of key issues that need to be addressed to move forward with a 5G deployment agenda, notably in the fields of spectrum, standards, pre-commercial introduction trials, investment-friendly regulation and support. These correlate with the set of actions proposed in the 5G Action Plan and provide supporting material in view of its wider European adoption.

[36] See page 3 and 4 of *the 5G Manifesto for timely deployment of 5G in Europe*, 7 July 2016: http://ec.europa.eu/newsroom/dae/document.cfm?action=display&doc_id=16579.

Annex: 5G Targeted Survey, Summary Figures

A total of **249 replies** were submitted within the deadline.

- 197 (79%) are providers or users of communication products and services.
- 224 (90%) are relying on connectivity as the main means or as an important part of doing business.

Country distribution:

Institution/organisation/business operating in:	Total
Germany	48
United Kingdom	23
Belgium	20
Sweden	16
Netherlands	15
France	15
Ireland	14
Spain	11
Finland	9
Italy	8
Austria	8
Portugal	7
Poland	6
Romania	5
Denmark	4
Hungary	2
Slovak Republic	2
Bulgaria	2
Luxembourg	2
Cyprus	1
Slovenia	1
Lithuania	1
Latvia	1
Other	28
Grand Total	249

Type of organisations and sectors:

National Authority: 5
Regional Authority: 2
Representative Association at EU level: 11
Non-governmental organisation: 21
Representative Association at national level: 0
SME: 83
ICT Industry: 97
International organisation: 19
Other: 58 (includes non ICT industries)

Note: Respondents had the possibility to select none, one, or **more than one type of organisation or sector** to characterise their area of activity. This means that the total of this distribution list does not match the total of respondents.

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THE INTERNET OF THINGS

SEIZING THE BENEFITS AND ADDRESSING THE CHALLENGES

2016 MINISTERIAL MEETING ON THE DIGITAL ECONOMY

BACKGROUND REPORT

2016 MINISTERIAL MEETING
THE DIGITAL ECONOMY:
INNOVATION, GROWTH
AND SOCIAL PROSPERITY

OECD
BETTER POLICIES FOR BETTER LIVES

FOREWORD

This report was prepared as part of the documentation for Panel 2.2 of the OECD Ministerial Meeting on the Digital Economy, "Tomorrow's Internet of Things". It provides information and discussion on the opportunities and challenges around this emerging set of technologies.

Preparation of the document was undertaken by Gaël Hernández, OECD, with the support of an expert group from Canada, the European Commission, Germany, Korea and the United States. We would like to thank, in particular, Julia Marquier, Nae-Chan Lee, Young-gyun Jeon, Achilleas Kemos and Rudolf van der Berg for their contributions together with delegates from the Working Party on Communication Infrastructure and Services Policy and the Working Party on Security and Privacy on the Digital Economy.

This report was approved and declassified by the Committee on Digital Economy Policy on 13 May 2016 and prepared for publication by the OECD Secretariat.

Note to Delegations:
This document is also available on OLIS under reference code:
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EXECUTIVE SUMMARY

The Internet of Things (IoT) could soon be as commonplace as electricity in the everyday lives of people in OECD countries. As such, it will play a fundamental role in economic and social development in ways that would have been challenging to predict as recently as two or three decades ago. IoT refers to an ecosystem in which applications and services are driven by data collected from devices that sense and interface with the physical world. Important IoT application domains span almost all major economic sectors: health, education, agriculture, transportation, manufacturing, electric grids, and many more. Proponents of IoT techniques see a world in which a bridge's structural weaknesses are detected before it collapses, in which intelligent transportation and resilient electrical grids offer pleasant and efficient cities for people to live and work in, and in which IoT-supported e-applications transform medicine, education, and business.

The combination of network connectivity, widespread sensor placement, and sophisticated data analysis techniques now enables applications to aggregate and act on large amounts of data generated by IoT devices in homes, public spaces, industry and the natural world. This aggregated data can drive innovation, research, and marketing, as well as optimise the services that generated it. IoT techniques will effect large-scale change in how people live and work. A thing in IoT can be an inanimate object that has been digitised or fitted with digital technology, interconnected machines or even, in the case of health and fitness, people's bodies. Such data can then be used to analyse patterns, to anticipate changes and to alter an object or environment to realise the desired outcome, often autonomously.

More generally, the IoT allows for tailored solutions, both in terms of production and services, in all industry areas. For example, insights provided by IoT data analytics can enable targeted medical treatment or can determine what the lot-size for certain products should be, effectively enabling the adaptation of production processes as required. In the context of manufacturing this would enable greater use of customised outcomes rather than trying to predict mass market demand. The IoT can also empower people in ways that would otherwise not be possible, for example by enabling independence for people with disabilities and specific needs, in an area such as transport, or helping meet the challenges associated with an ageing society. Those countries that anticipate the challenges while fostering greater use will be best placed to seize the benefits.

The incorporation of the IoT into people's lives will require evaluating implications for their safety and privacy, including the security of their personal information and the development of appropriate safeguards. Appropriate legal privacy and consumer protection frameworks will be fundamental enablers of acceptance and trust.

The IoT promises to enable firms and public authorities to meet their objectives in new and innovative ways. The IoT is already empowering people to interact with technology and improve their lives. All stakeholders can only gain from sharing good practices to harness the benefits of the IoT while addressing the related challenges. Significantly, this will be in an environment of rapid commercial, technological and social change around the potential of the IoT. Accordingly, principles such as flexibility, transparency, equity, and, to the extent possible, farsightedness will be critical to avoid barriers to the diffusion of the technology.

The IoT will place different demands on communication infrastructures and services. Underlying these developments will be policies that promote the availability, quality and use of such infrastructures and services. In this regard, international governance and norms may need to be reviewed to ensure the performance and security of communication networks and services and thus contribute to building trust in the IoT.

With this in mind, this paper highlights good practices to help policy makers move ahead and promote the positive elements of the IoT while minimising challenges and ensuring broader goals, including the following:

- **Encourage private sector innovation** taking advantage of the IoT and improve the conditions for the creation of new firms and business models that are built around the opportunities created by the IoT. In some cases, value chains could leverage the IoT opportunities across firms and cost sharing could create multiplier effects. For example: the IoT allows firms to more widely deploy service-based business models. Enterprises both small and large will increasingly lease their product and compete on the total cost of ownership, instead of on the initial purchase cost.

- **Adapt research and innovation policies** across a broad range of sectors and applications so that the IoT is a prioritised part of the overall research effort, including by providing funding. This will, for example, help measure and evaluate progress so that policies are adapted to current and future IoT developments. While gains from improvements in the base components of IoT, such as better M2M communications, data processing, sensors and actuators will be visible and measurable, the measurement of returns to investment in innovation, application and integration of IoT is, as with many emerging research topics, more challenging.

- **Evaluate and assess existing policies and practices** to see if they are suitably supportive of the IoT, and do not constitute unintentional barriers to potential IoT benefits. There may be a need to consider adaptation of existing regulations and practices if they are based on assumptions that may inhibit the application of the IoT. For example: health care rules that reimburse medical practitioners for a physical visit or require a physical signature might need to be reviewed in the light of the use of remote monitoring and treatment.

- **Promote the use of global technical standards for the IoT** developed by standards setting bodies or industry consortia. Standardisation plays a key role in the development of an interoperable IoT ecosystem, and is essential for stimulating the emergence of new systems, boosting innovation and reinforcing competitiveness. Over time, technological maturity and end-user choice will ultimately identify the most promising standardisation approaches.

- **Evaluate spectrum resources to satisfy IoT needs**, both current and future. Different elements of the IoT, from machines to sensors, need a variety of spectrum resources that is fit for purpose. Relevant authorities should assess future demands for spectrum and review the mechanisms by which spectrum could be made available for a range of uses, including for the IoT.

- **Promote skills to maximise opportunities in the labour market** and support workers whose tasks become displaced by IoT-enabled and robotic machines and systems, with adjustment assistance and re-skilling programmes. For example: new jobs in IoT-related services will be created, e.g. in data analytics, while existing tasks may be enhanced through the availability of new tools. In an area such as warehousing, the IoT may improve the quality of jobs, though fewer employees may be required in increasingly “roboticised facilities”.

- **Build trust in the IoT** by managing digital security and privacy risks in line with the OECD 2015 *Recommendation on Digital Security Risk Management for Economic and Social Prosperity* and OECD Privacy Guidelines. Trust would benefit from increased cross-border and cross-sector interoperability of policy frameworks, particularly for IoT products in the consumer market. Privacy, security, liability, consumer protection and safety are affected by the pervasiveness and longevity of the IoT. Governments could encourage further dialogue across regulatory agencies and with industries that traditionally were not closely involved in communications, such as transportation or utility services. For example: what rights or controls should a consumer be able to exercise over data collected by a connected automobile or a smart-meter and what is a satisfactory level of granularity for rights or controls?

- **Further develop open data frameworks** that enable the reuse of government data sets and encourage industry to share their non-sensitive data for public benefit. This could require updating the roles and processes of public authorities and the infrastructures they administer to make use of the IoT. For example: transportation companies could benefit from real-time data on road conditions, but can also report such data back to the drivers of road maintenance machines as well as those responsible for maintaining such infrastructures. In urban planning, for instance, connecting traffic lights could optimise traffic flow across a city. These efforts should take into consideration the security and privacy challenges that may arise.

- **Flexibility is essential for numbering** as different services or M2M users may have different requirements. Industry makes use of national numbers in an extra-territorial way (e.g. extra-territorial use of national numbers) as well as of international numbers in order to deploy IoT connected services. Furthermore, regulators should carefully assess introducing additional, and remove existing, restrictions or administrative barriers related to the assignment and use of numbering resources, as it could act as a barrier to the roll-out of a global M2M market.

- **Stimulate the deployment of IPv6 as an enabler to the IoT.** With the current address depletion scenario, deployment of IPv6 is inevitable and promoting the IPv6 transition is the most effective way to support the IoT. Many governments have already established promotion programmes, adapted government purchasing and established task forces with industry to further accelerate IPv6 support to the IoT.

INTRODUCTION

This document examines the current state of the Internet of Things (IoT) and identifies a set of areas for stakeholder engagement specifically designed to facilitate its deployment by all stakeholders and particularly for the private sector.

In this document, the IoT is considered both as an evolving technology, and also as an emerging catalyst for innovation. The form of the innovation, the sector in which it is applied and the potential benefits achieved depend to a large extent on the capacity of innovators to conceive and implement novel IoT approaches and on the capacity of governments to create policy and regulatory frameworks in key areas including telecommunications, privacy, security and consumer policy. Member countries can benefit from understanding best practices and policy approaches in the emerging IoT environment.

Further work on this topic by the OECD could deepen analysis of IoT technologies, applications, products and services and highlight their economic and social effects on market structures, regulation and behaviours. Several specific areas of interest arise: helping policy makers in further understanding any need to adjust policy and regulatory frameworks to tackle technical barriers; analysing initiatives and policy approaches linking the IoT to data-driven innovation; and developing metrics necessary to measure the effects of the adoption of IoT solutions in areas such as economic growth, employment and education needs, analysing privacy and security implications, or consumer protection.

The document is organised in three main sections. Part I introduces the building blocks of the IoT as an emerging platform for innovation and situates it among other ICT trends. Part II discusses the benefits and associated risks of introducing IoT techniques and methods in several industries and sectors. This part highlights the positive aspects for both the private and public sectors and presents several risks that are today preventing its widespread adoption. Part III focuses on what actions could be taken to facilitate the deployment of IoT techniques and processes. This part identifies a number of policy areas in which different stakeholders have an active role to play and provides a roadmap of actions that can facilitate its implementation.

SECTION I: THE INTERNET OF THINGS, AN EMERGING PLATFORM FOR INNOVATION

IoT refers to an ecosystem in which applications and services are driven by data collected from devices that sense and interface with the physical world. In the Internet of Things, devices and objects have communication connectivity, either a direct connection to the internet or mediated through local or wide area networks. In addition to IoT, another related topic is Machine to Machine (M2M) communications, most notably characterised by autonomous data communication with little or no human interaction between devices and applications[1]. In that case, M2M would not require human mediation because intelligence is built into the system to facilitate automated decision and action. The broader concept of IoT may include sensors just providing information for use in other systems. A number of other terms are also evolving which has led some to coin the term Internet of Everything. In some ways, the term Internet of Everything is the most accurate, as the Internet-connected sensors and actuators are not just linked to things, but also monitor health, location and activities of people and animals, monitor the state of the natural environment, the quality of food and much else that would not be considered a thing per se.

IoT exists as part of an emerging technology ecosystem with cloud and big data analytics. Interactions occur among and between people and objects in computer aware environments that can avail themselves of new and innovative services delivered through the cloud and supported by an ever more powerful set of analytical tools. Sophisticated data analysis techniques will enable applications to aggregate and act on large amounts of data generated by devices in homes, public spaces, industry, and the natural world. This aggregated data can drive innovation, research, and marketing, as well as optimise the services that generated it. The ecosystem must be considered to be an overlapping continuum where it is impossible to isolate the impacts of one technology from the others. To that end, the policy issues should consider and address the ecosystem impacts.

Visions of smart, communicating objects are not new, and were imagined well before the World Wide Web, for example, became commonplace.[2] By the early 1990s, ideas about ubiquitous or pervasive computing and embodied "virtuality" were well advanced at Xerox PARC, where they imagined that "specialised elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence."[3] Similarly these concepts were being raised in APEC by both Japan and Korea in the late 1990s and early 2000s under the term U-Computing. Still, the consumer products that many have envisaged for the IoT have been a long time coming. Even today, as more and more IoT products reach the stores, their manufacturers are still not entirely sure what features may be those that will attract consumers (Harwell, 2014). By way of example, there are now websites dedicated to collecting unexpected "smart" devices from toothbrushes and baby pacifiers through to luggage and all manner of devices found in kitchens to bedrooms.[4]

As an event and outcome driven technology, IoT could drive consumer demand. The current outlook is positive, with some studies projecting more than threefold growth on the number of global M2M connections, from 3.3 billion in 2014 to 10.5 billion by 2019.[5]

The IoT is still evolving, and is at a similar stage as the World Wide Web two decades ago as it was emerging to become a commercial network, when there was considerable diversity in experimentation across industries, with competing standards and unclear expectations from consumers. The wireless capabilities of smartphones, from NFC to low energy Bluetooth, and their pervasive adoption in such a short timeframe mean that the devices to read and interact with the IoT are available at scale for the first time. Many IoT applications and techniques will be in manufacturing and industrial settings. In the subset of IoTs that are consumer-facing, smartphones play an important role in bringing the IoT to the consumer (Yared, 2013).

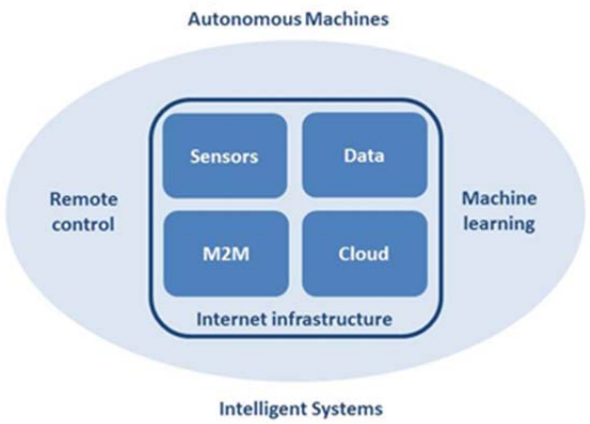
A definition of IoT is not a simple matter. In a previous report (OECD, 2011) the term IoT was said to be mainly associated with applications that involve RFID. In that report the term M2M was used for:

> "Devices that are actively communicating using wired and wireless networks, that are not computers in the traditional sense and are using the Internet in some form or another. M2M communication is only one element of smart meters, cities and lighting. It is when it is combined with the logic of cloud services, remote operation and interaction that these types of applications become "smart". RFID can be another element of a smarter environment that can be used in conjunction with M2M communication and cloud services."

Since 2011, the term IoT has gained prominence to describe a wider variety of developments where "things" are connected to the Internet. Traditional M2M solutions typically rely on point-to-point communications performing actions without the manual assistance of human interaction using embedded hardware modules and either cellular or wired networks. In contrast, IoT solutions rely directly or indirectly on IP-based networks to interface device (object or things) data to a cloud or middleware platform.

Four main elements can be seen as underpinning the development of the IoT –data analytics, cloud computing, data communication and sensors or actuators (Figure 1). Cloud computing and data analytics include improved machine learning applications, operating at a new level of artificial intelligence. IoT also incorporates the notion of sensing and data analysis driving remote control. For example, a smart transportation scenario might include sensing and analysis of a city's current traffic flow, followed by control responses to adjust traffic stop lights or congestion tolls. In the case of remote control, human interaction may still be needed, but is typically limited to very specific actions. The combination of remote sensing and actuation, along with advanced machine learning will lead to the development of autonomous machines and intelligent systems, including robots.

Figure 1. The IoT ecosystem: enablers and applications

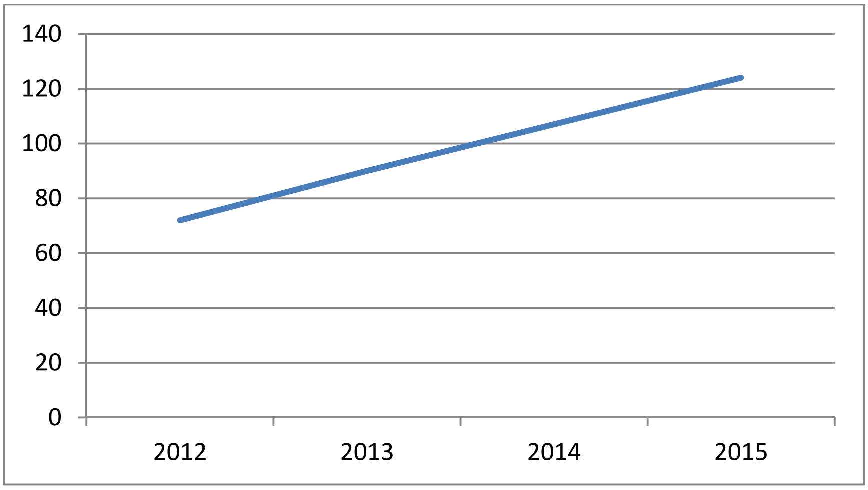


The contributions of sensors and actuators to "Green Growth" were considered in a previous report (OECD, 2010). It stated that sensors measure multiple physical properties and include electronic sensors (accelerometers, hygrometer and so forth), biosensors, and chemical sensors. These sensors can be regarded as "the interface between the physical world and the world of electrical devices, such as computers".[6] The counterpart is represented by actuators that function the other way round, i.e. whose tasks consist in converting the electrical signal into a physical phenomenon (e.g. displays for quantity measures by sensors such as speedometers, temperature reading for thermostats, but also those that control the motion of a machine).

In early sensor and actuator systems, such as a vehicle engine, the data were measured, processed, and acted upon largely in isolation, and then discarded. Today, however, more and more of the data generated is communicated to other machines for storage and for integration and analysis with other data, potentially from very different types of sensors. This cross-analysis of data can usefully integrate together data from different types of sensors using advanced machine learning techniques to support sophisticated cross-analysis. The type of communication used can be varied – wired and wireless, short or long range, low or high power, low or high bandwidth. Many of these options are discussed in (OECD, 2012a) and (OECD, 2013) and this paper will not repeat an examination of the various networks that could be used but offer suggestions for reviewing current telecommunication policies, which assume prior knowledge of the types of networks used.

An important aspect in the development of the IoT is the ability to create "big data" ecosystems, potentially increasing the value of the service provided. For example, a smartphone application could empower individuals with a specific allergy, to provide information on symptoms as they move across different locations. Correlating thousands of geotagged datasets with environmental sensors could alert residents of high risk areas in real time. Alternatively, the allergy data could be correlated with socio-economic data producing maps for health and urban planning authorities. Collecting, compiling, linking and analysing very large data flows in real time requires powerful data analytics techniques, which can be provided by cloud computing platforms in a flexible, elastic and on-demand way with low-management effort.

Figure 2. M2M SIM card subscriptions in the OECD area, millions



Note: The data are estimates. 2015 data are estimates from June 2015. There are 4 countries in the OECD area for which data are not available.

Measuring the growth of the Internet of Things is not a simple task because the IoT does not have clear boundaries. Several alternatives can be used, such as the number of sensors per device, communication chips or the number of M2M SIM card subscriptions. That being said, there are other difficulties, such as counting sensors/devices deployed by private firms inside corporate networks or manufacturing plants. Efforts to develop metrics are still in their infancy but the OECD has explored several proxy measurements (OECD, 2015). One of the most accurate measurements though not complete, is the number of M2M subscriptions[7]. The OECD has collected data from regulatory authorities since 2012. This enables the number of M2M SIM subscriptions observed in the OECD area to be tracked and in that time they have grown from 72 to 124 million (Figure 2). Examples of use cases for such subscriptions are smart-meters, points of sale and connected cars among others.

SECTION II: SEIZING THE BENEFITS OF THE IOT

Benefits of the IoT

Facilitating private sector innovation with the IoT

IoT techniques support a wide range of innovative businesses. In addition to using IoT approaches to build applications for smart transportation, health, and other sectors, IoT techniques may also support more responsive business models in which more granular and frequent data reported by IoT services will allow businesses to better assess how their customers use their products. In turn, firms could offer tailored solutions to their customers while contracts between supplier and customer could be dynamically adapted so that the actual functioning of the service is the main focus for any business. While such transformations have been on-going for several decades, IoT techniques can accelerate this process.

Using IoT approaches also allows firms to fundamentally integrate sensing, analytics, and automated control into business models. Some firms have called it the 'Industrial Internet' and have estimated gains of USD 10-15 trillion to global GDP over the next 20 years.[8] Moving towards equipping machines with a range of sensors in order to be able to do predictive maintenance, firms are improving processes, becoming smart and more efficient. The effects do not have to be large to be noticeable: a 1% efficiency increase in the aviation industry could, for example, save commercial airlines globally USD 2 billion per year.[9] According to a study by a network operator, the average cost saving for industry in general is 18%, and nearly 10% of M2M adopters have reduced their costs by over 25% (Vodafone, 2015). Apart from cost savings, firms mention the following areas where improvements can be identified after adoption of IoT-measures: processes and productivity; customer service, speed and agility of decision-making; competitive advantage; innovation; consistent delivery across markets; sustainability; transparency/predictability of costs; revenue; and performance in new markets (Vodafone, 2015). A report of a stakeholder organisation states that in 2020 benefits of the IoT could be at USD 2 trillion, where USD 1 trillion could be based on cost reductions (e.g. by increasing energy efficiency using smart meters in large quantities - analysts forecast that 1.1 billion smart meters could be in use in 2022 (Navigant Research, 2013)) and another USD 1 trillion could come from improved services such as remote monitoring of chronically ill patients (GSMA, 2014). These figures are outnumbered by an analysis which predicts that for the car industry alone annual global savings of over USD 5.6 trillion could be achieved by cars based on advanced connectivity technology such as semi-autonomous and autonomous cars (Morgan Stanley, 2015).

The IoT might facilitate the so-called "next production revolution" (NPR). Three key trends – the spread of global value chains (GVCs), the increasing importance and mainstreaming of knowledge-based capital, i.e. software, data, intellectual property, firm-specific skills and organisational capital, and the rise of the digital economy – have been identified as ushering in the NPR (OECD, Forthcoming). This implies a potential step-change in the way goods and services are produced at the global level, with many possibly disruptive IoT technologies holding the promise of higher productivity, greener production, and new products, services and business models that could help meet global challenges. At the same time, these technological changes could contribute to shifts in global value chains, as reshoring to advanced economies might become more attractive as labour cost advantages diminish.

Already warehouses are becoming increasingly robotic. Today, manufacturing largely limits its reliance on robots to well-defined, carefully programmed areas, such as making automobiles but could expand to consumer electronics if more flexible reprogrammable robots can be built. Hon Hai Precision Industry, a multinational electronics contract manufacturing company employing over 1.2 million people and best known for assembling Apple's devices, has stated that it is looking into deploying over one million robots in its business in the coming years. Substantial changes are also in the process of being deployed in the areas of product storage and distribution related to employing IoT in the design and operation of warehouses. Modern warehouses use digital technologies such as barcodes to direct human workers to what shelves to visit and what items to pick. Other warehouses use conveyer belts for workers to put products on and these employees are directed by computers as to the tasks they undertake. In Amazon's warehouses, for instance, shelves are transported by small self-driving robots, so that employees are stationary and the position of the shelves is dynamic.

Optimised warehouses will need fewer human workers to handle the same amount of orders. The Baxter Research Robot is an open source platform enabling researchers to customise a range of applications for robots and drive robotics innovation.[10] For the immediate future, people will still be needed for maintenance, quality control, training robots and many other aspects of production processes. Combined with robotic advances in manufacturing, it might lead one day to a fully automated production process from design to delivery (Box 1). New tasks could offer more job satisfaction as opposed to the current repetitive nature of some tasks, even though in some sectors a net loss of jobs might be possible.

Autonomous machines and the use of big data are increasingly present in agriculture. Robots can now sort plants based on optical recognition, harvest lettuce and recognise rotten apples. Tractors are being used today that steer themselves and only need minimal operator intervention to spray fields as they use algorithms to vary the spraying of pesticide and fertiliser based on yield data from previous years. Combine harvesters are also able to operate semi-autonomously or work together with a lead-harvester. Sensor-equipped machinery can independently improve working processes and inject real-time data on Internet platforms during the working process. When all units involved in the harvesting process are networked, they can exchange data and coordinate the current harvesting process among themselves.[11] In today's world, even cows are often autonomously milked using sensor-based IoT systems (McKinley, 2014). Robots clean the stables and ensure that grass for feed is pushed back to the cows, so that it does not get wasted.[12] While robotics and IoT techniques are distinct, they overlap in the sense that cloud-connected autonomous robots can be viewed as IoT sensors or actuators in large, distributed, intelligent systems.

The automotive industry is one of the sectors most affected by interconnectivity and enhanced efficiency in both production and operation of vehicles. In this respect, the development of highly automated and connected vehicles is at the forefront. Recent studies illustrate that automated and connected driving will dramatically change the global automotive market during the next two decades. While only tens of millions of cars are said to be connected to the Internet today, this is expected to become hundreds of millions in the near future (T-Systems, 2015). Meanwhile companies from PricewaterhouseCoopers to CISCO expect that both the market and market share of automated/autonomous cars will rise sharply in the coming decades (e.g. for CISCO from 0.1% in 2020 to over 35% in 2040) (PricewaterhouseCoopers, 2014).

Box 1. IoT and the "next production revolution" (NPR)

The recent productivity slowdown has sparked interest among academics and policy makers alike, with the debate centering on the extent to which the slowdown is temporary or a sign of more permanent things to come. Productivity (principally labour productivity) drives the large differences in income per capita currently observed across countries and it is expected to be the main driver of economic growth and well-being over the next 50 years (OECD, forthcoming d).

The spread of global value chains (GVCs), the increasing importance and mainstreaming of knowledge-based capital and the rise of the digital economy are ushering in the "next production revolution". Countries need to seize this opportunity to harness innovation to boost economic growth and spur job creation. In the near future, maybe as early as 2025, the process of manufacturing could become an almost completely autonomous activity with little human interaction. Though hypothetical and stylised, the process could work along the lines of the following example:

In 2025, a group of designers have created a new device. They showed a number of 3D printed prototypes to potential buyers and, as a result, received a contract from a retailer in a different country. The design, packaging and component list is uploaded to an online marketplace where manufacturers compete against each other for the contracts to create the parts and assemble the device. One contractor wins the contract to assemble the device. This contractor uses a cloud-based computer-aided design tools to simulate the design and manufacturing of the device. Machine learning algorithms test which combination of robots and tools is the most efficient in assembling the device which may lead to further optimisations of the product. Some components, such as systems-on-a-chip and sensors, can be sourced from manufacturers. Other elements have to be specifically created for the device. Specialist manufacturers that 3D-print the initial molds for the design and then mass-produce the elements using a variety of technologies to produce these elements. Robotic devices execute mass production of the components.

All the components and the associated data are then sent to the assembly facility. On the assembly line, the robots in the line retool and arrange themselves. Robotic vehicles move the components across the floor to the correct robot workstations and the robots start assembling the devices. Every time the robots assemble a device, the machine learning algorithms in the cloud analyse the sensor data and compare this to the simulations, re-simulate and establish whether the process still fits the parameters and whether the process can be optimised. If something goes wrong in the process, the machines can work around the problem, based on what is necessary. The finished product is packaged by a robot and put into a box, which is loaded by a further robot onto a pallet and then loaded by another robot on a self-driving truck, which takes it to the retailer.

At the retailer, robots unload the truck, move the product in the warehouse and then place it in the correct storage location. When the product is ordered another robot picks it up, delivers it to picking and packaging, where robots pick and package the widget and send it to a robot that puts the package on a self-driving truck. The truck is equipped with a smaller delivery robot that carries the product to the front-door of the customer.

In this hypothetical example, the sales of the product prove much better than expected with orders increasing around the world. The designers need more production capacity and again turn to the market, where manufacturers in the regions where the product has been ordered, compete for larger or smaller batches of the product. The results of the earlier machine learning algorithms are communicated to the factories around the world, where different robots, with similar functionalities assess how to manufacture the product in the factory. When a factory is done with the batch of widgets that it was hired to do, the robots reorganise and retool for a different product, until another batch of the widget is demanded.

From the moment the design was finalised until it arrives at the customer, no worker has been employed to manufacture the device. There were employees monitoring the manufacturing process. However neither in the plastics molding nor the assembly nor the logistics surrounding the device were humans necessary.

Facilitating innovative public sector delivery with the IoT

Public authorities have a number of roles, processes and infrastructures that they need to execute and maintain, including: roads and public spaces, emergency services, and safety and security. In many countries, they are either directly or indirectly responsible for health care, energy provision, public transport, garbage collection and sewage. These roles can be made more efficient by the IoT and authorities should actively investigate how the IoT can help them better achieve their objectives and measure the effectiveness of their policies and implementation. According to Cisco forecasts, the economic opportunity of the implementation of IoT in the European public sector is USD 2.1 trillion (Pepper, 2015). As a comparison, the estimation for the private sector is USD 4.3 trillion.

Innovation in healthcare practice and delivery

Health systems today are predominantly facing chronic diseases instead of acute care. In the introduction of the OECD publication '*Health Reform, Meeting the Challenge of Ageing and Multiple Morbidities*" it is stated that:

> "*When the OECD was founded in 1961, health systems were gearing themselves up to deliver acute care interventions. Sick people were to be cured in hospitals, then sent on their way again. Medical training was focused on hospitals; innovation was to develop new interventions; payment systems were centred on single episodes of care. Health systems have delivered big improvements in health since then, but they can be slow to adapt to new challenges. In particular, these days, the overwhelming burden of disease is chronic, for which 'cure' is out of our reach. Health policies have changed to some extent in response, though perhaps not enough. But the challenge of the future is that the typical recipient of health care will be aged and will have multiple morbidities."* (OECD, 2011)

According to the publication, this calls for an approach to health care that focuses on prevention and disease management, because the causes and effects of the disease can be the result of life style choices and environment. The role of a medical practitioner has been changing from being primarily a healer to placing more emphasis on advice in managing cause and effect because of the new tools available.

The IoT can support changes in the delivery of healthcare. Smaller sensors, smartphone assisted read-outs, big data analysis and continuous remote monitoring can enable new ways of managing care. Sensors now exist that can be swallowed with a pill and are being used to improve the accuracy of clinical trials by monitoring and managing participants' use of medication (Box 2).[13] Such a digital health feedback system includes wearable and ingestible sensors that work together to gather information about medication-taking, activity and rest patterns. Weight management can benefit too from regular monitoring.[14] Other devices can measure the amount of sleep a person has over time, activity and blood pressure, glucose levels and heart rate, which are the types of measures medical practitioners need to monitor their patients.

Implementing these new technologies in a health system may be challenging. The health management chain, as well as regulation in this sector, may need to be adapted to take advantage of the potential benefits. One example might be to switch from reimbursement for physical visits to payments for packages of treatments.[15]

Box 2. Digital Health Feedback System and Anonymised Big Data Analytics

The ingestible sensor technology is made entirely of ingredients found in food and activated upon ingestion. Patients take it alongside their medications, capturing the exact time of ingestion. The patient's own body powers the ingestible sensor. With no battery and no antenna, their stomach fluids complete the power source and their body transmits the unique number generated by the sensor. The patch, body-worn and disposable, captures and relays their body's physiologic responses and behaviours. It receives information from the ingestible sensor, detects heart rate, activity, and rest, and sends information to the patient's mobile device. Using a Bluetooth-enabled device a patient can access secure applications that display their data in context and support care in a variety of different ways.

In the United States, for example, asthma and chronic obstructive pulmonary disease (COPD) are said to be the 5th and 6th most costly conditions estimated at USD 50 billion annually, each. Improved self-management through use of the IoT could reduce the cost of treating them by eliminating unnecessary hospitalisations or other medical visits. Also, by gathering information on the symptoms, triggers and use of medications and making that information readily available on devices such as smart-phones, patients can be better informed for their own action as well as communicating this information to caregivers and clinicians.

By providing direct and rapid validation of the quantity of medication a patient ingests and the time of ingestion, the information can help lower the risk of clinical trial failures by identifying medication adherence issues early, improving dosage decisions, and enhancing drug safety.

The benefits of taking advantage of 'big data' related to the use of IoT in healthcare could be substantial. Information on health issues and diseases could be used on an anonymised basis in order to draw conclusions in relation to disease prevention, forecasts of epidemics, customised treatments and locations where a certain disease is more widespread, which in turn can be used for cause studies. Not only could health professionals have more information about the environment and the use of medical devices at certain locations. IoT devices linked to smartphones can not only enable people to better monitor their own situation but to also share such information in a way that can be used by others to avoid locations or for authorities to identify why people experience more incidents in one area than another

Source: Proteus Digital Health at http://www.proteus.com/technology/digital-health-feedback-system and http://propellerhealth.com

The proliferation and absorption of health-related IoT devices by health systems will allow all patients to receive the kind of real-time monitoring once reserved only for urgent cases in specialist wards (Murray, 2015). It will allow clinicians and other medical professionals to tailor and adjust treatment specific for every patient. In addition, once all aspects of healthcare from devices to treatments have their own digital identification these data can be cross-referenced to improve processes and available combined data, overcoming technological hurdles facing the sector, such as the lack of connections between medical systems (Murray, 2015).

Smart cities, smart street lighting and traffic flow optimisation

In the context of smart cities, a municipality can control, administer and plan public infrastructures, utilities and services by means of the IoT so that cities are managed more efficiently and in a more environmentally friendly way. Smart city plans explore the ability to process huge masses of data coming from devices such as video cameras, parking sensors and air-quality monitors to help local governments achieve goals in terms of increased public safety, improved environment and better quality of life. Examples for IoT-managed public infrastructures and services are lighting, public transportation, parking, garbage collection as well as smart meters for residences (Box 3).

Box 3. Energy provision: smart meters and smart grids

The energy sector is under transformation with the introduction of smart meters informing consumers of their energy usage and patterns, and driving down their consumption and saving energy as a result. Following the result of a cost-benefit analysis required by the European Commission for all member states, 16 members have started to implement smart meters in 80% of the positively assessed locations by 2020. Even in countries with negative or inconclusive analysis, rollout will begin for a selected group of customers. In some countries such as in Germany, a differentiated rollout-approach will be taken, that will commence with some groups of customers and with regard to the individual cost-benefit-relation of that consumer group.

Decentralised generation of energy and delivering it to the grid is a development that is also furthered by smart grids. Prior to communication technologies being used it was sometimes difficult to adequately remunerate the energy generated, including differential payment for energy. Communication makes Smart Grids possible, where demand, input and market prices are known on a continuous basis. In liberalised energy markets this is now so common, that a fifth of electricity capacity used in the Netherlands comes from combined heat-power exchange generators (CHP) in greenhouses where flowers, plants, vegetables and fruits are grown and where the heat and CO2 are essential for the growing of produce. Renewable energy sources such as solar and wind, which do not provide energy on a continuous basis as they depend on the weather conditions as well as hydrogen vehicles which can deliver energy back to the grid will only add to the need for Smart Grids.

Dublin (Ireland), Oslo (Norway) and Chattanooga, Tennessee in the United States have started to use smart street lighting systems.[16] Often triggered by replacing municipal lighting with LED solutions to save on energy costs[17], smart street lighting can offer combined savings of up to USD 100 per streetlight per year because the status of each lamp is known in real-time and maintenance can be scheduled when needed. By integrating two-way communications new functions also become available, such as selectively to dim or brighten the lights depending on the weather, traffic flows, time of day or based on requests from emergency services. Streetlights could become a communication hub that is fitted with or communicates with nearby sensors, such as parking bay sensors, rubbish bin sensors or noise and pollution sensors.

In the same manner, smart traffic lights in larger cities can be instrumental in optimising traffic flows. The SCOOT system developed by Transport for London uses data on road usage with real time control of traffic lights in the city to deliver on average a 12% improvement in traffic flow.[18] Other large cities, like Beijing, São Paulo, Toronto or Preston have introduced SCOOT and similar systems will be increasingly developed to improve in-city traffic flows.[19] Scientists are even looking further and believe that with fully automated vehicles it might be possible to operate intersections without traffic lights. Instead vehicles book a path over the intersection with a central control system. This may in the future allow vehicles to traverse intersections without significantly reducing speed or having to come to a standstill, which would speed up traffic flow, reduce emissions, and save fuel which is wasted in acceleration.[20]

In some ‘smart cities’, public authorities have a full view of how infrastructure and services are functioning. In Korea, the smart city of Songdo has extensive and high-bandwidth fibre connectivity to enable low-latency communication for the different computer systems that keep the city running. Telepresence is installed in homes, offices, hospitals and shopping centres so that people can make video calls wherever they want. Sensors are embedded in streets and buildings to monitor everything from temperature to road conditions. Residents can monitor the pollution concentration in each street of the city. It is also possible for the authorities to optimise the irrigation of parks or the lighting of the city. Water leaks can be easily detected or noise of vehicle traffic can be monitored in order to modify the city lights in a dynamic way. Traffic can be reduced with systems that detect where the nearest available parking spot is, saving time and fuel. Finally, rubbish bins can report their status, enabling more efficient collection only when required.

Unlike Songdo, which has been built top-down as a new city, most existing cities will instead become smart gradually through small-scale experimentation and optimisation of the parameters of the machine learning systems. Traffic lights, road conditions, and other data sources will enable the organic growth of "smartness" in the city, as it incorporates and adjusts IoT elements. Cities may be able to do similar experimentation with lighting levels, for example to see whether they increase or decrease crime and accident rates. What may work best for a city may depend on its unique characteristics (Box 4).

Box 4. Smart-city projects in Denmark

Copenhagen Solutions Lab is the City of Copenhagen's incubator for smart city initiatives and a new governing body for smart city projects working across all sectors in the capital. New ITS solutions, reduced carbon emissions, implementation of sensors that create real time data and information on current situations in the city as well as the build-up and architecture of a new 'Big Data Digital Infrastructure Platform' that shares data across public and private sectors are all focus points for the work within the Lab.

Copenhagen Street Lab situated around the city hall is Copenhagen's test area for smart city solutions in real urban space. It will be a showcase for the newest technologies within smart city and IoT, to demonstrate the potential in these technologies to citizens, decision-makers and companies, and provide a proof of concept for scaling the qualified solutions to larger parts of the city, as well as to other cities in the region, nationally and abroad.

Source: Danish Energy Agency, part of the Ministry of Energy, Utilities and Climate.

Smart governments

According to a market research company, big data, cloud and the IoT are three strategic technology trends affecting governments. In their view, "smart government" integrates information, communication and operational technologies to planning, management and operations across multiple domains, process areas and jurisdictions to generate sustainable public value (Gartner, 2014). For instance, a local government might want to explore the ability to process parking sensors, air quality monitors and video cameras to achieve goals such as increased safety and better quality of life. Even the internal organisation of governments is likely to change as the IoT progresses. For example, in the Netherlands the Department of Defence is moving from 6 000 departmental vehicles[21] to 4 800 of which 3 500 are part of a pool of shared cars, vans and different types of small trucks. Where personnel or units once had dedicated vehicles, they can now reserve vehicles online for official purposes and choose any vehicle available that fits that requirement. The identity card of the person ordering a vehicle unlocks the vehicle. All trips are logged via GPS ensuring that vehicles are used correctly and delivered on time and can report their technical status. In the future vehicles can be used for one-way trips and do not need to be delivered back to their home base. As a result the utilisation of vehicles is higher, malfunctioning vehicles are not a burden to a specific part of the organisation, all trips are now accounted for, no informal or unauthorised lending of vehicles is possible or necessary and all trips are properly insured (van Lisdonk, J. R., 2014).

Challenges relating to the deployment of the IoT

Digital security and privacy risks

The growth of the IoT and the realisation of the economic and social benefits related to its use will in part depend on the extent to which potential users will trust the technology and the products and services that rely on it. This means that users will have to come to terms with the fact that connecting any physical device to the Internet exposes them to some degree of digital security risk, and when personal data is involved, to potential privacy challenges.

The digital security challenges posed by the IoT are largely the same as those associated with industrial control systems: digital incidents involving IoT can have significant physical consequences in addition to affecting other aspects such as an organisation's finance and reputation. Experience shows that this is not a new phenomenon (Box 5). In this respect, the OECD 2015 Recommendation on Digital Security for Economic and Social Prosperity provides an effective framework for managing digital security risk. However, managing digital security risk may become an even greater policy imperative as the IoT connects a much larger number of devices, in industrial and consumer contexts.

The privacy challenges posed by the IoT are also similar to those posed by existing digital technologies which generate and capture data, particularly cloud computing and radio-frequency identification. The OECD Privacy Guidelines provide a framework for addressing these issues, especially as IoT devices become ubiquitous and users have less visibility into how and what data is being collected.

According to the OECD Recommendation on digital security risk management, leaders and decision makers should address digital security as an economic and social risk rather than solely as a technical issue. When carrying out an activity that relies on digital technologies, including the IoT, they should consider the potential economic and social consequences of a possible digital security incident affecting the availability, integrity or confidentiality of the information in the information system. These consequences can damage revenues (e.g. through disruption of operations), undermine reputation (e.g. through the exposure of personal data, or website defacement), or affect market position (e.g. through theft of innovation).

As do industrial control systems, the IoT bridges the digital and the physical world: through various types of sensors, connected objects can collect data from the physical world to feed digital applications and software, and they can also receive data to act on the environment through actuators such as motors, valves, pumps, lights and so forth. Thus, digital security incidents involving the IoT can have physical consequences: following a breach of integrity or availability, a vehicle might stop responding to the driver's actions, a valve could liberate too much fluid and increase pressure in a heating system, and a medical device could report inaccurate patient monitoring data or inject the wrong amount of medicine. As with the industrial control systems that have long operated in some sectors, the potential exists that such physical consequences as human injury and supply chain disruption could result from digital security incidents affecting IoT devices. (Box 5).

Box 5. Examples of digital security incidents with physical consequences

In 2000, a disgruntled former employee of a software development team released 800 000 litres of raw sewage into nearby rivers and local parks, after hacking into the system controlling an Australian sewage treatment plant (Abrams and Weiss, 2008).

In 2003, the computer worm “Slammer” crashed an Ohio nuclear plant network. The worm penetrated a private computer network at the plant and disabled a safety monitoring system for nearly five hours (Poulsen, 2003),

In 2005, DaimlerChrysler automobile manufacturing plants went offline for an hour stopping all work after being hit with the Zotob Worm (Cisco, 2015b).

In 2006 in Harrisburg, Pennsylvania, a foreign-based hacker planted malicious software in a water treatment system by infiltrating the laptop of an employee. The hacker used the employee’s remote access as the entry point into the system.[22]

In 2007 in Willows, California, an intruder sabotaged the industrial control system of a water canal, damaging the system used to divert water from the Sacramento River (McMillan, 2007).

In 2008, a teenage boy in Poland hacked into the track control system of the Lodz city tram network, derailing four vehicles and injuring 12 passengers (SANS, 2008; Cisco, 2015b).

In 2009, in Austin, Texas, hackers changed the messages on multiple digital road signs; one sign was altered to read “Zombies Ahead” (Goodwin, 2008).

In 2011, the water treatment system in Illinois was shut down. A hacker managed to remotely disable a utility’s water pump used to pipe water to thousands of homes in Illinois. The hacker broke into a software company’s database and obtained user names and passwords of control systems (Rushe, 2011).

In 2014, hackers attacked a German steel mill control system such that a blast furnace was unable to shut down resulting in massive damage (SANS ICS, 2014).

In 2015, researchers took control of a Jeep Cherokee remotely, without prior access to the car. They wirelessly interfered with the accelerator, brakes and engine. Following this experiment, Fiat Chrysler recalled 1.4 million vehicles (Greenberg, 2015; Greenberg, 2015b).

Depending on the use scenario, breach of confidentiality can also be an issue with the IoT. For example, a competitor could steal innovation by taking control of networked cameras in a factory or boardroom (Pelroth, 2012). A breach of confidentiality of personal data would raise privacy issues. Here again, the level of risk will depend on use scenario and, in particular, the nature and sensitivity of the data. For example, intruders could remotely access simple home devices such as smart televisions equipped with microphones and listen into households’ living rooms. They could also hack into IoT health and fitness devices or more professional medical devices, collecting more sensitive location and health data.

It is important to address digital security risk related to the IoT within the context of the broader computing ecosystem rather than in isolation. In fact, the IoT is rarely a standalone building block isolated from other digital components. Instead, all digital components in an organisation or on a personal network will often need to be considered as interconnected and interdependent. Vulnerabilities or incidents affecting parts of an organisation’s information system that may seem unrelated to the IoT can affect it, as much as the exploitation of IoT components can have consequences in other parts of a system. For example, in 2015, a security firm investigated a hospital information system where attackers exploited a vulnerability in a networked blood gas analyser to ultimately infect the entire hospital IT department’s workstations (Storm, 2015). As the common metaphor goes, a chain is only as strong as its weakest link, so it is important that we learn from the example of the industrial control systems and ensure that IoT devices incorporate appropriate security measures from the start. In general, decision makers should ensure that digital security risk is treated on the basis of continuous risk assessment, and that security measures are appropriate to and commensurate with the risk. Digital security risk management should be integrated to the broader risk management framework of the organisation and become part of economic and social decision making, rather than being addressed in silo.

In industrial environments, some digital components that used to be standalone or isolated from IP networks have been progressively upgraded and connected to the Internet, either directly or indirectly, without embedding at the same time basic technical security measures to protect them against simple well-known attacks. For example, some equipment still has easily guessable or hardcoded default passwords, or lacks sufficiently strong authentication or cryptographic protections (Potoczny, 2015). In some cases, this situation can be aggravated by the fact that some of these devices that are not software upgradeable are deployed in remote places where they are difficult to upgrade physically, or have limited or no user interface for remote maintenance. In some cases, the drive for efficient use of resources (memory, processing power and energy) has left security concerns on the side.

The absence of basic security measures or the presence of well-known vulnerabilities also appears in consumer IoT devices and applications. For example, a 2015 study by Hewlett Packard Enterprise Security Research which reviewed 10 of the most popular devices in some of the most common IoT niches revealed a high average number of vulnerabilities per device. 70% of devices used unencrypted network service, 60% provided user interfaces vulnerable to basic attacks, 80% used weak passwords (HP Enterprise, 2015). In 2015, security researchers reviewed nine models of baby monitors with remote access capability, and determined that all but one were vulnerable to the most trivial attacks. This report coincided with a report that someone had hacked a couple's baby monitor, attracting widespread media coverage (CBS, 2015). This situation reflects some level of insufficiency in security practice. In 2013, one of the first cases of a regulator charging an IoT firm occurred, following lax security practices that exposed the private lives of hundreds of consumers to public viewing on the Internet (Box 6).

Box 6. Enforcement action in the IoT space by the United States Federal Trade Commission (FTC)

In 2013, the FTC charged that TRENDNet, a maker of video cameras designed to allow consumers to monitor their homes remotely, had lax security practices that exposed the private lives of hundreds of consumers to public viewing on the Internet. In its complaint, the FTC alleged that, from at least April 2010, TRENDnet failed to use reasonable security to design and test its software, including a setting for the cameras' password requirement. Under the terms of its settlement with the FTC, TRENDnet is prohibited from misrepresenting the security of its cameras or the security, privacy, confidentiality, or integrity of the information that its cameras or other devices transmit. In addition, TRENDnet is required to establish a comprehensive information security programme designed to address security risks that could result in unauthorised access to or use of the company's devices, and to protect the security, confidentiality, and integrity of information that is stored, captured, accessed, or transmitted by its devices. The settlement also requires TRENDnet to notify customers about the security issues with the cameras and the availability of the software update to correct them and to provide customers with free technical support for two years to assist them in updating or uninstalling their cameras.

Source: United States Federal Trade Commission.

The 2015 OECD Security Risk Recommendation notes that all stakeholders – governments, public and private organisations, and individuals who rely on the digital environment for all or part of their economic and social activities – have a role in managing the digital security risk to their own activities. However, those who are in charge of developing and maintaining the digital environment "should also implement appropriate security measures in their goods and services, where possible, to empower their users to manage digital security risk." This may be challenging for manufacturers and designers of products in areas that have not previously focused on digital security such as health devices makers, energy providers, or automobile manufacturers. For example, the automotive sector is moving quickly to make cars into IoT devices. Ford and BMW recently announced that the same software security updates that personal computers receive today will be sent to cars wirelessly.[23] Support for ongoing updates can mitigate many of the security vulnerabilities mentioned above. Connectivity has security implications of its own, however, as underlined by the early-2015 Chrysler recall of 1.4 million vehicles after vulnerabilities in their UConnect Internet-connected hub were disclosed by security researchers (Greenberg, 2015). The application of a digital security risk management approach in the design of a product or service that was not previously networked requires a change in the engineering culture. Nevertheless, product design methodologies should address digital security risk reduction measures as they do with other categories of risk.

Several stakeholders are developing IoT digital security guidance. They include, for example, the GSMA set of security guidelines to promote best practice for the secure design, development and deployment of IoT services[24], the European Commission “Alliance for Internet of Things Innovation (AIOTI)” which published ten policy recommendations in relation to privacy which could be adapted to a greater geographical scope, the Open Web Application Security Project (OSWAP) Internet of Things Project[25], and the Cloud Security Alliance “Security Guidance for Early Adopters of the IoT”.[26] In the United States, other recommendations and standards documents are being developed by specific agencies, such as by the Federal Trade Commission[27], the Food and Drug Administration with respect to medical devices (FDA, 2016), or NIST with respect to smart grid (NIST, 2014). The FBI, as well as other United States law enforcement agencies, is conducting ongoing research into the ways that criminals exploit IoT systems and other computer resources remotely, and provide advice and data to help consumers and businesses to avoid these intrusions.

Comprehensive data collection

The promise of IoT technologies is dependent on the data generated by the connected ‘things’. Data about how customers in a given region actually use energy can make for more efficient use of scarce resources as well as providing guidance on the best way to heat and cool for individual users. The data generated for medical devices can drive widely-applicable research even as it alerts doctors to the need for different treatment or the presence of malfunction. Data about traffic patterns in relationship to any number of factors already contributes to the way the traffic system operates.

Data processing in the IoT can take place in a variety of ways ranging from locally, on the device itself, to remotely, with information being sent for processing to servers elsewhere. Governments, businesses and data protection authorities around the world are trying to anticipate the possible potential privacy implications of having an extraordinary amount of data points that could be collected, aggregated across devices and analysed not only by the device owners, but also by other third parties unknown to the individual. A key challenge for using the data, and in particular personal data, obtained through the IoT, is in developing approaches to accountability, transparency, and consent for data use.

Inference and the loss of control

Privacy principles dictate that users should be able to keep control of their data as well as to opt out of the “smart” environment without incurring negative consequences. There are a number of means that individuals use to protect their own privacy. Intuitively, the most obvious way is to withhold or conceal information relating to them. However, the ubiquitous nature of IoT, coupled with technological advances in data analytics, makes it increasingly easy to generate inferences about individuals from data collected in commercial or social contexts, even if these individuals never directly shared this information with anyone.

An example is geolocation data from mobile devices, which on the one hand can be used to improve the location-based services on which many rely today, but at the same time leaves a trail of an individual's daily routines and movements, which are increasingly used for other services including for process improvements. Tracking enables businesses to enhance their practices by providing them with an enhanced means to "know" the customers and can be used in multiple ways to expand customer behaviour analysis. Value is derived from the rich information about the individual, their activities, their movements, and their preferences.

With the IoT, sophisticated tracking and profiling can occur, involve third parties that individuals may not be aware of, and result in a combination of online and offline information such as location patterns (inside a store or across a city), online browsing, purchase history and social media activity.

In September 2014, Europe's Article 29 Working Group – composed of data protection authorities of European Union member countries – issued an Opinion on Recent Developments on the Internet of Things. In the opinion, the Working Group emphasised the importance of user choice, noting that "users must remain in complete control of their personal data throughout the product lifecycle, and when organisations rely on consent as a basis for processing, the consent should be fully informed, freely given and specific."

Some privacy issues are not specific to the IoT context. For example, the question as to what constitutes personal data becomes particularly important when there are combinations of online and offline tracking. There are some cases where organisations may advise that they are not collecting personal data such as names and addresses, but they do collect IP addresses or other identifiers which could be considered personal data depending on the context and what other data is being collected. In addition, while some have argued that the information at issue in the Internet of Things environment is anonymised or pseudonymised, there are difficulties with anonymisation in this context. As the Article 29 Working Party noted, even pseudonymised or anonymised data may have to be considered personal data.

Data analytics extracts information from data by revealing the context in which the data are embedded, including patterns, correlations among facts, interactions among entities, and relations among concepts (Merelli and Rasetti, 2013). Thus, data analytics enables the "discovery" of new information.

Data analytics is not a new phenomenon. However, as the volume and variety of available data sets increase, as well as the capacity to link different data sets, so does the ability to derive further information from these data, for example for profiling purposes. Advances in analytics now make it possible to infer sensitive information from data that may appear trivial at first, such as past purchase behaviour or electricity consumption. The IoT will likely accelerate this trend, generating a large number of diverse but inter-linkable data sets that directly or indirectly relate to economic and social activities.

Transparency and purpose of data collection

Promoting transparency and the rights to access and correction have been part of the OECD Privacy Guidelines since their initial adoption in 1980, and have been incorporated to varying degrees, into many national laws around the world. Transparency and access have long been recognised as powerful tools to enable data subjects to make informed decisions and to ascertain the basis on which decisions about them are taken, thereby reducing the potential for discrimination. The Council of Europe recommends that, in some circumstances, transparency requirements include the logic underpinning the processing (Council of Europe, 2010). However, devices in the IoT may often be designed to operate in the background as part of home or living environments so that individuals may never know they are there. As a result, individuals may have difficulty knowing what information about them is being collected, used and disclosed by such devices.

In the retail environment, for example, passive in-store tracking and profiling raises questions as to how individuals are made aware of the purposes of the collection of their personal data, how transparent the information management practices of all the stakeholders involved are, how individuals are notified about such practices, and how these communications are presented to them in order for them to give meaningful consent.

As a 2016 report by Canada's Office of the Privacy Commissioner (OPC) notes[28]: "binary, one-time consent and traditional definitions of personal information are increasingly perceived as outdated because they reflect a decision at a moment in time in the past, under specific circumstances and are tied to the original context for the decision. Simplistic, "on/off" personal data management policies may be neither flexible, nor appropriate, in the fast-developing IoT environment". In addition, the 2015 report by United States' Federal Trade Commission on the Internet of Things recognised the practical difficulties of providing consumer choice where there is no consumer interface and suggested new options, including choices at point of sale, tutorials, during device set-up or codes on the device.

There are challenges with the current consent model and further work is needed to identify, explore and validate possible options to deal with these challenges so that concerns raised both by individuals and organisations are addressed.

Raising individual awareness and promoting responsible use by organisations

These considerations require implementing a user-centric approach that empowers users to play a meaningful and active role with respect to the collection, use and disclosure of their data, including by providing them the ability to make informed choices. This requires education and awareness, which are specifically identified in the revised OECD Privacy Guidelines' call for "complementary measures".

Focusing more explicitly on promoting responsible usage by organisations could also complement efforts to improve transparency and consumer empowerment. Policy makers and enforcement authorities may need to play a role in helping organisations to identify appropriate substantive limits. Examples can be drawn from guides to credit scoring, policies against the use of genetic information by insurers, and prohibitions on the use of social networking data by employers.

The White House Big Data Report recently concluded that, putting greater emphasis on a responsible use framework has many potential advantages.[29] It shifts the responsibility from the individual, who is not well equipped to understand or contest consent notices as they are currently structured in the marketplace, to the entities that collect, maintain, and use data. Focusing on responsible use also holds data collectors and users accountable for how they manage the data and any harms it causes, rather than narrowly defining their responsibility to whether they properly obtained consent at the time of collection.

Accountability and privacy risk management

Accountability is a key new provision in the Privacy Guidelines. To be accountable, an organisation needs to be able to demonstrate what it is doing and what it has done, with personal data and explain why.

The revised OECD Privacy Guidelines introduce risk management as a key approach for implementing privacy protection, especially in the context of developing privacy management programmes for accountability. Risk assessment can consider data sources and quality as well as the sensitivity of the intended uses. In addition to mitigating the risks of misuse, the assessment can also examine the process by which the data have been analysed; this can help identify where errors or mistakes may have been introduced into the analytical process itself. To be effective, the scope of any privacy risk assessment must be sufficiently broad to take into account the wide range of harms and benefits, yet sufficiently simple to be applied routinely and consistently.

The IoT environment may make risk assessment challenging, due to the many stakeholders, such as device manufacturers, social platforms, third-party applications and others. Some of these players may collect, use or disclose data, and can have a greater or lesser role in its protection at various points, though where to draw the line between them can be challenging at the best of times. For example, who is ultimately responsible for the data which the smart meter broadcasts? The homeowner who benefits from using the device, the manufacturers or power company which provided it, the third-party company storing the data, the data processor who crunches the numbers, all of the above, or some combination thereof? And to whom would a privacy-sensitive consumer complain? Should privacy be breached, where does the responsibility of one party end and another begin?

Thus, the extent to which a comprehensive risk management approach can strengthen application of the OECD Privacy Guidelines' principles is a topic for further work that could also consider aspects that may be specific to the IoT.

Interoperability of technologies and policy frameworks

As a result of the vast diversity of IoT application topic areas and the vast heterogeneity in their goals and requirements, many IoT devices and techniques will exist, and interoperability is crucial. While for some the current explosion of products and services is the signal of a growing IoT marketplace, a fragmented ecosystem with non-interoperable technologies could undermine the efficiencies achieved by large economies of scale. The IoT ecosystem will employ hardware and software from many different vendors, and the ability to employ functionality from many devices and vendors is key to IoT techniques reaching their potential. An effective approach to solve this problem is to rely on global, voluntary standards developed by standards development organisations and industry consortia. The diversity of potential IoT applications, device technologies, business and operational models will require flexible approaches, so it is important to not tie the IoT ecosystem prematurely to burdensome or conflicting standards, particularly those of a one-size-fits-all nature. Furthermore, rapid technology innovation in this domain may mean that early approaches will be quickly surpassed.

Functional interoperability must take into account radio technologies, RFID and mobility. As opposed to data and service portability, feature/function portability in the IoT might not always be possible because this is the way innovation occurs across products. A balance must be found between proprietary non-interoperable systems and unified systems which, in turn, could enable the sharing of information across services generating a loss of privacy and control if not carefully designed. Such a fragmented ecosystem in which users requires multiple systems which do not interoperate does not encourage consumer adoption and stresses the need for compatible systems. In France, for example, a survey reported that 74% of people found the multiplicity of applications to control IoT objects a barrier to buy one.[30]

There are a number of issues related to the interoperability of policy frameworks across borders and sectors, in areas such as consumer protection, safety, privacy and security, particularly when products are designed, manufactured and sold in countries with different approaches. It is necessary to address the gaps between different approaches and practices. It is also important to identify and highlight the responsibilities of different actors. For instance, the consumer experience in IoT connected services will likely fall under the responsibility of the private sector. In the case of consumer protection or safety, the role of governments may be more prominent. To foster policy interoperability, governments could encourage further dialogue across regulatory agencies and with industries that traditionally were not closely involved in communications, such as transportation or utility services.

Investment

According to industry experts, the adoption of the IoT in homes, cities and industries is not expected, in the short term, to dramatically increase the demand on current networking infrastructure.[31] Thus, the traffic increase due to the IoT adoption would be gradually absorbed by connectivity providers with their network upgrade investment cycles. However, it is necessary to ensure a continuous stream of investment in several areas such as sensor technology development, energy-saving techniques and interoperable software platforms.

An increasing number of large ICT companies are investing significantly in IoT projects. Some governments are looking for ways to promote this activity while others prefer to take a technology neutral approach. Multinational firms are advocating for more transparent, predictable, and technology neutral laws and regulatory requirements to avoid impeding the pace of IoT innovation and economic growth. The European regulatory framework for electronic communications can be mentioned as a good example as it enshrines the principles of predictability and technological neutrality. Its pro-competitive regulatory approach promotes investment when imposing proportionate and appropriate regulatory measures. Many firms engaged in IoT development and businesses argue, however, that the global nature of IoT services and the need to promote innovation in the private sector require a “light-touch” regulatory approach.

Some OECD countries may take actions to reduce the barriers to entry for new players, while other countries are likely to refrain from influencing current market conditions, especially where IoT applications may compete with existing licensed services. One consumer-related example is a home security service provided through a mobile operator versus a set of Internet-connected devices owned and controlled by the homeowner. The mobile provider may want to maintain its revenue stream from the subscription service rather than allowing consumers to perform those functions themselves. Many regulators, such as in the United States, may be reluctant to attempt to influence markets by creating incentives for competition among vendors. For the larger economies, such industrial policies may not be necessary. Six of the 10 largest IoT investments in the world to date are being made by United States based companies, where the federal government adheres to a policy of technology neutrality in most instances.[32]

Jobs and skills

A question that arises around the IoT concerns its implications for employment. The competitiveness of the market of an economy is dependent upon having the most efficient tools and processes. It is likely that countries that invest more in the development of sensors/actuators and autonomous systems, data analytics and machine learning, and data communications will benefit more greatly from them. Whether this will lead to economic growth or will influence jobs is a source of debate among economists - see, for instance (OECD, Forthcoming a). It is likely, that if robotic warehouses perform as well as suggested by those implementing them, then jobs in the warehouse sector will decrease and firms will try to compete on building more efficient warehouses.[33] This will lead to efficiency, reducing costs and prices, and which could in turn lead to greater purchasing power for consumers. It also could lead to job loss and frictions in the economy.

There are many other “routine” jobs that might decline in the coming years. If fully autonomous vehicles were successful, then autonomous taxis, buses and trucks would be likely candidates for reduced employment. For example, one automobile manufacturer has estimated a return on investment in a self-driving truck in 2025 of less than 24 months, or significantly less than the economic life of such a vehicle.[34] The effect could be that some jobs that in the past absorbed unskilled or low-skilled workers may not exist to the same degree in the future. There will still be jobs associated with providing these functions. But many of them will require higher skills, such as for repairs and programming of robotic functions. Having a skilled labour force is therefore crucial (OECD, Forthcoming b) though even here some traditional jobs may be eliminated. On the other hand, there are also cost savings associated with autonomous machines, which may allow the re-employment of people in other parts of the economy. In addition, greater efficiency in transport may support increased demand across the whole economy enabled by these gains.

Brynjolffson and McAfee mention in their book “Race against the Machine” a possible future in which machine learning allows robots to replace humans in many “lower skilled” jobs. Their work aimed at bringing technology into the discussion on unemployment and the global financial recession. The “End of Work” as this hypothesis is known, after a book by Jeremy Rifkin, has in the past been proposed by many economists, but has not received much attention as technological changes have generally been accompanied with increases in employment in other parts of the economy, such as the services economy and the IT-industry. To many economists, the proposition is therefore also known as the Luddite fallacy (Economist, 2011). While there are different views on the implications of technological change for employment, the IoT promises to increase the discussions of this topic. Brynjolffson and McAfee point to the introduction of mechanisation at the start of the 20th century, which led to an almost complete replacement of the use of horses in only two decades. In many ways, the world is today at the dawn of machine learning similar to where it was in 1994 with respect to the Internet. Practical commercial examples are now available, but much is still to be learned. Technology has moved quickly and the integration of low-cost electronics, large scale processing power and ubiquitous networking has allowed new generations of autonomous and semi-autonomous machines. These machines are moving into every part of the economy and are displacing work in various sectors. This could theoretically lead to workerless factories. Even if it causes only temporary friction problems in the economy, as Keynes once suggested, it is a development that policy makers need to consider. Machine learning is as much about the competitiveness of the economy as it is about labour policy.

Even though the effects of the IoT cannot be evidenced yet in changes in employment, it is illustrative to make use of studies of a broader “digitalisation” in businesses. Recent studies with regard to the German market show that a majority of companies do not expect negative effects of digitalisation on the number of jobs offered by their company.[35] In the cited study 23% of the interviewed companies even expect new hires to manage the digital transformation. In summary, while the introduction of digital technologies into businesses could bring more jobs in the short term, the long term effects on jobs are rather unclear.

Measuring the adoption of IoT systems by firms and consumers is an area hardly explored at the moment due to the emergence of operational IoT platforms. There is a lack of appropriate metrics to gauge the penetration and effects of the IoT on the labour market. The measurement of the digital transformation should incorporate the IoT among its elements. Stakeholders could provide data that could help in the measurement efforts, for example, the number of sensor networks or devices installed and the benefits (economic, social, environmental and so forth) involved, or the skills required to develop in order to fully adopt and seize the benefits. Concrete actions to consider could be the development of measurement guidelines based on knowledge gaps identified.

SECTION III: AREAS FOR STAKEHOLDER ACTION

Evaluate and assess existing policies

Authorities should evaluate existing policies and practices to see if they are suitably supportive of the IoT, and do not constitute unintentional barriers to potential IoT benefits. Some regulations or practices have assumptions that inhibit the application of the IoT, and consultations with the sector's main stakeholders may highlight such barriers. The incorporation of IoT in people's lives will also require evaluating the implications for privacy and security with the current international frameworks, and work towards ensuring sufficient safeguards in the context of consumer protections.

The IoT provides opportunities to promote public interest through public policy, including those that empower consumers to a greater extent than may have been possible in the past. The challenge with encouraging the development and use of novel and innovative uses of IoT, however, may sometimes be that existing actors may see the current rules as a shield protecting their interests from easier entry in a market by competitors. These actors will raise questions associated with changes in opening markets and will often raise valid points that need to be addressed (e.g. public safety, consumer protection). Governments will need to find a balance between these interests and the objective to foster innovation, competition and growth through the IoT sector.

One example of an industry where regulations need to be adapted in order to benefit fully from the possibilities of IoT is the health sector. In some countries, medical practitioners may receive reimbursement based on the number of visits by patients. Such visits may be billed according to the average duration of appointments (e.g. increments of 15 minutes), with this time being used for discussion, assessment, tests and so forth. A challenge with this model is that rigid schedule may not necessarily be applicable to an individual's requirements.. The IoT could potentially change that by enabling monitoring and reporting of information to both medical practitioners and patients. Not only could it be used to schedule appointments only when needed but also to aggregate data in ways that could be beneficial to those directly concerned and to the wider community while ensuring that the parties respect legal requirements and specific privacy policies for data processing and transfer among entities.

The IoT has the potential to alter the traditional (legal) understanding of "service attendant" and associated laws, be it healthcare or any vertical where the attendant was previously physically present. Similarly there are a large number of codes, practices, standards and other types of regulations that govern how devices operate, how services are performed and how consumers and businesses interact. Such standards can, for example, be building codes. These codes are often conservative, based on years of experience. However, they can also have the drawback that the codes limit innovations in the IoT to be implemented.[36] Authorities would do well to evaluate such regulations, with a specific focus on the new opportunities offered by the IoT.

Governments could also review their existing telecommunication laws in order to evaluate whether they provide for an adequate regulatory framework for M2M-communications and the IoT. Since telecommunication laws generally date from a time when only voice telephony existed, it is not a given that these laws are fit for purpose in a digital era. For example, this question is one aspect of the Digital Single Market (DSM) Initiative of the European Union. Similarly, the Body of European Regulators for Electronic Communications (BEREC) assessed, in its report on "Enabling the Internet of Things", whether M2M services might require special treatment with regard to current and potential future regulatory issues (BEREC, 2015). Generally speaking, it needs to be determined which players and/or which services in the M2M value chain could be subject to telecommunication regulation, taking into account both the benefits and the costs of such regulation. While the connectivity service provider is the right addressee of sector-specific regulations, this might not hold true for producers of connected devices, or at least not the majority of them.

Promote the use of global technical standards

When considering standards issues for the emerging IoT, it is important to recall that IoT neither refers to a single technology nor a new phenomenon. Due to the vast diversity of application areas and heterogeneity in their goals and requirements regarding sensing, actuation, data communication and data analytics, there will be many IoT techniques devised, each addressing different aspects of a nearly-limitless design space. The diversity of potential IoT applications and device technologies alone leads many to conclude that it would be detrimental to this ecosystem to be tied at an early stage of technological development to one-size-fits-all type of standards or standards that might prove burdensome or conflicting. Over time, technological maturity and end-user choice will ultimately identify the most promising standardisation approaches.

IoT standards are regarded particularly positive when they offer, as opposed to proprietary solutions, net positive effects in regards to large scale deployment, lock-in prevention and improved security. In the development of the IoT ecosystem and its interoperability, global, voluntary standards developed by standards setting bodies or industry consortia play a key role. Interoperability is essential to stimulate the emergence of new systems, boosting innovation and reinforcing competitiveness. Standardisation efforts, for instance, can also reduce the costs of producing electronic modules for the IoT.

Proprietary solutions, or country-specific standards, on the other hand, tie users to a specific vendor or country requirement to the exclusion of all other vendors. While the solution may be effective in the short term, the lack of competition in the industry can make the solution costly to acquire and maintain, and it may not be interoperable with other products resulting in lock-in issues. Proprietary solutions, may however, provide a competitive advantage in markets such as connectivity. Sigfox, for example, a French-based connectivity provider that uses a cellular-style proprietary system has now deployed nationwide infrastructure in eight European countries and projects expansion to 50 by 2019.[37]

Standards development for IoT interoperability, which encompasses multiple actors (hardware/device manufacturers, software platform providers, communication service providers, application developers and cloud providers) across very distinct sectors such as health, lifestyle, connected home, transport and industrial Internet among others, is still in its relatively early days. Organisations involved in IoT standardisation work include European, American and global standard organisations such as the International Telecommunication Union(ITU), the European Telecommunication Standards Institute (ETSI), the American National Standards Institute (ATIS), the Telecommunications Industry Association (TIA), the International Standards Organisation (ISO) and the International Engineering Consortium (IEC) as well as international fora and consortia such as the World Wide Web Consortium (W3C), the Institute of Electrical and Electronic Engineers (IEEE), the Industrial Internet Consortium (IIC) and the Internet Engineering Task Force (IETF) among others. Industry has also organised itself to ensure interoperability at a functional level, with several initiatives. Some of the relevant work on IoT related standardisation is displayed here (Box 7).

Box 7. A myriad of IoT standardisation initiatives and bodies

International Standard Development Organisations (SDOs) and other technical standardisation bodies involved in telecommunications and the Internet are also involved in the IoT:

- The ETSI focuses on the development of an application-independent M2M horizontal service platform.
- The IEEE has some related work through their P2413 Standard for an Architectural Framework for the Internet of Things.
- ITU-T Study Group 20 studies the development of international telecommunications standards relating to Internet of Things (IoT) and its applications, with an initial focus on Smart Cities and Communities (SC&C).
- The IETF participates in IoT standardisation particularly through Authentication and Authorization for Constrained Environments (ace) and IPv6 over Low power WPAN (6lowpan), which has already concluded.
- The World Wide Web Consortium (W3C) via the Web of Things, "standards for identification, discovery and interoperation of services across platforms".

Leading industry players are also active developing horizontal standards to enable different architectural modes of IoT functionality.

- The OneM2M initiative was founded in 2012 by seven SDOs including ETSI along with over 230 ICT companies. OneM2M is developing specifications for a common M2M service layer, focused on security and privacy, which can be embedded in various hardware and software to connect a myriad of devices with M2M application servers worldwide. It relies on liaison relationship with other standards bodies such as 3GPP, BBF, HGI, TIA, and ITU-T.
- The Industrial Internet Consortium: formed in 2014 by AT&T, IBM, Cisco, GE, Intel and academic and United States government entities to develop and make more widely available intelligent industrial automation for the public good. The IIC's work includes influencing the global standards development process and developing new approaches to security for electricity, gas pipeline and water distribution systems and maintenance of manufacturing equipment. It currently has over 200 members.
- The AllSeen Alliance: initiative to enable industry standard interoperability between products and brands with an open source framework (AllJoyn) that drives intelligent experiences for the Internet of Things. The initiative includes more than 185 members such as Microsoft, LG, Canon, Electrolux, Qualcomm, SONY, Phillips, etc.
- The Open Interconnect Consortium: group of industry leaders that have prepared a specification and promote an open source implementation to improve interoperability. The consortium groups more than 50 members, and includes Cisco, GE Software, Intel, Mediatek and Samsung.

In March 2015, the European Commission launched the Alliance for Internet of Things Innovation (AIOTI). AIOTI is an open stakeholder platform encompassing all actors of the IoT value chain, working to address these barriers within the IoT ecosystem and with the support and active involvement of the European Commission. AIOTI's workgroup (WG3) focused on standardisation recommends the use of standard-based solutions for the deployment of IoT in future projects. [38] The complexity and interdependence of IoT standards is illustrated by the interoperability "plugtests" that are performed by the ETSI for key IETF protocols for the IoT developed on IEEE technologies.

As much as global standards provide a solution to interoperability issues, companies have vested interests in driving the adoption of particular standards. This translates into companies being part of multiple standardisation efforts to ensure their optimal position as the market develops. Given the high degree of standardisation activity, it is also noted that, without careful attention, there is a high risk for considerable duplication of effort. Because of the degree to which IoT technologies represent the natural extension of other existing technologies, any new policy or standardisation action will almost undoubtedly have significant duplication with existing efforts.

In Europe, for example, the European Commission proposed in the Digital Single Market (DSM) Strategy to launch an integrated standardisation plan to identify and define key priorities for standardisation with a focus on the technologies and domains that are deemed to be critical to the DSM. In this context, the objective is to avoid fragmentation between national initiatives in Europe, allow cross-fertilisation between different application domains, and make sure that the regulatory framework supports seamless up-take across borders. The European Commission is also looking for input on standards in the IoT and related areas such as 5G communications, Cloud computing, Intelligent Transport Systems (ITS), Smart Cities and efficient energy use. A public consultation to gather views on priorities for standards closed in January 2016 and results will be published soon (EC, 2015). The promotion of global standards in these areas would increase the opportunities to deliver interoperable products and services to a global audience using economies of scale for the different elements (sensors, chips, platforms, etc.) across the supply chain.

In summary, standards are essential for IoT devices and services to operate. At the same time there are so many standards families to choose from that it is nigh impossible to determine whether a standard fits a situation well, or whether it will be supported industry-wide and in the future. This is true for both applications for businesses and consumers and for every layer from network to services. Stimulating research into standardisation itself appears to result in more standards, instead of one standard. Researchers of IoT technologies and solutions should acquaint themselves with existing standards and standardisation initiatives to avoid duplication of standardisation efforts.

Evaluate spectrum resources to satisfy IoT needs

Different parts of the IoT need a variety of spectrum resources that is fit for purpose. Because every part of the electromagnetic spectrum is used, developers of new applications find it challenging to obtain spectrum that meets their requirements. Regulators are aware of the general scarcity of spectrum supply for all uses and endeavor to make spectrum available, but existing users often have valid objections to vacating or sharing spectrum. Spectrum needs may be mainly addressed through two different types of spectrum: *licensed* spectrum allocated to commercial mobile networks and spectrum available under general authorisation models or *license-exempt* spectrum (Box 8).[39] In addition, it appears that because mobile networks are not always accessible under competitive terms, some users are looking for regulatory arbitrage, using license-exempt spectrum or alternative bands to satisfy their needs. Particularly, the use of technologies developed in license-exempt spectrum bands, such as Wi-Fi, which can keep prices low for consumers and gives innovators the extra spectrum space to develop new products.

It is illustrative to analyse different wireless technologies and how they relate to specific types of spectrum schemes. Starting from within the home and moving outward, the 2.4 GHz band is probably the most saturated band for all kinds of applications, including for the IoT. The band supports Wi-Fi, Bluetooth, Zigbee, Thread and many other networking protocols. Originally allocated as spectrum for industrial, scientific and medical (ISM) applications, today several applications share this band. This is why spectrum managers decided to allow unlicensed use of the band and would, in many cases, like to make more available when appropriate according to market demand. For IoT manufacturers, the benefit of unlicensed spectrum lies in the low transaction costs of introducing a new innovation. There is no need to negotiate access or face upfront costs from third parties, which makes it effectively a platform for innovation and a greenfield space for technology startups, entrepreneurs and established companies alike. Unlicensed spectrum levels the playing field.

The predicted growth of IoT applications will indeed increase demand in existing unlicensed bands, especially in frequency bands dedicated to short range devices (SRD) below 1 GHz, for example in the 433 MHz band in Europe and 900 MHz[40]. The need for a predictable sharing environment and also the need to find more efficient spectrum sharing solutions for some IoT applications has already led to investigations in the CEPT on more sophisticated technology and application-neutral spectrum access and mitigation techniques. At the same time, other countries are also exploring spectrum issues with respect to IoT. Any evolution of SRD regulation should carefully consider results of sharing studies.

Box 8. Unlicensed spectrum research on congestion and quality of service

A question arises as to the extent unlicensed bands suffer congestion or diminishing quality of service which could be problematic if more IoT devices use technologies operating in such bands. The bands around 900MHz (SRD band 868MHz in Europe, ISM band 915MHz in the United States) provide an example of how different technologies attempt to co-exist and compete in this band: Z-Wave (short range/low power), Wi-SUN (short range/low power), LoRa (long range/low power), Sigfox (long range/low power) and Weightless-N (long range/low power). It will be necessary to monitor whether the technologies can peacefully coexists as the number of users increase.

In 2009, a consultancy report undertaken for Ofcom found that the majority of problems experienced by Wi-Fi users in the 2.4 GHz band were not spectrum-related, but mostly due to configuration issues or problems with the wired Internet. The report said, however, that some inner city locations, such as in central London, exhibited signs of congestion and interference, which they said was expected to increase. Wi-Fi in the 5 GHz band is less congested and has much more bandwidth, enabling non-overlapping channels and higher throughput, and Ofcom is continuing to monitor the use of these license-exempt bands.

In the Netherlands, a study found that in inner cities, shopping malls and high density housing, users of Wi-Fi could find as many as 50 active access points at any given time. These would interfere and significantly decrease the throughput of the spectrum. It expressed concern for the 2.4GHz-band’s utility in the future given the extensive use today, but also noted that the 5GHz band offers much better performance and less interference, in part because it is less used and carries less far and less well through objects such as walls than 2.4GHz.

Furthermore, FCC’s Technological Advisory Council, an outside group of industry experts, suggested that the planned additions of unlicensed spectrum (predominantly in the 5 GHz band) should be sufficient for IoT evolution but that this could change if image and video were widely used as cheap sensors. It therefore recommended continual oversight of the evolution to monitor spectrum sufficiency.

Source: Mass Consultants Limited and Radiocommunications Agency Netherlands – Ministry of Economic Affairs.

Unlicensed bands also involve requirements, such as mitigation techniques, as the devices should not cause harmful interference or expect protection against interference. Wi-Fi technologies in the 2.4/5 GHz bands and applications in the 800/900 MHz band are the most significant examples of such unlicensed bands. Wireless microphones, radiofrequency identification (RFID) systems, medical equipment, or smart grid communications make use of license-exempt spectrum. The development and use of Wi-Fi is one of the most successful examples of the use of unlicensed and shared spectrum. Today, it is not only used by millions of users around the world but it is also playing an increasing role in areas such as offloading mobile traffic on to fixed networks.[41] In Australia, this type of regulation for spectrum is referred to as “class licensed spectrum”. The economic significance of license-exempt spectrum to the future of the Internet is not contested.[42]

Efficiency gains in radio technology are positively affecting the viability of IoT. As radio transceiver technology improves, higher frequencies will be utilised with a better precision and lower costs than before. Current market developments are reducing the power that mobile stations, the most expensive and power hungry component in the mobile network, require to transmit their signals by improving the amplifiers design with software defined radio technology.[43]

Box 9. Allocating spectrum for V2V communication

Authorities are looking at other spectrum for the IoT for Intelligent Transport Systems and vehicle-to-vehicle communication (V2V), which have the potential to make vehicles safer to use and to allow future innovations for autonomous vehicles. For example, vehicles and roadside equipment, such as traffic lights can signal the state of an intersection, whether vehicles are (abruptly) braking and so forth. The United States and Europe have made spectrum available at 5.9 GHz for V2V and Japan aims to use the 760 MHz band for V2V which is unlicensed but limited only to safe-driving support

In May 2015, the United States Government asked the National Highway Traffic Safety Agency for acceleration of the introduction of V2V technology by the end of the year, in order to make roads safer and facilitate the introduction of self-driving vehicles. In Europe 30 MHz has been designated for Intelligent Transport Systems in the 5.9 GHz band. In the United States, 10 MHz is used exclusively for safety-related V2V communications. It is under discussion in the United States whether it is possible to share the relevant band with other license-exempt services/applications like Wi-Fi.

For its part, the United States favours spectrum sharing opportunities over spectrum segregation per application. Europe has considered whether it is possible to share the 5.9 GHz band with other license exempt services/applications like Wi-Fi. However, according to the feasibility studies undertaken, it is unlikely to make the band available for mobile applications.

Source: OECD delegates and blog post by Mr. Foxx, Secretary of Transport of the United States.

For devices that need coverage over a large area, traditional mobile 2G/3G/4G networks are commonly used. However, because of signaling and mobility requirements of mobile phones and smartphones, these networks are not always optimised for IoT applications (Box 9). Some mobile devices impose high energy overheads on initiating data communications, which means that the intermittent and low data rate transmissions common to some IoT applications has in the past led to higher-than-necessary battery drains. There are technology and standards developments underway to make transmission approaches in mobile networks better suited to IoT requirements. LTE Cat-0 and LTE-M, for instance, are standards that will reduce the modem complexity relative to current LTE (4G) systems by 50% and 25%, with similar costs reductions (Leckie, 2015).

Numerous M2M services are currently served through mobile 2G/3G/4G networks (e.g. credit card machines linked to the 2G network in the 900 MHz). However, users with a high number of devices in operation find that such networks do not always provide a competitive option for M2M. As a result of the potential lock-in and the challenges in achieving coverage, large-scale suppliers and users of the IoT have been examining alternative networking solutions. Telefonica and the Swedish company Connode won a 15-year contract to supply smart metering solutions in the United Kingdom that uses a combination of IEEE 802.15.4 IPv6-based mesh networking and cellular connectivity. The mesh networking allows the smart meters to use other smart meters to get to a hub that has cellular connectivity and if coverage is lost on one node, another node can act as a hub.

As mentioned by a recent CEPT analysis in June 2015, there does not seem to be a strong case for the specific designation of specific frequency bands for IoT, since most IoT applications existing today or foreseen can be carried over commercial mobile broadband networks.[44] Nevertheless, Ofcom has made available frequency bands on a license-exempt basis for IoT applications in the United Kingdom.[45] Moreover, after a consultation launched in September 2015 Ofcom concluded that a new license is not necessary to roll-out new services in the 55 MHz-68 MHz, 70.5 MHz-71.5 MHz, and 80 MHz-81.5 MHz bands and that the current license is appropriate for providing access to the spectrum for IoT and M2M services.[46] Other opportunities for IoT could come from the development of a fifth generation (5G) of mobile radio technology that would substantially exceed the capacity of existing mobile technologies and would be IoT-ready. In the United States, the FCC expressed that 5G will likely have to use diverse types of radio access technologies, including macro cells, microcells, device-to-device communications, new component technologies, and unlicensed as well as licensed transceivers (FCC, 2014).[47] When developing 5G, requirements from industry such as the automotive (e.g. very low latency time, mission-critical reliability) need to be taken into account.

Adapt research and innovation policies

Many governments have recognised the potential benefits of the IoT and reflect that through a number of public policies, either as an enabler of goals or as an area targeted for research.[48] There is no uniform way that governments approach the IoT, but some examples can be provided. The European Union has made the IoT an essential part of its Digital Agenda for Europe 2020. It focuses on applications, research and innovation and the policy environment. As a result, the European Union has been particularly active in promoting research and innovation.

The Internet of Things European Research Cluster groups together the IoT projects funded by the European research framework programmes, as well as national IoT initiatives. The requirements of IoT will also be fed into the research on empowering network technologies, such as ‘5G mobile technologies’. The Future Internet public private partnership will develop building blocks useful for IoT applications, while Cloud Computing will provide objects with service and storage resources. On the application side, initiatives like Sensing Enterprise and Factory of the Future help companies use the technology to innovate, while experimental facilities like *FIRE* (Future Internet Research and Experimentation) are available for large-scale testing.[49] A study mandated by the European Union has identified the following IoT research challenges: open integrated architecture, end-to-end connectivity, security by design, semantic-driven analytics (IDC and TXT, 2015).

In May 2014, the Korean government published its plan for building the IoT with the aim of a hyper-connected, “digital revolution” to address policy goals. Among the aims is to attain IoT-driven economic development. Some examples already visible are Songdo Smart City and smart eel farms. It targets the commercialisation of 5G mobile communications by 2020 and aims for Gigabit Internet to achieve 90% of national coverage by 2017. In relation to spectrum, the Korean government’s plans would see a total of 1 GHz of spectrum freed by 2023, and IPv6 infrastructure into the subscriber network by 2017. It will promote the development of low-power, long-distance and non-licensed band communication technologies for connecting objects in remote areas (Ministry of Science, ICT and Planning, 2014).

When introducing IoT services in a nationwide manner, conflicts with existing regulation can be a bottleneck. Regulatory uncertainty can also be a large barrier. For example, the current medical related regulations may hamper innovative services by requiring a doctor to be present on both sides of a tele-medicine consultation. With this in mind, the Korean government has established a ‘telecommunication strategy council’, which will take the initiative to improve general regulations. It will also establish an IoT test bed as a regulation-free zone and aim to improve the legal system.

Further, the Korean government announced the “IoT Promotion Strategy” in December 2015 with the objectives of developing and commercialising IoT-based business models and improving industrial competitiveness by encouraging private investment. The government will invest USD 110 million by 2017. An “IoT Promotion Task Force” composed of officials from different ministries will identify regulations hindering the use of the IoT and suggest reforms. Most, if not all, national governments acknowledge the need for research in IoT in areas of cybersecurity, interoperability, privacy, energy efficiency, and several other aspects of IoT development.

In Europe, individual countries are investing in research and development on IoT. In the United Kingdom, USD 110 million was allocated in 2014 and previous years (Novet, 2014). France is financing embedded systems and IoT from a USD 55 million fund for digital development, with a new USD 440 million fund expected in 2015 (Barbaux, 2015). In the framework of the German government's "*Industrie 4.0*" strategy, industry-related programmes add up to over USD 500 million during a period of around five to seven years.[50] "*Autonomics for Industry 4.0*" is a technology programme by the Federal Ministry for Economic Affairs and Energy designed to merge state-of-the-art ICT technology with industrial production by exploiting the potential offered by innovation in order to accelerate the development of innovative products.[51] With the 'Smart Service World' technology competition, the Federal Ministry for Economic Affairs and Energy intends to promote research and development activities, thus facilitating innovative ICT-based services.[52]

Canada's largest province, Ontario, launched a new pilot programme to allow for the testing of driverless vehicles on its roads. The province also pledged funding towards the Centres of Excellence Connected Vehicle/Automated Vehicle Programme, which brings academic institutions and business together to promote and encourage innovative technology. In Australia, the State of South Australia has mirrored this approach with the state government introducing legislation to permit on road trials as encouraging R&D and start-ups.[53]

Some governments are providing financial incentives or subsidies (e.g., grants, loans, venture capital support programmes, platforms for industry to showcase new technologies and innovations) to support projects by start-up companies and corporations, many of which utilise IoT technologies. In the United States, the White House announced in September 2015 a new "Smart Cities" initiative. Other major economies such as India and the People's Republic of China have also similar programmes. India's Smart City plan is part of a larger agenda of creating Industrial Corridors between India's big metropolitan cities. These include the Delhi-Mumbai Industrial Corridor, the Chennai-Bangalore Industrial Corridor and the Bangalore-Mumbai Economic Corridor. It is hoped that many industrial and commercial centres will be recreated as "Smart Cities" along these corridors. The Delhi-Mumbai Industrial Corridor (DMIC), which is spread across six states, seeks to create seven new smart cities as the nodes of the corridor in its first phase.[54]

Box 10. The Smart Cities initiative in the United States

Over USD 160 million in federal funds will be invested in research projects and leverage more than 25 new technology collaborations to help local communities address key challenges: reducing traffic congestion, fighting crime, fostering economic growth, managing the effects of a changing climate, and improving the delivery of city services. This initiative includes more than USD 35 million in new grants to build a research infrastructure for Smart Cities by the National Science Foundation and the National Institute of Standards and Technology; nearly USD 70 million in proposed investments to unlock new solutions in safety, energy, climate preparedness, transportation, health and more, by the Department of Homeland Security, Department of Transportation, Department of Energy, Department of Commerce, and the Environmental Protection Agency; and more than 20 cities participating in major new multi-city collaborations that will help city leaders effectively collaborate with universities and industry.

The United States government also hosted a forum coinciding with Smart Cities Week, highlighting new steps and brainstormed additional ways that science and technology can support municipal efforts. The Forum included the creation of test beds for IoT applications and big data analytics, with the intention of helping United States companies to become global leaders in this field.

Source : https://www.whitehouse.gov/the-press-office/2015/09/14/fact-sheet-administration-announces-new-smart-cities-initiative-help

A challenge that governments will have when funding research into IoT is measuring returns, but this is analogous to similar challenges in gauging the benefits of other ICT investments. In addition to quantifying gains from improvements in the base components of IoT, such as better M2M, data processing, sensors and actuators will be visible and measurable, there also needs to be measured returns from investment in innovation in applications and the integration of IoT.

Encourage private sector innovation

In several countries, industry has not yet fully utilised the potential of IoT/M2M-solutions. For example, the adaption of IoT by small and middle-sized businesses in Germany takes various degrees: Whereas three out of ten companies state that they have a (very) high degree of digitalisation, while 27.5% state that have not made use of the IoT, or only very little stating that they have a (very) low degree of digitalisation (BDI and PwC, 2015). There are also regional differences with regard to digitalisation as well as differences regarding the different degrees of digitalisation of sales and distribution on the one hand and production on the other hand. Still, due to their size and flexibility, small and middle-sized companies are predestined to implement the ideas of "*Industrie 4.0*". In order to encourage this industry segment, the German government has launched the initiative "Small and Middle-Sized Businesses 4.0 - Digital Production and Work Processes", which aims at supporting these companies with the digital transformation by means of new information and communication technologies and the development of new business areas in the context of the IoT.[55] Several centres and agencies will inform, qualify and support the companies under this initiative. The Canadian government has established a Centre of Excellence for Wireless Communications called Wavefront, which is focussed on the development of M2M and IoT companies in Canada by connecting them with critical resources, partners and opportunities.

The German government has launched innovation clusters that are directly tied to the IoT. For example, the "Cool Silicon" innovation cluster in the south of Germany aims to develop low energy and energy self-sufficient processors and sensors.[56] Another innovation cluster "IT's OWL", in the central part of Germany, focuses on *Industrie 4.0*, where the goal is to create intelligent and autonomous industries through the use of robots.[57] Also in Germany, Microtec Südwest aims to develop microsystem technology, focusing on the areas smart production, smart mobility, smart health and smart energy.[58] A fourth cluster focuses on software for new industries. Each of the research clusters is tied to a large number of businesses, universities, and research centres in this region that combine to deliver the output.

In Denmark, the DOLL initiative in the Copenhagen suburbs is aiming at creating future LED-lighting solutions and to generate jobs. The current initiative, a consortium between Gate 21, Albertslund Municipality, Technical University of Denmark and the GTS institute DELTA, is focusing on energy efficiency and intelligent indoor and outdoor lighting solutions.[59] In June, an extension focused on testing and demonstrating Smart City solutions in DOLL Living Lab was awarded additional funding. The purpose is to look at different types of public services and make them smarter. This could have implications for the operation of roads, sewers, water, energy, traffic and more.

Brazil encouraged the use of IoT by adapting its tax policies. In May 2014, the government introduced a special tax regime for M2M systems without human intervention to foster adoption and use of the IoT. The decree cut fees in SIM activations, and an annual fee for SIM cards, totalling a reduction of 80 per cent. According to the regulator, Brazil now has with 11 million of M2M connections, the fourth most in the world and the most by far in Latin America. Of those, 2.3 million are special M2M connections and 8.7 million are standard M2M connections. The evolution of the number of connections from May 2014, when the Decree took effect, to July 2015 shows large growth of the "special" category, from 161 thousand to 2.3 million; while the "standard" connection have actually decreased from 8.8 million to around 8.7 million. A controversial question is how to separate M2M with human intervention to those without in contexts such as an environmental sensor, a car control system or a home appliance.

Promote skills needed to maximise opportunities in the labour market

The implications of the IoT for labour markets are still uncertain. Understanding how other technological revolutions in the past affected the employment and the global economy may provide some assistance. The introduction and popularisation of the Internet in the 1990s provides a useful benchmark. After 1995, ICT investment increased across the world, with advanced economies and emerging Asia in the lead. By some measures, the contribution of ICT investment to growth roughly doubled in emerging Asia, Latin America, Eastern Europe, Middle East and North Africa, and Sub-Sahara Africa after 1995 (Jorgenson and Khuong, 2010).

Job from ICTs occurs through the mobility of resources – financial capital, knowledge assets and labour – across firms and sectors. By its very nature, this process of structural change takes time and may be hampered by institutional barriers and market imperfections. The diffusion of ICTs is also changing the way work is carried out, raising the demand for different types of ICT skills. In the context of the IoT, the integration of such technologies and methods will require *ICT specialist skills* to be able to develop applications using new frameworks and paradigms or manage new types of IoT networks.

The IoT could bring changes to the labour and workforce in similar ways than the introduction of the World Wide Web has effectively achieved with the media industry, for instance. Traditional media agencies have developed digital expertise in-house to cover customer relationship via the web and social media and new digital agencies have filled up the demand for such services. In such context, there has been a transformation on the skills required to fill these new professional profiles (graphic designers, web developers, social media agents, community managers, and so forth), with a greater opportunity for jobs requiring creativity and more intellectual challenging tasks. As an example, Amazon's AWS IoT platform allows business to connect devices to the cloud and communicate with cloud apps. With such solutions, managers and product developers will require their skills to be upgraded.

In a broader sense, the IoT brings a skills opportunity in several areas such as data curation, open data, big data analytics and cloud computing processing. For each of these areas, there is a need to identify the skills required by future workforce, align the curricula to support the development of the skills and promote training opportunities through a combination of formal and informal methods. Countries that will be able to do so, will be able to position themselves at the forefront of an emerging industry and seize the benefits of the IoT also in the labour market.

Societies influenced under the IoT will create an impetus to change traditional education from one, which in many ways is still designed to fill traditional workforce or assembly line jobs, to one that encourages entrepreneurism, experimentation or invention. Governments and policy makers need to understand how to adapt the education system so that its alignment with industry also improves. Skilling programmes covering both generic and technical skills should adjust displaced workers ensuring that the supply of new skills keeps pace with the new demands in IoT related sector such as sensors, robotics, data analytics and software development. Broad skills strategies, as recommended by the OECD Skills Strategy (OECD, 2012b), will increasingly be required.

Build trust in the IoT

Privacy, security, liability, reliability and consumer rights are affected by the pervasiveness and longevity of the IoT. Policy makers should ensure that the diversity of policy and regulatory frameworks in place globally enable trust in the IoT[60]. These frameworks, both domestic and international, should be interoperable in nature because IoT goods and services will be sold on a global scale and consumers will often want these devices to work wherever they are. Interoperable frameworks could provide consumers and businesses with greater certainty when purchasing and manufacturing IoT goods and services.

The current approach towards different national or regional frameworks is finding compatible regimes that can interoperate. There are already a number of regional and international frameworks that could be built upon such as the *OECD Recommendation on Cross-border Co-operation in the Enforcement of Laws Protecting Privacy*, the *OECD eCommerce Guidelines*, the *Council of Europe Convention 108* and the *APEC Privacy Framework* (OECD, 2007; COE, 1981; APEC, 2005) to name a few of them. To the extent issues arise that are unique to the IoT, it may be necessary to create additional frameworks or revise the existing ones. An example of current practices in this area is the joint working group of the Article 29 Working Party and the APEC Data Privacy Subgroup on the development of tools that help companies become certified and approved both under the EU Corporate Rules ("BCRs") and the APEC Cross-Border Privacy Rules (CBPRs).

In some ways, many of the IoT objects in people's homes will become household goods that have traditionally had much longer replacement cycle (8 to 15 years for washing machines for instance). Devices are expected to work for these periods and in some countries consumers can lay claim to warranties during the reasonably to be expected lifetime of a device.[61] For consumers, the question with IoT enabled devices is whether their IoT functions will be supported for the lifetime of the device and whether software updates might improve performance or even introduce new features.[62] IoT device makers may gain a competitive advantage by offering such updates. Transparency and truthfulness in advertising should be key consumer policy issues. The information provided to consumers at the time of the purchase should clearly indicate what expectations a consumer should have over the lifetime of a device with regards to the functioning of and updates to the software on the device and to the apps that are controlling it.

The complex structure of the IoT market may obscure which provider is responsible for a particular problem in the value chain, but also which authority can help consumers and be involved in the policy decision-making and enforcement process. In the case of a malfunction for an IoT object, it should be relatively easy to point to a responsible party. A connected light bulb, for example, may work well in a store but not connect to the consumer's home network. This raises the question of who is responsible as the problem may be in the wireless connection of the bulb, in a home network or in the software managing the system. Consumer policies could give some guidance on the responsibility for such issues.

The challenge for regulators is that there is no coherent approach that brings the various elements of this problem together. There are consumer rights issues (liability, longevity, and compatibility), privacy issues (data collection, use and processing) and security issues (vulnerability, upgradeability). Depending on the country there may be multiple agencies involved in dealing with the resulting issues. It is likely that regulators will primarily step in after breaches of security, privacy or consumer rights have happened and regulation may be more incident-driven than from a coherent policy approach. This could also lead to trade issues, when different countries have different rules and it then becomes difficult for businesses to facilitate the various demands.

In the United States, the National Institute for Standards and Technology (NIST), the standard-setting body for federal agencies, released its draft Framework for Cyber-Physical Systems in 2014. The Framework is intended to serve as a common blueprint for the development of safe, secure and interoperable systems, including IoT systems such as smart energy grids, wearable devices, and connected cars.

In the European Union, data protection rules are currently under review and shall be adopted in a future General Data Protection Regulation. The aim of the reform is to strengthen individual rights of citizens and to ensure a high standard of protection adapted to the digital era. Protection is increased inter alia by the following rights: easier access to data, a right to data portability which shall make it easier to transfer personal data between service providers, enhanced transparency (e.g. informing about a privacy policy in clear and plain language), a right to erasure of personal data and "to be forgotten" as well as limits to the use of "profiling" (Council of the European Union, 2015). It is expected that the new rules will be adopted in 2016 (Council of the European Union, 2015). The Art 29 Data Protection Working Party issued recommendations on the application of current European Union rules on data protection to the IoT. One suggestion is to incorporate privacy issues in the design phase ("privacy by design" process) and make the terms of data collection and processing more user-friendly (Article 29 Data Protection Working Party, 2014).

The ongoing development of separate responses to emerging technology developments risks an overall loss of regulatory coherence, with consequences for industry participants in terms of increased compliance costs. For consumers, increased complexity and regulatory fragmentation can make it more difficult to manage their communications experience. A single regulatory framework, or at least a joint approach, for addressing the changing dimensions of IoT activities would offer a more coherent arrangement for both businesses and consumers engaging in such activities.

Better information for consumers in a digital world should not only be the aim with regard to data collection and processing but also with regard to a company's general terms and conditions. Such consumer information should be simplified and made more comprehensive. This holds in particular true for the use of apps and intermediary platforms (e.g. Google, Facebook). New, simple and creative forms of consumer-information are advisable (e.g. short summaries/"one-pager", icons/pictograms). To strengthen private sector implementation of data protection practices, consumer associations could offer educational programmes with regard to the digital world as well as better interaction with supervisory authorities. The German government programme "More security, sovereignty and self-determination in a digital economy" supports such actions (BMWi and BMJV, 2012).

Further develop open data frameworks

The IoT is built around data, particularly its communication and analysis. Where governments have access to open public-sector IoT data from transportation systems or other infrastructure, they could further develop frameworks that allow for the re-use of public sector IoT data. This would allow industry to share their open data for public benefit and allowing interested parties access to a new range of open data. Government data is generally available under re-use conditions, but these frameworks could encourage broader public use of open data from other sources. Public data reuse is a very appealing area that also requires some degree of care in order to balance against unintended data usage or privacy loss.

Public sector information is defined by the *OECD Recommendation for enhanced access and more effective use of public sector information* as: "information, including information products and services, generated, created, collected, processed, preserved, maintained, disseminated, or funded by or for the Government or public institution" (OECD, 2008b). The OECD Council Recommendation aimed "to increase returns on public investments in public sector information and increase economic and social benefits from better access and wider use and re-use, in particular through more efficient distribution, enhanced innovation and development of new uses." In addition, "to promote more efficient distribution of information and content as well as the development of new information products and services particularly through market-based competition among re-users of information."

Apart from the OECD Council's Recommendation, the value of access to and re-use of public sector information was acknowledged in frameworks such as, the European Directive on the re-use of public sector information (European Parliament and European Council, 2003) and the Freedom of Information Act in the United States. The Internet has made the use of such data easier to access and more widely available. Particularly the development of the site: Data.gov in the United States can be seen as a catalyst in governments publishing and re-using data, with many governments following suit with similar sites.[63]

Such sites have served as a catalyst for other data to be put online. Though the data sets are very varied, they also contain data that could be characterised as IoT generated data or data that can be combined with private IoT data. Many governments have also followed up their sharing of data with contests and "hackathons" to stimulate new and creative use of these data.

Government generated data has been reused in a variety of ways. For example:

- The authorities in London have been very active in opening access to data. Transport for London data has led to a number of apps that support travellers in London. The council of Westminster provides real time access to data from parking sensors.

- Real time data feeds on flights have led to flight tracking websites and mobile phone apps that update travellers on the status of their flights, potentially indicating to passengers their flights are delayed even before airport announcements.

- Meteorological data, such as rain radar websites[64] has become very popular with users. This data often has to be licensed for a fee, but some businesses have created models, which enable them to give access to the data for free.

- The government in the Netherlands publishes every 10 minutes data on water levels throughout the country and the prognosis for expected water levels (Ministerie van Infrastructuur en Milleu, n.d.). Professional users then use such data, such as on ships, as do recreational users, such as divers.

- In the European Union, a harmonisation measure aims at granting access to digital geo-data generated by public authorities (European Parliament and European Council, 2007).[65]

- In France the Government passed a bill with an open-data policy that makes official documents and public sector research accessible to everyone online (French Government, n.d.)_

- The Municipality of Aarhus in Denmark shares real-time traffic information to enable smart city innovation within traffic and mobility, and provides a visual map of the space available at its recycling stations through open garbage data.[66]

The private sector also collects data that can be of use for the public sector. For example, data collected by *TomTom* are actively used by governments to evaluate the effect of changes in road conditions. In Scandinavia, Volvo Cars, the Swedish Transport Administration and the Norwegian Public Roads Administration are working together on a project to enable vehicles to share information about conditions that relate to road friction, such as icy patches. The information will be shared through a cloud-based network – a revolutionary approach to improving traffic safety. It is being tested on a fleet of 1000 vehicles, though this is expected to be expanded to cover all vehicles (Volvo Cars, 2015). Sensor data was available to vehicles for two decades as part of the electronic stability control but since November 2014, such systems are a requirement on all new vehicles sold in the European Union. The IoT only needs to add communication to make the data available to other services. In Norway and Sweden the data will be used to caution other drivers, but also to warn the various road services and their contractors of adverse road conditions.

When there is private data that could be beneficial for public use, authorities need to consider balancing the benefits for the individual market player with a public good. It could be said, for example, that data or road conditions could be beneficial to a corporation to make its vehicles safer than those of competitors by sharing these data among drivers of that company's vehicles. Certainly innovation that promotes safety should be rewarded. On the other hand, the drivers of these vehicles will almost certainly wish for these data to be shared with the drivers of other brands, as it is in their interest for conditions to be made safer for all drivers. In addition, drivers as consumers would likely not want to see network effects, where their choice of purchasing a vehicle was governed by the wish to access the brand with the most vehicles on the road, and therefore the best data, rather than the one that best suited their other requirements. Hence, there are compelling reasons why drivers are likely to grant their consent to such use of their data. However, it is possible that not all drivers wish to share their data. Even if the public value of preventing accidents must take priority, a public debate is necessary concerning the questions if and to which extent the drivers' data may be used in order to help achieve this aim.

Consider adapting numbering policies to foster competition and innovation

The IoT needs various forms of identifiers to address devices in networks. The type and number of identifiers required depends on their connectivity model: tag identifiers such as Universal Product Codes (UPCs) or RFIDs; Object Identifiers (OID) and Digital Object Identifiers (DIO); layer-2 numbers that uniquely identify the device within a given network, such as MAC-addresses; global routing addresses that allow for routing of data across different networks, such as IPv4 and IPv6 addresses; service specific addressing, such as domain names and telephone numbers and global identity numbers that allow for the identification of the network responsible for the device. In the following paragraphs, there is a description of the identifiers, which might require some form of government attention due to their importance in unlocking larger benefits for the IoT.

IPv6 as a fundamental enabler for the IoT

Increasing demand for IoT applications may accelerate the deployment of IPv6. According to data from Cisco, 21% of M2M connections will be IPv6-capable, reaching 2.2 billion by 2019, a 64% compound annual growth rate. Some argue that the use of IPv6 would also alleviate shortages in telephone numbers and IMSI-numbers. These numbers are, however, still likely necessary to identify a device in a mobile network, over which IPv6 is run.[67] And many applications, especially equipment with personal sensor networks do not use IP at all (health monitors, smart-watches, NFC payment terminals) but a LAN gateway.

Some existing deployments of sensor networks and mobile devices are using the existing IPv4 network. This is seen as a simple pragmatic choice of using what is available. Estimates vary, but there is some level of consensus behind a figure of eight billion to 10 billion Internet-connected devices in 2012. At that time, the Internet had used some 2.5 billion addresses, meaning that the majority of these connected devices are located behind conventional Network Address Translation (NAT) units that allow one IPv4 address to be shared across multiple devices simultaneously. IPv4 addresses are, however, a very limited resource and the five regional Internet registries have either fully assigned those available to them or will do so in the near future. In 1996, the Internet community developed IPv6 in preparation for this eventual exhaustion of IPv4 addresses. IPv6 expands the protocol address space to 3.4×10^{38} addresses instead of the 4.3 billion addresses of IPv4, this is effectively more than 7.9×10^{28} times as many as IPv4.

IoT devices connecting directly to the Internet would greatly benefit from the massively expanded protocol address space that only IPv6 can provide. At the same time, network providers can identify the IoT market as a compelling use case to justify the additional expenditures associated with a widespread deployment of this new protocol. This raises the question of whether IPv6 could be seen as an enabler for IoT systems which otherwise would require to be deployed within today's framework of address sharing of IPv4 and IPv6. Much of the debate over this question relates to the nature of the embedded device and the way in which it communicates within its external environment. In addition, it can be noted that many IoT scenarios can rely on devices communicating to a local gateway, with only the gateway being Internet-connected.

For some sensors and devices, IPv6 is generally thought to be a necessary precondition. Using IPv6 for dozens of millions of micro devices, however, makes them vulnerable since they are exposed to the whole Internet. This has critical issues relating to security and abuse, and the experience of such devices has highlighted the risk of such addressable devices being co-opted into participating in various forms of high volume distributed Denial of Service (DOS) attacks. The question of whether the larger address space of IPv6 effectively prevents the opportunistic discovery of sensor devices, or whether operational prudence requires that such exposed sensors are equipped with robust security and continual monitoring and maintenance, is at present an open issue for the sensor industry. The technical community is engaged in strengthening the Internet architecture against various forms of abuse, such as efforts to prevent IP address spoofing within access and hosting networks

Not having IPv6 active in many networks makes the discussion moot. Promoting the IPv6 transition is the most effective way to support the IoT. With the current address depletion scenario, the deployment of IPv6 is inevitable for the Internet to continue to operate and is the only future-facing "Internet" in the IoT. It is difficult, however, to see what governments can do to further accelerate IPv6 to support the IoT. Many governments have already established promotion programmes to adjust Internet services for which they have responsibility, adapted government purchasing and established task forces with industry and the Internet technical community.

Telephone numbers for the IoT

Telephone numbers have become so engrained with the operation of mobile and satellite networks that their availability is assumed. Billing systems, customer relationship management systems, network management systems and roaming management systems all assume the existence of a telephone number. In addition SMS, which is often used to wake-up a sleeping device, assumes a phone number, particularly in situations where a device is roaming. The result is that numbering policies may need to be adapted to fit the IoT.

The Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT) published a report on scarcity of E.164 numbers due to M2M, with an outlook to 2020 (ECC, 2010). The report concluded that seven of the 29 countries were expected to face problems with the exhaustion of existing E.164 numbers and another two could face a similar scenario. Several European countries have updated their numbering policies reflecting ECC/CEPT considerations. Netherlands and Norway, for instance, have introduced dedicated M2M number ranges for mobile. Sweden also introduced separate dedicated M2M number ranges for fixed and for mobile whereas Belgium and Spain have a non-geographic, fixed-mobile agnostic network code dedicated to M2M. In addition, Japan is expecting to allocate a dedicated block of mobile numbers for M2M communication during 2016. Whether a country decides to have a dedicated M2M numbering range or not, always depends on the specific national situation regarding number exhaustion.

For numbering, flexibility is essential as different services or M2M users may have different requirements. Both, industry makes use of national numbers in an extra-territorial way (e.g. extra-territorial use of national numbers) as well as of international numbers in order to deploy IoT connected services. Furthermore, regulators should carefully assess introducing additional, and remove existing, restrictions or administrative barriers related to the assignment and use of numbering resources, as it could act as a barrier to the roll-out of a global M2M market.[68]

Solutions to facilitate provider switching and avoid lock-in

When connectivity is provided via SIM over public mobile networks, switching the connectivity service provider is a key issue regarding the development of IoT services and the functioning of the market. At present, switching connectivity provider requires a hardware modification of the connectivity module of the device, which will require technicians to replace SIM cards or communication modules. There are two solutions being researched by industry and/or numbering administrators that could meet M2M user's expectation and solve this issue: the assignment of MNC, and hence a range of IMSI numbers, for large IoT users such as automobile manufacturers or utility companies (energy, water, etc.); and the use of over-the-air (OTA) provisioning of the Subscriber Identity Module (SIM), requiring the use of reprogrammable eUICCs.

Firstly, the assignment of MNC numbers to IoT players would allow them to manage their own range of E.212 IMSI numbers, switch between several MNOs or become an MVNO themselves. Ericsson calls such networks Private Virtual Network Operators (PVNOs) and in principle one user needs only one IMSI-range for it to work globally. Several vehicle manufacturers, consumer electronics companies and energy companies have expressed their interest in this solution to the lock-in issue. The Netherlands has already changed its regulations.[69] The Dutch Ministry of Defence uses a range for its own communications and a utility company, Enexis, used their own range for a 2.6 million smart-meter roll-out (Enexis, 2015). Germany and Belgium have consulted on regulatory changes.[70] Germany opened up its numbering scheme so that besides MNOs also MVNOs and MVNEs may apply for a block of IMSI numbers; however, a corresponding right was not granted to large-scale IoT users.

CEPT ECC has researched the changes and proposes that countries consider relaxing their allocation rules in order to allow for PVNOs. They have also advised the ITU to change the E.212 recommendation to allow for the emergence of PVNOs. This is in order to provide the flexibility to authorities to decide, at a national level, if a PVNO shall be granted a right to request an IMSI–range or not due to any limitations in their availability (i.e. scarcity). Even with their own IMSI-range and the ability to issue its own SIM cards, PVNOs would still need a contract with an MNO or MVNO in order to get access to a mobile network. The main difference is that broadening the possibility for access to IMSI-ranges makes this a decision for each large-scale IoT user to meet their own requirements (ECC, 2014). One automobile manufacturer estimates that the combined savings would be around 1 USD per vehicle per month, which given a life time of 15 years for vehicles, would be the equivalent of 180 million dollar per one million vehicles manufactured per year (or the equivalent of USD 2 billion per year for all vehicles manufactured in Japan or the United States).[71]

A second solution has been suggested in ETSI/3GPP standardisation circles and it entails to use over-the-air (OTA) provisioning to switch service provider. The GSM Association, an industry group of MNOs, is proposing its own *de facto* standard supported by many but not all its members, which is a step forward in standardisation but not yet a global solution (GSMA, n.d.). The OTA solution requires the use of reprogrammable SIM-cards, also called eUICCs. Such a solution would allow large scale users of IoT the possibility to change mobile operators through an over the air update of the IMSI-number and relevant security credentials of the SIM. This approach would be operator led and it could be combined with a multi-IMSI solution, where the credentials of multiple networks are stored on the SIM.

Many large scale IoT users would like to use OTA, either in order to easily update the installed base of their connected devices when they switch service provider or for their own business purposes, for example to be able to sell a business unit and all associated IoT devices and service contracts without having to retain a business relationship. In this light, there is the chance that development towards a standardised OTA process is driven by industry (e.g. Apple, the automotive industry) and developed within ETSI. No dates for an OTA standard are available at the time of writing this report.

Both a PVNO solution and an OTA solution have advantages and drawbacks. An OTA solution is at present more limiting than a PVNO solution for practical reasons. If an IoT user wants to make a change using OTA, it will always depend on the cooperation of mobile operators and it will certainly not be instantaneous for all devices, in part because it takes time to update devices, and because not all devices will be on at all times. For example, vehicles and consumer electronics may be off for long periods of time. In addition, there is limited space on a SIM-card and mobile operators do not want to reserve numbers for potential customers, so for customers that are roaming occasionally the device may not be able to select a less expensive local offer, because the credentials have not been updated. If the PVNO solution is used, switching across connectivity service provider requires seamless transition without interruption. This is particularly important for mission-critical services such as connected cars. Hence, an uninterrupted transition would presuppose that all contracts and routing are changed accordingly at an effective date. To date, no process exists to guarantees such seamless transition. In addition, in order to conclude contracts with multiple mobile networks in a country, national roaming would need to be supported, either voluntarily by network operators or by law. Another important drawback is that the PVNO solution most probably would lead to a scarcity of E.212 resources since in most cases only 100 IMSI-blocks (mobile network codes, MNCs) can be assigned per country, or more specifically per mobile country code (MCC).[72] Even if it is in principle possible for a country to apply for a new MCC at ITU, these resources are not limitless.

If in the near future market players cannot reach a solution on a standardised switching process which is workable, sufficiently secure, transparent and non-discriminatory, governments might want to consider regulatory intervention in order to foster, or to make mandatory, OTA provisioning in order to facilitate switching the service provider in the IoT context (BEREC, 2015).[73] Similar to the provisions on number portability in e.g. Article 30 of the European Union Universal Service Directive, governments could prescribe that the switching process via OTA provisioning has to occur in a synchronised manner so that all connected devices of an IoT customer are switched to the new connectivity service provider at the same time and/or within a short time frame. In order to respond to violations of such provision, it would need to be supported by adequate sanctions.

In the auspices of ECC/CEPT a working group “Project Team Future Numbering Issues” is at present working on a deliverable on the assignment of MNCs (E.212) to other entities (M2M-users) than providers of electronic communications networks and services. Another working group “Project Team Number Portability” is at present working on a deliverable on switching in the M2M-sector (OTA, embedded SIM, soft SIM etc.).

Extra-territorial use of numbers

The IoT will bring many applications that will traverse borders, particularly in transport, heavy machinery and consumer electronics. The numbers that are used by these machines will cross borders with the machines, often for prolonged periods. For regulators this raises the question of whether they allow the use of their national numbers across borders or whether they allow use of foreign numbers in their territorial jurisdiction on a permanent basis (“extra-territorial use”). It has been discussed at international level for quite some time whether extra-territorial use of numbers shall be permitted for M2M services. Until a solution is found, large-scale IoT users would need to check with each national regulatory authority prior to any extra-territorial use of numbers if they want to obtain legal certainty. There is also the risk that a country does not allow such extra-territorial use. This would make it very difficult for a large-scale IoT deployment to function in multiple countries, by using one mobile operator’s solution.

The problem of extra-territorial use of numbers arises both for E.164 numbers (typically mobile numbers in M2M) and E.212 numbers (IMSI).[74] Typically, both are used for IoT services. Outside the IoT context, the extra-territorial use of numbers has so far been limited. Mobile roaming is the most well-known example but given that it is short-term, hasn't attracted a close scrutiny from regulators. There are some VoIP services that allow the nomadic use of E.164 telephone numbers. Regulators have generally frowned upon such use and only allowed it in exceptional circumstances (ECC, 2013). In practice businesses do sometimes use foreign E.164-numbers, to purport to have a local presence.

With regard to the IoT, there appears to be more and more extra-territorial use of numbers. In practice operators are already using international numbers abroad. Statistics collected by the OECD show that Sweden leads the OECD in number of M2M devices deployed per capita. However, when asked about these numbers they appear to be in use by Telenor for its M2M devices, which are deployed globally. It is also reported that numbers from the Netherlands, Malta, Luxembourg and some islands are used globally for M2M purposes. This is because it is possible to buy national roaming and failover for these devices in the countries where they are used, unlike the use of a national number.

Authorities could, however, reconsider their positions and evaluate whether it is possible to open the extra-territorial use of these numbers. Only where there is provable harm, such as the risk of national number exhaustion, should countries restrict how the numbers are used. Currently, work on extra-territorial use of E.164-numbers, including IoT/M2M, is being carried out within CEPT at the "Project Team Future Numbering Issues"(ECC, 2013). In Belgium, the regulator has recommended to allow extra-territorial use of numbers in the M2M context without any further conditions (BIPT, 2015). In the United States, the regulation does not prohibit extra-territorial use of numbers either. Denmark has not yet made a formal decision regarding use of Danish numbering resources on a permanent basis in other countries. Germany is consulting on a numbering plan and requirements to permit the extra-territorial use of IMSIs in the M2M context, with the possibility to intervene in case of harm to public or private interests.

Access to efficient numbering schemes is essential to the operation of the IoT as was underlined by the European Commission's DG CONNECT Director General (Viola, 2015). In this respect they are no different than other identifiers, such as IP addresses. IP addresses are allocated to network operators on the basis of demonstrated need and are governed by allocation policies established through the community processes of the relevant Regional Internet Registry.[75] This regional approach to the management of unique identifiers has resulted in IP addresses with a global scope and has worked for 25 years without difficulty.

In addition, the international shared country codes issued by the ITU to some telecommunication operators with international footprints may play a role in meeting demand for cross-border IoT usage. Such international numbering resources may be used worldwide. For example, it is noted that more and more MNOs and full MVNOs as well as providers of IoT service platforms have become assignees of an MNC under the shared MCC 901 as well as under the shared country codes (CCs) 882/883.[76]

NOTES

1 See for example ECC Report 153, Numbering and Addressing in Machine-to-Machine (M2M) Communications, November 2010, p. 5, section 1: "M2M is a communication technology where data can be transferred in an automated way with little or no human interaction between devices and applications."

2 For an entertaining list of milestones in the evolution of the mashing of the physical with the digital, see Press, Gil (2014).

3 See, for instance, Weiser (1991).

4 See, for instance, "We put a chip in it" blog at http://weputachipinit.tumblr.com/

5 See trend 3 on Machine-to-Machine communications (M2M) from Cisco (2015).

6 See Wilson, J. (2008).

7 The number of M2M SIM cards/modules only indicates the number of M2M devices which use mobile connectivity. However, M2M communication may be based on all kinds of connectivity and mobile connectivity only represents a small part of connectivity used in M2M communication.

8 General Electric adopted this name to describe the innovation and change that could come from the union of physical world and the digital world. Estimations for gains of 10-15 trillion USD to global GDP over 20 years, see page 3 of Evans and Annunciata (2012).

9 General Electric estimates for 1% savings across several industries and segments, see page 4 of Evans and Annunciata (2012).

10 A Baxter robot can be purchased for USD 22 000, which can be far less expensive than comparable robots and can be programmed quickly on the job in a matter of minutes, unlike traditional industrial robots that require days or weeks of highly specific programming by dedicated engineers. This robot is already available across a number of OECD countries and is supported by an active development community, see Rethink Robotics (2014).

11 In a field test, the agriculture machinery producer Claas worked together with Deutsche Telekom AG to digitize the harvesting process. The driver of the harvesting machine could use tablets with constantly updated representations of harvesting operations. The harvester, for example, detects when the grain tank is full and automatically calls a tractor for off-loading. Each machine knows the terrain and all equipment locations and looks for the best possible way to the destination. Here, the system pays attention to time optimization and soil protection. Moreover, the analysis of data on soil, wind, weather or the optimal sowing and fertilizing parameters for each square meter of a field opens the seed and chemical companies new business opportunities. They can evaluate the data of the land and make optimized offers - a package tailored from seed, fertilizers and pesticides to the customer and the field in question.

12 See the websites of John Deere or Lely for many examples of such developments.

13 See Murray (2015) and a description of the technology at: http://www.proteus.com/technology/digital-health-feedback-system/

14 Alexis Normand of 'Withings' emphasised in a presentation at the 2014 OECD Technology Foresight Forum that "measures foster results". He stated that individuals weighing them self, on a daily basis

compared to weekly or monthly monitoring, could improve their management of weight, and change dietary habits.

15 Alexis Normand of "Withings" stated that in some countries, for example, medical practitioners only get paid for a physical visit by a patient, whereas time spent monitoring a patient or interacting with them through other communication tools may not be reimbursed. Instead of "…the fee-for-service model, under which health providers were reimbursed for each consultation or medical intervention", healthcare provision may evolve "…to one where payment is made for packages of care delivered by teams".

16 The DOLL initiative in the Copenhagen suburbs is aiming at creating future LED-lighting solutions. DOLL's aim is to create energy efficiency and intelligent indoor and outdoor lighting solutions, and to generate jobs. DOLL supports municipalities, regions and private companies, in cooperation with scientists, with the development of new and improved lighting solutions. For further information see http://www.lightinglab.dk/UK/About-DOLL/

17 LED street lights are significantly more energy efficient than traditional streetlights, saving up to 50% in energy use, or roughly 30-50 USD per street light/per year.

18 The Vehicle SCOOT system developed by the Transport Research Laboratory in collaboration with the UK traffic systems industry, which uses sensors at intersections to gather traffic data and a computer system that adjusts light timings to allow traffic to flow as efficiently as possible. For further information see http://www.gizmag.com/pedestrian-scoot/31154/

19 See results of introducing SCOOT http://www.scoot-utc.com/GeneralResults.php?menu=Results

20 Autonomous Intersection Management: Traffic Control for the Future, University of Texas, https://www.youtube.com/watch?v=4pbAI40dK0A

21 These are non-operational vehicles, meaning they do not have an active military role, such as cars, vans, small trucks.

22 See (Tudor and Fabro, 2010).

23 Ford announced a switch to over-the-air updates in March 2015 see Sorokanich (2015). and BMW used wireless updates to patch a hackable security flaw in door locks in January. February 2015. https://securityledger.com/2015/02/bmw-fixes-connecteddrive-flaw-with-over-the-air-patch/

24 See GSMA IoT Security Guidelines at www.gsma.com/connectedliving/future-iot-networks/iot-security-guidelines/

25 For more information on the project, visit www.owasp.org/index.php/OWASP_Internet_of_Things_Project

26 For more information see Cloud Security Alliance (2015).

27 For more information see https://www.ftc.gov/news-events/blogs/business-blog/2015/01/internet-things-ftc-staff-report-new-publication-businesses

28 See Office of Privacy Commissioner of Canada (2016).

29 See White House (2014).

30 Study carried out by the group "La Poste" in December 2014, see http://www.docapost.com/wp-content/uploads/2015/01/infographie-la-poste-generique.pdf

31 Global M2M Internet (IP) traffic: From 1% (2014) to only 3% in 2019. See Cisco (2015c).

32 The US based companies are Intel, IBM, Google, General Electric, Qualcomm and Cisco. See http://www.cbronline.com/news/internet-of-things/behold-the-10-biggest-iot-investments-4549522

33 Wehkamp.nl, a Dutch online retailer, which announced in October 2013 that it would build the world's largest robotic distribution centre to replace its traditional warehouse, exemplifies that the market is moving in this direction. This centre will enable order-to-package times of 30 minutes and same day delivery, which customers will likely appreciate. Robots will manage the warehouse, pick goods and move to and from picking stations, where employees will pick and pack the goods. A clip of the announcement and the new Distribution centre can be seen at http://www.youtube.com/watch?v=Q5eie0IgccY

34 Thielman (2015) mentions 2025 for a self-driving truck by Daimler.

35 See for example a recent study by the Association of German Chambers of Commerce and Industry (Deutscher Industrie- und Handelskammertag, DIHK), "Wirtschaft 4.0: Große Chancen, viel zu tun", cf. www.dihk.de/ressourcen/downloads/ihk-unternehmensbarometer-digitalisierung.pdf

36 An example is revolving doors that have a number of safety sensors integrated. Such sensors have to be connected using wires and cannot be wireless. A manufacturer of such doors suggested that such sensors could be operated wirelessly, simplifying construction and allowing new solutions. However, the codes require a wired solution, though it is for some manufacturers unclear why a wired solution is safer than a battery operated wireless solution. The standard covering powered doors (sliding and revolving) is in Europe En16005. This example was told orally by an engineer at a major manufacturer of revolving doors, when asked where the IoT would be of influence in his business.

37 Luxemburg follows Portugal, Belgium and Denmark, where plans were announced earlier this year. The network already operates in France, the Netherlands, Spain and the UK (Bourne, 2015).

38 WG3 has published interoperability documentation to support SDOs and businesses: an IoT Landscape and IoT LSP Standard Framework Concepts, presenting the global dynamics and landscapes; IoT High Level Architecture (HLA) that may be applicable to Large Scale Pilots. The HLA takes into account existing SDOs and alliances architecture specifications; and IoT Semantic interoperability recommendations for IoT LSPs.

39 "*Unlicensed spectrum*" in understood as a general authorisation, which may contain generic conditions of spectrum use but not addressed to a specific operator (see for example the definition of "general authorization" in the EU authorisation Directive 2002/20/EC).

40 The regions 2 and 3 have not foreseen the 433 MHz band. With regard to the 433 MHz band in Europe, cf. Radio Regulations Footnote 5.138. "5.138 The following bands: […] 433.05-434.79 MHz (centre frequency 433.92 MHz) in Region 1, except in the countries mentioned in No. 5.280, […] are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radio communication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant ITU R Recommendations."

41 See Burns (2011) and http://www.comscore.com/Insights/Press-Releases/2012/4/iPhones-Have-Significantly-Higher-Rates-of-Wi-Fi-Utilization

42 A study looking at the economic value of license-exempt spectrum estimated that the unlicensed Wi-Fi use provided a consumer surplus of between USD 52 billion to USD 99 billion per annum globally, by enhancing the value of fixed broadband connections. This study estimated a further value of between USD

560 billion to USD 870 billion per annum in 2020 for machine-to-machine communications (M2M) using Wi-Fi (Thanki, 2012).

43 Base stations transmit the wireless power with less than 40% efficiency nowadays, that's more than 60% of their consumed power is wasted as heat by their transmitters, more specifically, mainly by their power amplifier. See http://www.radio-electronics.com/articles/rf-topics/utilizing-sdr-for-greener-wireless-communication-157

44 Minutes 40th ECC meeting, ECC(15)063 Rev1(1), Helsinki, Finland 20th June- 3rd July 2015 with further references. It is noted that there are other views on that, also among CEPT countries. In particular the UK point out the benefits of dedicated spectrum for IoT/M2M applications, cf. Ofcom (2014a).

45 Ofcom (2014b) , p. 7, fn. 4: "The 870 – 876MHz and 915 – 921MHz bands were made available on a licence exempt basis on 27 June 2014. We will also be consulting on proposals to authorise the use of higher duty cycle Network Relay Points in the 870 – 876MHz band. ". See also Ofcom (2015), sections 1.4.1, 1.2.2, 5.1, 5.15.2, 7.15, Annex A A.1 1.1.1.

46 See http://stakeholders.ofcom.org.uk/consultations/radio-spectrum-internet-of-things/statement/

47 FCC (2014), p. 4: There is as yet no consensus definition of 5G, but some believe it should accommodate an eventual 1000-fold increase in traffic demand, supporting high-bandwidth content with speeds in excess of 10 gigabits per second (Gb/s); end-to-end transmission delays (latency) of less than one-thousandth of a second; and, in the same networks, sporadic, low-data-rate transmissions among an "Internet of things" — all of this to be accomplished with substantially improved spectral and energy efficiency.

48 See for example: Government Office for Science (2015)

49 CI-FIRE is part of the European Union's programme for experimental platforms (FIRE). This programme has brought Europe large-scale test beds and platforms covering a wide range of applications, services and technologies for the Future Internet. http://www.ci-fire.eu/about-us

50 See http://www.mittelstand-digital.de/MD/Redaktion/DE/PDF/endbricht-industrie-4.0-kurzfassung,property=pdf,bereich=md,sprache=de,rwb=true.pdf

51 Cf. http://www.digitale-technologien.de/DT/Navigation/EN/Foerderprogramme/Autonomik_fuer_Industrie/autonomik_fuer_industrie.html.

52 Cf. http://www.digitale-technologien.de/DT/Navigation/EN/Foerderprogramme/Smart_Service_Welt

53 See http://dpti.sa.gov.au/driverlesscars

54 See http://www.makeinindia.com/article/-/v/internet-of-things

55 See http://www.mittelstand-digital.de/DE/Foerderinitiativen/mittelstand-4-0.html

56 Cf. https://www.cool-silicon.de/

57 Cf. http://www.its-owl.de/home

58 See http://microtec-suedwest.de/en/.

59 See http://www.lightinglab.dk/UK/About-DOLL/

60 The notion of "building trust" can be assimilated to the concept of "building trustworthiness", were trust must be properly earned and can be lost under certain circumstances. See O'Neill (2012).

61 The Netherlands is one such country, where there is no legal limit to the length of a warranty. If a clothes dryer of a good brand fails after four years because of a failure in the control circuits, the vendor may have to replace it without cost. The customer could have reasonably expected it to function and wear and tear should not fundamentally affect a circuit board of an otherwise well-functioning clothes dryer.

62 A positive example is Tesla, the electric vehicle manufacturer, who regularly updates the software on its vehicles to improve their performance, or even to introduce new features, such as self-driving (Rundle, 2015).

63 See for example data.gc.ca, Publicdata.eu, data.gouv.fr, data.go.jp and data.gov.uk

64 One of the most popular sites in The Netherlands is for example www.buienradar.nl

65 The directive covers spatial data sets which fulfill certain conditions, inter alia that they are in electronic format. For example, Germany has transposed this directive by adopting the "Law on Access to Digital Geodata".

66 The Municipality of Aarhus' open data portal is available at http://www.odaa.dk/ .

67 While mobile numbers will continue to be used as identifiers in the medium-term, it is likely that they will not be the only solution in the long-term. As noted in Ofcom's 2015 Statement on IoT: *"1.25 We believe that limits on the availability of telephone numbers will not be a barrier to the development of the IoT as a range of alternative identifiers, such as Internal Routing Codes, equipment identifiers and IP addresses could be used"*.

68 Some traditional consumer protection requirements commonly associated with E.164 numbers, such as number portability, are not needed or appropriate in the IoT context.

69 The Dutch regulations are available at http://wetten.overheid.nl/BWBR0010199/geldigheidsdatum_13-05-2015. Note that the current regulations require PVNOs to share 2 IMSI ranges, one for commercial companies and one for public organisations.

70 The Belgian consultation is available at http://www.bipt.be/public/files/nl/21394/Consult_review_KB_Nummering_NL.pdf

71 Vehicle production statistics per country are available at http://www.oica.net/category/production-statistics/

72 This is due to the fact that in most countries, MNC are only 2-digit long.

73 CEPT ECC is also currently assessing how switching and competition in the M2M sector can be facilitated using OTA provisioning of SIM.

74 With regard to E.212 numbers (IMSI), Annex E of the ITU-T E.212 which provides for an approval mechanism for certain types of extra-territorial use of MNC/IMSI, does not fit to scenarios of extra-territorial use in the M2M context. Rather, it addresses situations like extra-territorial use of MNC/IMSI numbers of a bigger state in a small country (e.g. extra-territorial use of Italian IMSI in Vatican or San Marino).

75 Five Regional Internet Registries are responsible for coordinating and allocating global Internet resources and related services, including IP addresses: the American Registry for Internet Numbers (ARIN), the Latin American and Caribbean Network Information Centre (LACNIC), RIPE Network Coordinating Centre (RIPE NCC), the African Network Information Centre (AfriNIC) and the Asia-Pacific Network Information Centre (APNIC).

76 Assignees include international MNOs such as AT&T, Vodafone, Deutsche Telekom, Telecom Italia, Orange and Telenor as well as Jasper Technologies, a provider of IoT service platforms. For the use of international numbering resources, some initial investment has to be made (e.g. conclusion of new roaming agreements, testing). Still, in view of the support of international players it can be expected that ITU numbers will be reachable at a larger scale than before. However, it is noted that the costs associated to the request of ITU numbers, including the level of the membership fee, are regarded as a hurdle by some companies. A list over the current assignments of MNCs under the shared MCC 901 and CCs 882/883 can be found at http://www.itu.int/net/ITU-T/inrdb/e212_901.aspx and http://www.itu.int/net/itu-t/inrdb/e164_intlsharedcc.aspx?cc=881,882,883

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Enhancing economic performance and well-being in Chile

Policy Actions for a more dynamic telecommunication sector

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BETTER POLICIES FOR BETTER LIVES

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1. Key findings and policy actions

MAIN FINDINGS	KEY ACTIONS TO BE CONSIDERED
Ensuring Low Entry Barriers to Telecommunication Markets and Facilitating Infrastructure Sharing	
Multiple public entities and stakeholders (e.g. Ministry of Housing and Urban Development, Municipal Works Directorates, surrounding neighbours) participate in the review process for obtaining a permit for the deployment of antennas. The large number of heterogeneous prerequisites, procedures or permissions necessary for infrastructure deployment is an important roadblock. The costs for the installation of high towers are very high since operators are obliged to pay an equivalent of 30% of the project budget to improve the public space surrounding the antenna. Currently, there are no provisions that require passive infrastructure sharing. Network operators face several barriers when deploying their network infrastructure. Moreover, the existing regulation for concessions - an individual concession scheme for each type of service - is too burdensome for operators.	• Create a mechanism through which operators can file appeals against decisions by Municipal Public Works Departments regarding infrastructure deployment authorisations. • Eliminate high fees for cellular sites deployment to ease infrastructure deployment and facilitate market entry. • Create an infrastructure sharing system between sectors through a regulation for the use of poles, pipelines, cables, and infrastructure of the electricity, aqueduct and sewer sectors. • Create a simplified licensing procedure through which operators are authorised to provide all types of telecommunication services.
Reviewing Power Density Regulation and Addressing Public Concerns	
Power density regulation in Chile sets EMF (electromagnetic fields) limits substantially lower than those defined by the International Commission for Protection against Ionising Radiation (ICNIRP) guidelines. Chilean EMF limits fall within the average range of the five most stringent OECD countries. The Antenna Law prohibits the installation of cellular sites near "public or private schools, nurseries, kindergartens, hospitals, clinics, urban premises with high voltage towers, nursing homes, or other sensitive areas of protections so defined", except for cases of antennas between three and twelve metres high. In addition, Article 2 of the Antenna Law gives SUBTEL the power to "declare a specific geographical area as a saturated area or radiating telecommunication systems, when the power density exceeds the limits determined by the technical regulations dictated for that purpose by SUBTEL."	• SUBTEL and the competent authorities in Chile could review the current EMF limit regulation to align it with international standards as well as with growing demands for IP traffic. One way to tackle this trade-off would be by harmonising EMF limits to those accepted by the WHO (i.e. as provided by the EMF Guidelines of the ICNIRP). • Initiate a national campaign to ensure a better understanding of the health effects of non-ionising radiation of antennas, so as to reduce public concerns.
Creating a National Transfer System that facilitates Infrastructure Deployment	
Information regarding infrastructure deployment is not shared in the Information Transfer System managed by SUBTEL. Although Article 116 bis F of the Antennas Law requires municipalities to determine the best areas to deploy infrastructure, there is no legal obligation for municipalities to report their preferential areas to SUBTEL, the MTT, nor to the Ministry of Housing and Urban Planning. As a consequence, the current system creates excessive search costs to interested agents, which may prevent investment in new infrastructure.	• Consider the creation of a provision that obliges Municipal Public Works Departments to share land registry information regarding preferential zones for infrastructure deployment with relevant Ministries and national authorities. This would increase operators' incentives to verify preferential areas for infrastructure deployment throughout the national territory and rural zones. • Implement a National Information Transfer System with an inventory of all State's assets (e.g. public buildings) that can be used for communication infrastructure deployment. Ideally, this system would also include private real estate with geolocation details.

<table>
<tr><th>MAIN FINDINGS</th><th>KEY ACTIONS TO BE CONSIDERED</th></tr>
<tr><td colspan="2">Reference Framework for Spectrum Management and Spectrum Allocation</td></tr>
<tr><td>Although Chile experienced significant advances in spectrum availability and assignment, and shows higher mobile penetration than other Latin American countries, there are still areas that do not have mobile service coverage, or in which the technologies offered do not allow users to connect to the Internet at broadband speeds.

The parameters governing spectrum assignment in Chile are rigid and are in the Law since 1982. Those include the comparative selection model for spectrum assignment which is not the most efficient assignment model.

In addition, conditions that are currently set in the context of the comparative selection model are not established by involving reference studies through which it is possible to estimate the cost of such obligations.</td><td>• Adapt the conditions for future use of the 3.5 GHz band, considering possible reallocation and refarming schemes.

• Establish transparent and clear strategic guidelines regarding the current and future availability of radio spectrum for mobile telecommunication services in the country, based on projected needs and technological developments.

• Define technical and economic criteria in order to contribute to the determination of reasonable obligations for the assignees in future spectrum assignment processes for mobile telecommunication services.

• Include connecting strategic infrastructure (such as highways and ports) and industrial areas as additional criteria for future spectrum assignment processes in light of the increased importance of the Internet-of-Things and other advanced technologies to spur Chile's digital transformation.

• Create new rules in order to achieve more flexible spectrum assignment and use mechanisms, adapted to future requirements of the society and productive sectors in the country. Ideally, spectrum allocations should be based on auctions.</td></tr>
<tr><td colspan="2">Creating an Independent Telecommunication Regulator</td></tr>
<tr><td>The regulatory governance of Chile's telecommunication sector has not followed the evolution of the market over the last decades and sets Chile apart from international best practice.

SUBTEL is a centralised organism of the Ministry of Transport and Telecommunications and as such its resourcing framework differs from the requirements of a stable, independent and technical regulator for the telecommunication sector.

Furthermore, the nomination and appointment of the regulator's leadership, as well as the structure of decision-making mechanisms could be further strengthened and protected from political interference.

Therefore, there is scope to increase the accountability of regulatory decisions and actions through a more independent regulatory agency. In addition, a consolidation of regulatory functions for the sector would lower co-ordination costs, which currently rely on ad-hoc mechanisms.</td><td>• Set up an independent arms-length economic and technical regulator for the telecommunication sector, in line with OECD policy recommendations and practice across OECD member countries.

• In parallel to the legislative process, define and implement a phased approach for the creation of an independent telecommunication regulator. This will be necessary to bridge the duration of the legislative process and pave the way for the establishment of an independent regulator with strengthened regulatory capacities.

• Robust and transparent governance of Chile's telecommunication regulator will be key for ensuring the efficiency of the sector, in particular in deploying new technologies and infrastructures, such as the next generation of mobile networks 5G.</td></tr>
</table>

2. Introduction and overview

In recent years, the telecommunication sector in Chile has experienced rapid and impressive advances. In 2010, Chile was the first OECD country to legislate in favour of network neutrality and prohibit the blocking of unreasonable discrimination of services. Moreover, over the last decade, Chile has achieved one of the highest growth rates in mobile broadband penetration across OECD countries, with mobile broadband penetration rates rising exponentially from 3.5 in 2009 (Q4) to 94.6 in 2019 (Q4) (OECD, 2020[1]). In addition, from December 2018 to December 2019, Chile experienced a very high annual growth rate of fibre subscriptions, amounting to 36.2%.

Despite these significant improvements, challenges remain, preventing the digital economy to reach its full potential. For example, albeit rising, fixed broadband subscriptions still lag behind the OECD average (Figure 2.1, panel A). In fact, the deployment of high-speed fixed networks is not only important to increase fixed broadband penetration in the country, but also for the newer generation of mobile networks, with 5G networks relying mainly on fibre backbones (OECD, 2021[3]). Moreover, significant regional disparities persist in the country, with fixed broadband coverage standing at 76% of households in rural areas, as opposed to 89% in large metropolitan regions (Figure 2.1, panel B).

To help address some of these challenges, this Assessment analyses the existing concession system and the legal and administrative requirements for infrastructure deployment in Chile. It assesses how the Chilean system of granting permissions for infrastructure deployment may act as a barrier to deployment. It also identifies a number of issues that may discourage new operators from engaging in infrastructure deployment.

In addition, with growing demands placed on networks and more spectrum to be allocated to mobile communication services, efficient spectrum management should be a key objective. The current parameters that govern spectrum assignment in Chile are relatively rigid and date back to 1982, focusing primarily on the quality and geographic expansion of services. The Assessment reviews possible alternative approaches and identifies actions aimed at establishing clear criteria and conditions when assigning spectrum.

The governance of the telecommunications sector also needs attention and upgrade. Chile stands out among OECD countries for lacking an independent sector regulator. Currently, the Subsecretariat of Telecommunications (Subsecretaría de Telecomunicaciones, SUBTEL) sets sector policies and performs regulatory, inspection and enforcement functions. These multiple responsibilities strain SUBTEL's capability to effectively regulate the sector. Over time, the lack of an independent regulatory authority risks undermining the confidence in a stable regulatory environment in a critical moment for the sector, when new investments and upgrades are needed. Drawing on international best practices, the Assessment proposes the creation of an independent technical and economic regulator and points at avenues to strengthen the regulatory capacities of the current ministerial regulator as a way of transitioning into the establishment of an independent regulator.

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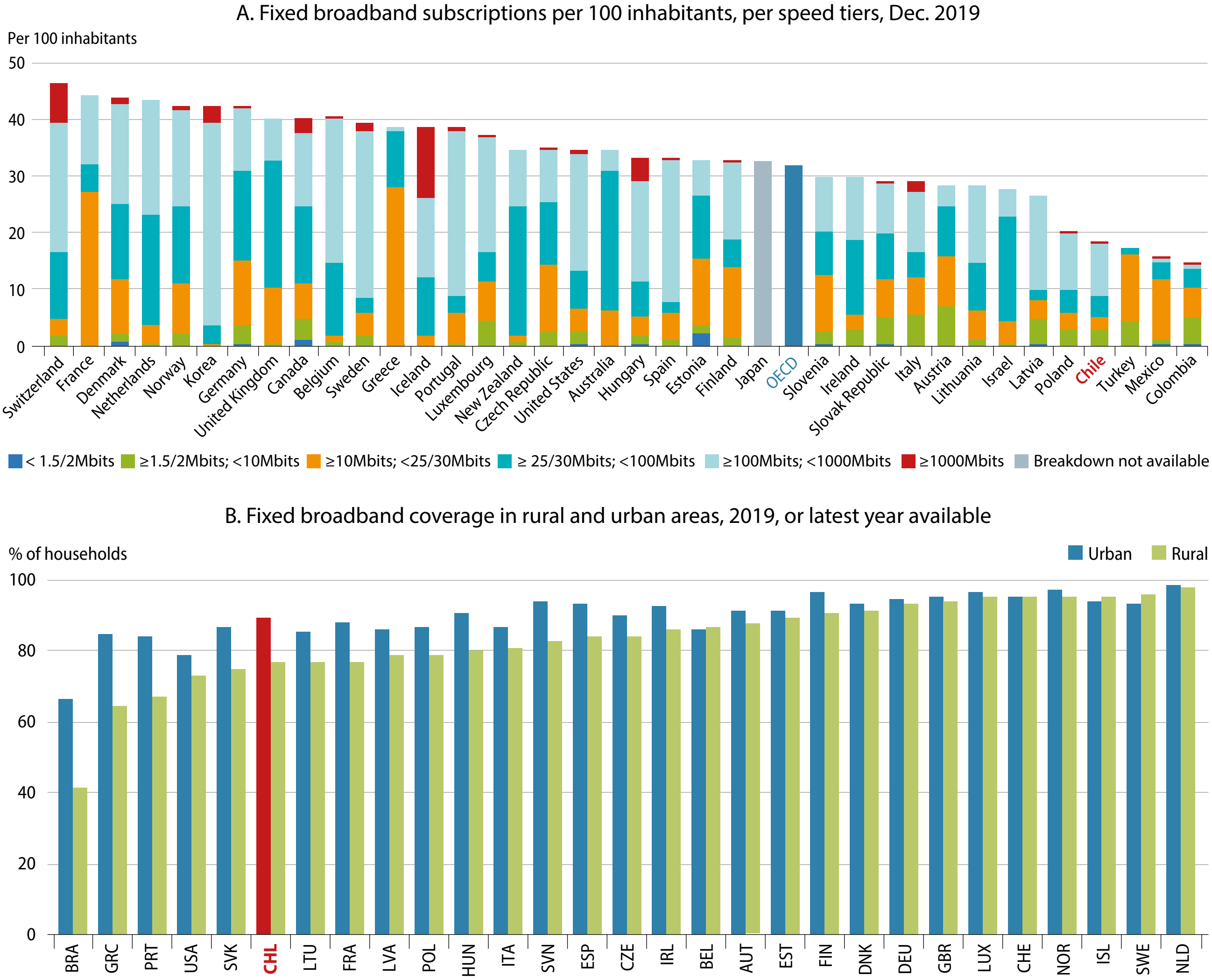
Figure 2.1. Fixed broadband coverage and penetration is low, with large regional disparities



Note: For Figure A. Australia: Data reported for December 2018 and onwards is being collected by a new entity using a different methodology. Figures reported from December 2018 comprise a series break and are incomparable with previous data for any broadband measures Australia reports to the OECD. Speed tier data are only for services purchased over the National Broadband Network (NBN), which comprise the majority of fixed broadband services in operation. There is no public data available for the speed of non-NBN services. Data for Canada, Switzerland and United States are preliminary. New Zealand: Speed tiers are for 2018 instead of 2019.

Source: OECD Broadband portal, http://www.oecd.org/sti/broadband/broadband-statistics/.

To support the achievement of these policy goals, the Assessment provides an overview of strategies and actions for consideration to improve Chile's communication policies and processes in the areas of infrastructure deployment, information sharing, spectrum allocation and management and the governance of the sector. It includes a detailed action plan to support the implementation of the proposed actions. Since infrastructure deployment is a key objective of the Chilean government, the proposed actions consist of near-term interventions with a suggested timeline and an indication of responsible authorities and milestones to track progress. The proposed policy actions form a comprehensive policy package to enhance Chile's telecommunication strategy on various fronts.

The Assessment was prepared by an OECD multidisciplinary team with experts from the Economics Department, the Directorate for Science, Technology and Innovation, and the Public Governance Directorate. The OECD team worked closely with a number of Chilean institutions, including the Ministry of Economy, the Ministry of Transportation and Telecommunications, and the Subsecretariat of Telecommunications (SUBTEL). The Assessment builds on information collected through a questionnaire, as well as meetings and interviews with key government institutions, operators, research institutions and civil society conducted during an expert mission to Chile on 8-10 July 2019.

3. Infrastructure deployment in Chile

3.1 THE GENERAL LEGAL AND REGULATORY TELECOMMUNICATION FRAMEWORK IN CHILE

Governmental agencies in charge of the telecommunication sector

In Chile, the main regulatory authority of the telecommunication sector is the Ministry of Transportation and Telecommunications (MTT), through its centralised organ Subsecretariat of Telecommunications (SUBTEL). The main functions of both entities in this field are to direct, control, promote, and develop public telecommunication policies in the country.

SUBTEL was created in 1977 as an organ under the oversight of the MTT, under Decree Law N° 1762. Since its creation, SUBTEL has been entrusted with the mission of developing Chile's communication sector, which has undergone a deep transformation over the past forty years. The attributions that were first assigned to the MTT are now exercised by SUBTEL as a technical and specialised body. However, the MTT still holds some special functions. For example, the MTT acts as first-instance court in case of infringement charges imposed by SUBTEL under article 36 of the General Telecommunications Law (hereinafter GTL).[1]

SUBTEL's functions cover a wide range of areas, including:

- Performing the necessary procedures to grant and modify the authorisations required for the operation of telecommunication services;
- Enforcing all processes for an efficient and timely processing of all concessions, permits and licenses that are required to operate telecommunication services;
- Maintaining administration, coordination, and management mechanisms for all cross-cutting activities related to the generation of concessions, permits and licenses; facilitating a fluid and efficient operation for telecommunication services;
- Enforcing the GTL and all regulations concerning the telecommunication services provided by concessionaires and permit holders;
- Promoting the increase of coverage of telecommunication services in rural or urban areas of low income, with low or no availability of these services, due to the economic unfeasibility of being served by the national telecommunication industry;

1. Article 36 of the GTL provides as follows: "Violations of the rules of this law, its regulations, fundamental technical plans and technical standards, will be sanctioned by the Ministry in accordance with the provisions of this law. The sanctions will only materialise once the resolution that imposes them has been executed. (…) "

- Designing strategies and instruments that ensure the development of the telecommunication market, promoting competition in this sector, and ensuring the availability of quality services and adequate prices.

Many of these actions are carried out jointly with other public bodies. These include the Comptroller General of the Republic (*Contraloría General de la República*, CGR); the National Service of the Consumer (*Servicio Nacional del Consumidor*, SERNAC); the National Economic Office (*Fiscalía Nacional Económica*, FNE); the Chilean Tribunal for the Defence of Free Competition (*Tribunal de Defensa de la Libre Competencia*, TDLC); and the National Council for Television (*Consejo Nacional de Televisión*, CNTV). The Supreme Court also produces rulings on topics that are closely relevant to SUBTEL's scope of work, such as infrastructure and spectrum access regulations, spectrum allocation and competition in the telecommunications sector.

Regulation for licensing, interconnection, access to infrastructure, and spectrum management

The Chilean telecommunications law establishes the principle of free and equal access to spectrum frequencies through concessions, permits, or temporary telecommunication licenses that must be granted by the State.[2]

Radio spectrum allocation is regulated by the GTL (Article 13C), as well as by Regulation N°412 of 1995 issued by the MTT. In accordance with this regulation, whenever SUBTEL's technical standards indicate to assign only a limited number of concessions, then the so-called **comparative selection model** prevails. This is an allocation model which assigns the concession or permit to the project which offers the best "technical conditions" (with respect to coverage, the network deployment period, quality, technology, guarantees), ensuring an optimal transmission and excellent service. If there are two or more equally qualified applicants, the tie is resolved by a public bid.[3]

Nonetheless, since the last modification to the GTL, at the beginning of the 1990s, an **individual concession regime** has been implemented. This means that, for each type of service provided, there is a specific authorisation defined by the relevant sector regulation. Thus, public, intermediate, and sound broadcasting services each require a different authorisation.[4] Concessions of public and intermediate services are granted by the State, and the procedure is found in articles 14, 15 and 16 of the GTL, as well as in article 13C, previously mentioned for public bids.

Regarding the deployment of antenna towers, the competence to approve concessions lies with each municipality, in accordance with the General Law on Urban Planning and Construction, Decree No. 458 of 1876 of the Ministry of Housing and Urban Planning, as amended by Law No. 20599 of 2012 that regulates the installation of antennas for the transmission of telecommunication services.

In order to apply these rules, the Ministry of Housing and Urban Development defined a set of unique national forms that the interested parties should present to each municipality.[5]

On the other hand, the concession for sectoral licenses and permits corresponds to SUBTEL exclusively, while the permits for passive infrastructure for the provision of telecommunication services are given by different agencies of the state apparatus (municipalities, Ministry of Housing and Urban Planning, or other ministries).

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2. Article 8 of the GTL provides the following: "For all purposes of this law, the use and enjoyment of radio spectrum frequencies shall be freely and equally accessible through telecommunications concessions, permits or licenses, especially temporary, granted by the State."

3. Article 13C of the GTL highlights the following: "Until the deadline for submitting to the public tender has expired, without the concessionaire who is in the case contemplated in the preceding number making such presentation. The concession will be assigned to the applicant whose project, fully complying with the contest rules, offers the best technical conditions to ensure optimum transmission or excellent service. In any renewal of a concession, the concessionaire who held it will have a preferential right for its allocation, provided that it matches the best technical proposal that ensures optimum transmission or excellent service, as appropriate. In the event that two or more contestants offer similar conditions, the contest will be resolved by public raffle between them, if none of them has the quality of a previous concessionaire. (…) "

4. Article 8 of the GTL establishes "a concession granted by decree will be required for the installation, operation, and exploitation of the following Telecommunications services: a) public services; b) intermediate provided for telecommunication services through facilities and networks intended for that purpose; and c) sound broadcasting (…)." In addition, the "Manual de Trámites de Autorizaciones" from Concessions Division of SUBTEL gives a general guideline for the obtainment of concessions for each service.

5. The SERVIU is an autonomous State institution with presence in each region of Chile, related to Chilean government through the Ministry of Housing and Urban Planning. This institution has legal personality of public law, with an independent patrimony.

In Chile, there is no clear universal-access obligation for operators. Hence, there is no obligation to undertake public bids for the provision of telecommunication services in remote or hard-to-reach-areas. Therefore, in accordance with Title IV of the GTL, the Telecommunications Development Fund was created; for the purpose of *"promoting increase in coverage of telecommunication services, preferably in rural areas, and urban areas of low income"* (See Box 3.1).

In turn, Chile recently introduced national roaming through two different decisions that were both issued in mid-July 2020. On the one hand, the Supreme Court[6] ordered the establishment of a new national roaming obligation. This obliges "incumbents", i.e. operators with a "national coverage network", to provide national, compulsory and temporary roaming to new entrants that are still deploying their own networks – thus allowing new operators to fully be able to compete with incumbents. This roaming obligation applies to all spectrum bands, and not only the ones allocated through new spectrum allocation processes. The decision of the Supreme Court does not define national coverage[7] and the concrete duration of the obligation – factors that will be important to determine in the future. The introduction of a clear and well-defined sunset clause is especially important, as this provides a necessary investment incentive for operators without a national coverage to extend their networks faster and compete against established operators. A sunset clause where the roaming regulation is set for too long (e.g. over five years) would harm investment incentives.

On the other hand, a different type of national roaming regulation was also introduced by Law 21,245, published in the Official Journal on July 15, 2020.[8] The Law amends the Telecommunications law, and determines that operators must allow access to and use of their facilities to other concessionaires for virtual mobile operations and automatic roaming. For this purpose, operators must formulate reference offers for wholesale access which need to be based on "general, uniform, objective, transparent, cost-oriented criteria, in economically viable and non-discriminatory terms, and sufficiently disaggregated in all its elements".[9] For some areas, such as sparsely populated areas, where only one operator provides services or projects funded by the Telecommunications Development Fund, as well as some services such as emergency services, no sunset clause has been defined. For other cases, a sunset clause is to be defined which cannot exceed five years.

Overall, the scope of Law 21,245 can be considered broader than the Decision of the Supreme Court, but it is unclear how the two decisions, which were published one shortly after the other, can be aligned. While the Supreme Court decision is an asymmetrical regulation imposed on networks with national coverage, Law 21,245 constitutes a symmetrical regulation. The latter can be regarded as particularly counterproductive for cases where no sunset clauses are defined,

6. Supreme Court, decision of 13 of July: Corte Suprema, Sentencia de 13 de julio 2020, Rol 181-2020. Justices: Jorge Dahm, Sergio Muñoz y Leopoldo Llanos (concurrent opinion); María Eugenia Sandoval y Ángela Vivanco (dissenting opinion).

7. e.g. whether this is geographical coverage, population coverage or how much coverage can be regarded as national coverage.

8.. Law 21.245 of 2020

9.. Article 26.bis. Law 21.245 of 2020.

Box 3.1: THE TELECOMMUNICATIONS DEVELOPMENT FUND

The Telecommunication Development Fund was created by Title IV of the GTL. The following characteristics of the fund are highlighted:

- The Telecommunications Development Fund (*Fondo de Desarrollo de las Telecomunicaciones*, FDT) is a financial instrument of the Chilean government whose principal objective is the increase of coverage in rural and low income urban areas. The rationale provided is that, in general, it is economically unfeasible for the national telecommunication industry to deploy communication infrastructure in those areas.
- The Fund determines which projects will be executed from those presented based on connectivity requirements or demands made by telecommunication services concessionaires, municipalities, neighbourhood councils, and other social or community organisations or third parties. These requirements are then technically and socially evaluated by the FTD Management Division of SUBTEL who is in charge of preparing the proposals that will be submitted to the Telecommunications Development Council (*Consejo de Desarrollo de las Telecomunicaciones*, CDT). If approved, they become part of the projects that are eligible for subsidies. Those projects are then submitted to a public tender during the following year.

as this creates no incentives to invest and thus can result in less infrastructure competition. The decision to grant automatic roaming to established players in the market can also be questioned, as those players are already in a position to expand their networks. Rather, it would be preferable to allow operators to sign infrastructure sharing agreements in areas where infrastructure is not built out, so as to extend overall coverage in the country.

3.2 MAIN BARRIERS TO INFRASTRUCTURE DEPLOYMENT

The level of infrastructure deployment by operators is key when it comes to competition and the expansion of coverage. For this reason, many OECD member countries are working towards removing barriers to deployment of fixed and mobile ICT (Information and communications technology) infrastructure.

Chile is at the start of another technological cycle for communication services, which will lead to the deployment of 5G networks. These networks will deliver new transformative services, so it is crucial that communication operators' investment decisions are not distorted by barriers. This section focuses on determining the principal barriers that Chile should eliminate in order to facilitate the entrance of new competitors and the expansion of coverage. It identifies specific issues that are likely to have a negative impact on the deployment of communication infrastructure, meaning that investment and hence coverage are likely to be lower than they could be.

The main barrier that operators face is the existence of various regulations at different levels of government and the lack of a unique and central entity that provides guidelines and standards for telecommunication infrastructure deployment.

Although regulations to grant permits for deployment of passive infrastructure are at the national level – under the GTL-, the actual power of authorisation of deployment is the responsibility of municipalities.[10] Municipalities, in turn, have different and unique legal frameworks that are not necessarily harmonised.

Similarly, the existence of various regulations (and regulators) makes it hard for new operators to enter the Chilean market. In particular, the current regulations do not encourage operators in the market to cooperate and share passive infrastructure under market conditions.

Overall, one key issue affecting competition is the existing concession regime. The current individual concession regime is not only too burdensome for operators, but also creates artificial barriers to market entry. Because competition fosters innovation in the market, it is desirable that the market is easily accessible to new entrants, i.e. that the market is "contestable". Instead of the current individual concession regime, a **single concession regime** may be preferable, in which the regulatory authority (SUBTEL) publishes a single concession class for all companies.

In other words, this would involve adopting a single licensing regime whereby operators are authorised to engage in all telecommunication services throughout the entire Chilean territory. This would encourage potential operators to enter the market and engage in infrastructure deployment, thus reducing barriers to entry and providing a contestable telecommunication market. Incumbent operators would be motivated to engage in new telecommunication services.

Additional key barriers are specific to either fixed or mobile communication infrastructure (Figure 3.1). Section 3.2.1. discusses specific barriers to the deployment of fixed communication infrastructure, while section 3.2.2 discusses barriers to the deployment of mobile communication infrastructure, with a focus on the challenges arising from the so-called Antennas Law.

10.. As defined by the General Law of Urban Planning and Construction (Decree No. 458 of 1976 of the Ministry of Housing and Urban Planning), as amended by Law N° 20599 of 2012 that regulates the installation of Transmitting Antennas of Telecommunications Services.

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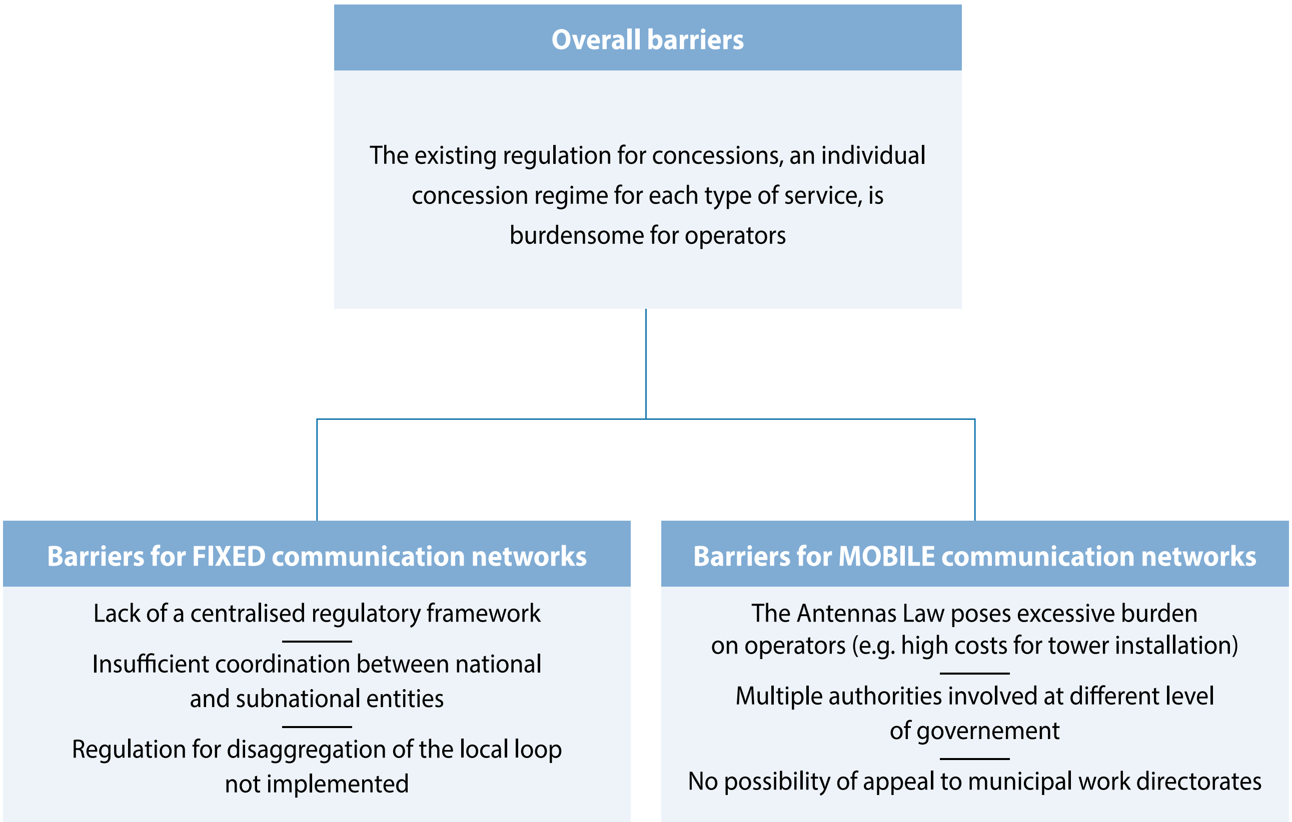
Figure 3.1 Overview of key barriers to the deployment of communication infrastructure



Barriers for infrastructure deployment of fixed communication networks

There are different barriers to fixed network deployment in Chile, both at the horizontal level (i.e. street level deployment such as streets, sidewalks, roads) and at the vertical level (in-building deployment).

Regarding horizontal deployment, the main barriers are the lack of a unique and centralised regulatory framework (given the powers of municipalities), the absence of mandatory coordination between national and subnational government authorities, and the lack of rules at the national or local level that provide incentives for operators to share infrastructure.

The dispersed and unstructured regulation is burdensome for operators and reduces the incentives for coordination between companies from different industries to share passive infrastructure. As a result, each company deploys its own infrastructure, which can result in multiple networks along the same sidewalk or street and an overall high cost burden.

In addition to what has been shown, the Tribunal of Competition Defense has intervened in the market under competition law grounds in order to facilitate infrastructure sharing, including the determination of areas of dominance and the obligation for the incumbent's network disaggregation. However, the Bill for network disaggregation "*(…) after the period of public discussion to which it was submitted, has not been enacted…*"[11]. As a consequence, the incumbent has no real incentive to share network elements since the regulation for disaggregation of the local subscriber loop and the bitstream is not applied in practice.

11 https://www.tdlc.cl/nuevo_tdlc/wp-content/uploads/informes/Informe_02_2009.pdf

With regard to vertical deployment, the same problems arise. An investigation by the national competition authority detected numerous local monopolies, due to the common practice of fixed communication operators to reach exclusive agreements with buildings for pipelines and interior installations. This investigation by the TDLC led to the issuance of the Law 20808 of 2015 on protecting the free choice of cable, Internet or telephony services. The law prohibits these exclusive agreements and obliges suppliers to coordinate in future buildings. The main aspects of this law can be found in Box 3.2 below.

BOX 3.2 THE LAW ON PROTECTING THE FREE CHOICE OF CABLE, INTERNET OR TELEPHONY SERVICES (LAW 20808 OF 2015)

The Law imposes the following obligations to real estate and construction companies:

- To inform telecommunication operators of new real estate projects that (i) include the installation of telecommunication facilities in the building design; and (ii) correspond to real estate projects that involve several units and contemplate laying networks underground or the installation in condominiums.
- To regulate the technical specifications and the necessary criteria for the installation of interior and exterior cameras, as well as the respective "polyducts" and the internal distribution network in condominiums of extension or height, in order to allow the use of said infrastructure by more than one telecommunication operator.
- It is prohibited to agree on provisions that unreasonably limit the entry of telecommunication companies.

Barriers for infrastructure deployment of mobile communication networks

Operators who want to deploy infrastructure must fully comply with the provisions of Law 20 599 of 2012 (Law of Transmission and Broadcasting Antennas for telecommunication services, hereinafter, Antennas Law) that regulates the deployment of towers for antennas and radiation systems, and establishes different obligations depending on the height of the antenna tower and its location.

The Antennas Law obliges operators to fulfil a series of multiple and burdensome requirements to comply with municipalities[12] – and their Works Directorates – as well as to liaise with the nearby neighbourhood council, with the obligation to offer economic compensation to all immediate property owners next to the antenna tower. This sometimes leads to a situation where people are encouraged to exercise their right of opposition or resistance to both infrastructure deployment and mobile access network expansion. Furthermore, the procedure with the neighbourhood councils can be difficult, since infrastructure deployment can affect the value of real estate surrounding mobile telecommunication infrastructure.

This law has proven to be highly burdensome and has generated long waiting times for industry actors to obtain deployment permits, due to the large and differentiated number of administrative requirements to be met. Each municipality or local government has the discretion to adopt different criteria for infrastructure deployment (local authorities or governments can vary their criteria independently throughout the Chilean territory). Moreover, each municipality can impose additional charges with respect to some additional procedures, such as the review of files or the fees for the installation of cabinets.[13]

In addition to these local procedures, each industry player who desires to deploy infrastructure is also required to complete a procedure with SUBTEL. The current procedure may entail a significant workload for SUBTEL divisions, and, hence, can generate a considerable delay in the response. The following tables, based on information obtained in an OECD mission to Santiago, summarize the average time the authority takes to issue an authorisation:

12. As stated, each municipality has its own regulation and infrastructure management system. There are approximately 345 municipalities in Chile, of which more than 50% are semi-urban with a medium or low technology development.

13. To address this challenge, some OECD countries put limits to municipalities on what they can charge to operators. The US, for example, limits such fees with a nationwide order, produced by the FCC, which "Accelerating Wireless and Wireline Broadband Deployment by Removing Barriers to Infrastructure Investment," adopted on the 26 September 2018, clarifies the FCC's views regarding the amount that municipalities may reasonably charge for small cell deployment given the practicalities of 5G deployment and the importance of 5G to the United States. In particular, the FCC declared that, pursuant to Section 253 of the Communications Act, fees should be a "reasonable approximation of the municipalities' costs". In offering guidelines for determining this value, the FCC cited the rules of twenty states that limit upfront pole fees to USD 500 for use of an existing pole, USD 1 000 for installation of a new pole, and recurring fees of USD 270.

Table 3.1 Requests submitted to SUBTEL for antennas attached to existing structures (approved in the same request year and authorised by Resolution)

Year in which the authorisation for deployment was granted	Average number of days taken for the authorisation
2016	115
2017	92
2018	111

Table 3.2 Requests submitted to SUBTEL for antennas attached to new towers (approved in the same request year and authorised by Decree)

Year in which the authorisation for deployment was granted	Average number of days taken for the authorisation
2016	131
2017	173
2018	153

Table 3.3 Requests submitted to SUBTEL for microwave links (approved in the same request year and authorised by Decree)

Year in which the authorisation for deployment was granted	Average number of days taken for the authorisation
2016	356
2017	208
2018	204

Source: Information gathered during the OECD fact finding mission. Information provided by operators.

In general, SUBTEL procedures for infrastructure deployment also require a public service concession, whose term is granted for 30 years to legal entities by a Supreme Decree. This Concession must be signed by the Minister of Transportation and Telecommunication by express delegation of the President. Since it is a Supreme Decree, its revision is referred to the Office of the Comptroller General (CGR).

Mobile operators also face the growing obstacle of theft and vandalism in sites and infrastructure that, in addition to hindering infrastructure deployment, can obstruct the provision of mobile services. Therefore, there is a need to develop a holistic public policy for the protection of mobile communication infrastructure and for critical telecommunication infrastructure, not yet protected through specialised instruments.

Regulation on infrastructure sharing is outdated, despite multiple attempts from SUBTEL to adapt it to new technologies and to the needs or requirements of the Chilean society. However, a new regulation faces multiple barriers that ultimately slow down the modernisation process. To modify the existing regulation, the participation of the regulatory entity (SUBTEL) and both branches of the Congress is required, since the bases of the existing regulation are enshrined in laws that can only be modified by the Chilean Congress. Delays in modifying the law mean that the current regulatory framework is not always in line with the advances in services and the needs of consumers and the community.

The Antennas Law

One of the objectives of the Antennas law (Law N° 20599 of June 11, 2012) is to reduce the amount of antenna towers through co-location, harmonisation on towers, and lower-rise towers, *"with the purpose of reducing the urban impact where these* *facilities are located"*.[14] A report from the Chilean Chamber of Deputies also stresses that the law was created *"with a special emphasis on the effectiveness and efficiency tools aimed at minimising the urban impact of antenna towers and radiation systems, the effectiveness of neighbour participation mechanisms, and the measures adopted by the law for the protection of people's health."*[15]

Under these criteria, the law requires a permit for all installations of antenna support structures that have a height above 3 meters including the tower, antennas, and radiation systems. The permit must be granted by the Public Works Directorate of the respective municipality. There are different procedures for obtaining permits depending on the height of the antenna tower. In general, the procedure for a tower over 12 meters of height is significantly more complex than the procedure for the installation of an antenna tower of a height between 3 and 12 meters.

Article 1 of the Antennas Law, which adds Article 116 Bis F to the General Law of Urbanism and Construction, establishes that *"every support tower for antennas and radiation systems over 12 meters high shall require a permit for the installation issued by the respective Municipal Construction Directorate"*. Moreover, the application for obtaining a deployment permit requires the submission of the following documents:

a. Installation request signed by the property owner and the responsible dealer. In the case of national goods for public use, and state property administered by municipalities, authorisation from the respective municipality is also required.

b. An antenna tower installation project plan with the signature of a competent professional complying with distance rules.

c. Project budget, including, structures, telecommunication transmission systems, equipment and rental income.

d. A technical project describing the structure of the tower, including its foundations (...) indicating the antenna support capacity, also prepared by a competent professional. (...)

e. Certificate issued by the Correos de Chile that accredits the communication by certified letter, to the respective neighbourhood council and to property owners in the area located in the surroundings of the tower[16].

f. Construction proposals to improve the public space surrounding the antenna equivalent to an amount of 30% of the project budget.

g. Certificate from the General Directorate of Civil Aviation that proves that the tower and antennas do not constitute a danger to air navigation.

h. SUBTEL certificate proving that a request for the granting or modification of the concession of telecommunication services has been submitted.

i. Information on the conditions of the property where the infrastructure will be deployed.

Three aspects can be highlighted from the requirements listed above:

1. There are too many mandatory technical requirements for the process of obtaining permits for the installation of towers or radiation systems of a height of more than 12 meters;

2. the coordination with neighbours surrounding the project is required to obtain installation permits; and

14. http://www.afinex.cl/web/wp-content/uploads/2015/05/RESUMEN-DE-LA-LEY-20599.pdf

15. http://www.evaluaciondelaley.cl/ley-n-20-599-que-regula-la-instalacion-de-antenas-emisoras-y-transmisoras-de-servicios-de-telecomunicaciones/foro_ciudadano/2014-04-29/100118.html

16. The radius of the area amounts to twice the height of the antenna.

3. infrastructure deployment of towers becomes extremely expensive since the board of neighbours must be compensated with an improvement of nearby public works with an equivalent value of 30% of the project's budget attached to the permit request– Letter F of Article 116 Bis F.

If an industry player aims to install an antenna between 3 and 12 meters of height, fewer documents need to be provided, but the requirements are still a barrier for infrastructure deployment since they are still too technical and time consuming. Specifically, documents a), b), h) and i) of Article 116 Bis F are required. Among these requirements, document b) should be highlighted since it requires the project to be signed by a *"competent professional"* and since it has to include *"plans for the installation of towers that comply with the rules on distancing"*, as well as presenting *"an explanatory report of the design and construction measures adopted to harmonise the structure with the urban environment of the site of installment"*. Hence, these examples reveal how burdensome it can be to install new antennas. For example, as will be explained below, the existing distancing rules in Chile are stricter compared to other OECD countries. Additionally, there are no criteria to determine what the term "harmonise" indicates in this context. As a result, municipalities have full discretion on the meaning and interpretation as well as in the decision regarding all completed requests.

The Antennas Law encourages the installation of smaller towers with low urban impact, since fewer requirements apply to these facilities, in comparison to those that exceed twelve meters. However, even though the law creates incentives for the installation of lower antennas, requirements are still too burdensome.

In addition to the large set of documents included in the Annexes that are required to be submitted, the active participation of other entities or agents is required to install higher antennas above 12 meters. The Municipal Council, the Municipal Works Directorate, Neighbourhood Councils, affected neighbours, the Ministry of Housing and Urban Planning, SUBTEL, as well as the community -which needs to be informed of the installation with a publication in local newspaper- all need to be involved in the overall process.

In particular, citizens have the possibility to make pertinent observations within a period of 30 calendar days after the communication of the project. Citizens have the right to:

a. "*Oppose the installation of a tower for technical reasons related to SUBTEL's grant of a telecom service*".

b. "*Make observations on the tower installation project to the Municipal Works Department of their neighborhood*". By exercising this right, the neighbourhood council must choose one of the following alternatives: (i) demand improvement works that would minimise the impact of the installation of the tower in the public space of the neighbourhood to the company as a compensation, or: (ii) require that the installation is harmonised with its urban environment, through a design that is harmonised with the urban landscape and the architecture of the place that surrounds it.

c. "*Ask for the prosecution of the property's tax appraisal, when being an owner of a property located within the radius associated with the installation of the antenna support tower.*"

d. "*To ask the company to comply with the maximum radio emission standard issued by the Ministry of Environment in the area*".

This means that although the Law does not explicitly state it, property owners located in the surroundings have the right to object to a planned antenna installation by submitting their comments. This is especially the case when there is a precautionary principle under which citizens can raise their doubts regarding the harmful effect of the radiations emitted by the antennas and, thereby, seek that authorities do not allow the installation of antenna towers.

This creates a delicate trade-off between the potential benefits of deploying infrastructure and the potential drawbacks for health and the environment.

There have been longstanding public concerns in many countries about the potential health effects of wireless services due to the exposure to electromagnetic fields (EMF). That is why numerous international organisations, including the World Health Organization (WHO), have studied the effects of EMF associated with mobile services, which has led to guidelines on EMF limits by the International Commission on Non-Ionising Radiation Protection (ICNIRP), a non-governmental organisation formally recognised by the WHO. The translation of these EMF limits into laws or regulatory measures in each country is known as power density regulation. Power density regulation can be a powerful strategy to balance cell site deployment with public health considerations and/or the goal to minimise environmental disruption at a local level (OECD, 2019[2]).

However, adding capacity to wireless networks can only be accomplished by making more spectrum available, making use of it more efficiently or increasing the number of cellular sites (OECD, 2019[2]). Therefore, if a country (or a municipality) decides to set very strict power density rules (as is the case for Chile, compared to international standards), a potential consequence is a direct increase of the cost of network deployment (i.e. as they may require more spectrum for operators to be able to meet the demand of data traffic). The deployment of cellular sites can therefore be an important way to help provide services that use a large amount of data with minimal delays and cope with the increased generation of data traffic. Moreover, cellular sites can be critical to address the demands of the digital transformation and to use technology for public policy goals, such as improved outcomes in transport or the provision of health services.

In Chile, the considerations about power density regulation are contained in the Antennas Law,[17] whereas the Ministry of Environment sets the EMF limits (Article 2 that modifies Article 7 of the GTL).[18] This Law grants SUBTEL the power to identify "saturated areas of radiation telecommunication systems." It also expressly prohibits the deployment of cellular sites in certain buildings such as schools and hospitals, among others.[19] The purpose of this section in the law is to protect people's health from radiation emitted by the equipment. In line with this standard, it is possible that additional places will become classified as sensitive areas in the future.

That being said, the main conclusion of the WHO is that mobile network deployments with EMF exposures below the standard set in the ICNIRP guidelines, "do not appear to have any known consequence on health" (WHO, 2019[3]). However, it appears that infrastructure deployment rules in Chile are stricter than these international standards. In fact, SUBTEL has recognised that *"in Chile the precautionary [health] principle is applied in a strict manner through technical regulation that limits the emission of antennas and cell phones. In the case of antennas, the Chilean protection standard is among the average of the five most stringent OECD member countries. The maximum antenna emission limit allowed in Chile is, on average, 10 times lower than the limit recommended by the WHO, and up to 100 times lower than that authorised in developed countries such as the United States."*[20].

Furthermore, from a more prospective point of view, the current law may have unintended consequences vis-a-vis the deployment of 5G networks. The importance of power density regulation has come to the fore in OECD countries, as the next generation of wireless networks, 5G, will require both macro and small cells to be closer to the user in order to cope with the increasing demands for data traffic. This process of expanding cellular sites, known as "network densification", has raised the issue of whether current power density regulations in OECD countries may impede the deployment of small cells required for 5G networks (OECD, 2019[2]).

17. Based on a principle contained in"Evaluation of Law No. 20.599 [GTL]" of the Chamber of Deputies.

18. Numeral 1 of Article 2 of Antennas Law provides the following: "1) Replace article 7 with the following: Article 7 °. - The Ministry of Transportation and Telecommunications shall issue the regulations that all equipment and networks that, for the transmission of telecommunications services, generate electromagnetic waves, whatever their nature, are installed, operated so as not to cause harmful interference to national or foreign telecommunications services or electromagnetic equipment or systems or interruptions in its operation. For its part, it will be the responsibility of the Ministry of the Environment to issue the environmental or emission quality standards related to said electromagnetic waves, in accordance with the Law on General Bases for the Environment."

19. Article 116 bis E of the Antennas Law provides the following: "(…) Nor may antenna towers be constructed inside of public or private schools, nurseries, kindergartens, hospitals , clinics, urban properties where there are high voltage towers, nursing homes, or other sensitive areas of protection as defined by SUBTEL nor in sites located at a distance less than four times the height of the tower of the boundaries of these establishments, with a minimum of 50 meters away."

20. https://www.subtel.gob.cl/images/stories/apoyo_articulos/notas_prensa/preguntas_respuestas_nueva_ley_torres_antenas.pdf

Likewise, according to the Antennas Law, the installation of the towers to support antenna, like any other construction work, requires a payment of a fee for the construction permit in accordance with the General Law of Urban Planning and Construction. In fact, the permit amounts to 5% of the antenna installation cost, raising the costs of infrastructure deployment.[21]

Thus, the process of obtaining permits for deployment of antennas contained in this Law is complex, not only because it involves the participation of several entities, but also because it entails harsh deadlines. For example, in the absence of approval from the Municipal Works Directorate, the permit is understood to be granted. Therefore, Municipalities have begun to require operators to have an Independent Reviewer[22] in obtaining permits.[23] Some actors in the sector indicate that, in order to obtain a permit for the deployment of 5G antennas, they would need to start this process prior to spectrum assignation in order to provide 5G services. These provisions of the Antenna Law may raise the costs of network deployment.

In addition, it is up to the municipalities to issue the permission for the installation of antenna support towers. However, the interpretation of the Antennas Law allows for discretion in the issuance of permissions, which, in turn, may lead to room for the respective municipalities to create artificial barriers when granting permissions. It is thus recommended that SUBTEL, together with the Ministry of Housing and Urban Development, develop regulations aimed at reducing the leeway for municipalities to generate artificial restrictions on infrastructure deployment.

Likewise, since municipalities are the only authorities in charge of the authorisation process for the installation of antenna support towers, there is no mechanism for operators to appeal decisions of the municipalities. It is therefore recommended to create a mechanism through which operators can file appeals against Municipal Works Directorates. Appeals should be handed in to SUBTEL as it is the regulatory entity in telecommunication.

In conclusion, it can be said that legal and regulatory procedures needed for the deployment of infrastructure are often too burdensome for operators. Together with imperfect rules for municipality administrations, this creates barriers to entry and deployment. Removing these barriers will generate tangible gains for downstream firms and consumers and

21. The Antennas Law adds section 10 to article 130 of the General Law of Urban Planning and Construction. Accordingly,"[p]ermission for the installation of a support tower for antennas and telecommunications transmission systems" corresponds to 5% of the installation budget. Said payment may represent a barrier to infrastructure deployment as it imposes a high cost for obtaining the permit.

22. An independent reviewer is a professional, with current registration in the corresponding Registry of the Ministry of Housing and Urban Planning, which verifies and informs the respective Director of Municipal Works if the project complies with all the relevant legal and regulatory provisions.

23. Article 116 Bis F of the General Law of Construction and Urbanism provides the following: "The respective Municipal Works Directorate, within a maximum period of fifteen days counted in accordance with the provisions of letter e) above, will grant the permit if, according to the annexes, the request complies with the provisions established in this law, upon payment of the municipal rights corresponding to the Provisional Works in accordance with section 3 of the table contained in Article 130 of the General Law of Urban Planning and Construction, or shall be pronounced denying it. If after this deadline there is no written statement about the permit, the interested party may expressly request that issuance of a decision granting or rejecting the permit within two business days. If silence persists, it is understood by that single fact the permission is granted by the Municipal Works Directorate."

BOX 3.3. MAIN BARRIERS TO INFRASTRUCTURE DEPLOYMENT CREATED BY THE ANTENNAS LAW (LAW N° 20599 OF 2012)

The Antennas Law creates, among others, the following barriers to Infrastructure Deployment:

- The law requires an installation permit for all cellular sites with a height greater than three metres.
- Several authorities, such as the Municipal Council, the Municipal Works' Directors, the Ministry of Housing and Urban Planning and SUBTEL, participate in the procedure for granting permits.
- Similarly, Neighbourhood Councils, affected neighbours, owners and / or users of special areas such as schools, hospitals, nursery rooms, nursing homes, and the community in general, participate in the procedure.
- Operators engaging in deployment of antennas bigger than 12 meters must present a proposal on how the deployment will be accompanied by construction work that would improve public spaces, which is financed by the operator with a budget equivalent to 30% of the cost of the cellular tower.
- Nonetheless, affected residents may ask for an alternative proposal harmonic with the urban environment and the architecture of the site.
- Currently, there is no mechanism for operators to appeal a decision by Municipal Work Directorates, which are the only authority with competence to approve the installation of antenna support towers.

foster digital technology adoption, as foreseen by Chile's digital agenda 2020, as it will increase both digital and non-digital trade prospects (OECD, 2018).

3.3 RIGHTS OF WAY

In Chile, there is no general regulation on rights of way. Nonetheless, Article 18 of the GTL establishes two relevant rules regarding rights of way for infrastructure deployment (aerial or underground networks). According to article 18 of the GTL (i), telecommunication service providers have the right of way over aerial or underground areas in streets, squares, parks, roads and other national public goods, only for the specific purposes of the respective service (….); while (ii) easements that fall on private property must be agreed by the parties and will be governed by the rules of common law.

However, in accordance with article 19 of the GTL, when interested parties do not reach a direct agreement for the use of an easement, *"a legal easement shall be deemed to be fully constituted for the purpose indicated in said article provided that the Subsecretariat of Telecommunications by a founded resolution, declares the service as essential*".

Such regulations contained in articles 18 and 19 of the GTL are the only mechanisms by which communication operators are granted access to state or local easements. However, this is not necessarily in line with presidential instructions. In a Presidential Order, the President expressed the need to *"facilitate said infrastructure for the installation or support of telecommunication systems that contribute to deployment and coverage of telecommunication services."*[24] Moreover, it is stated that promoting and facilitating the installation of towers in remote areas is a priority. The President also stated the need of a regulation that allows private infrastructure installation in public property.

In addition, Chilean regulation does not contain a provision requiring sectors to share their infrastructure with other sectors, except those regulating the fees and services associated to the use of parts of the electrical infrastructure[25]. As a result, the electricicty, aqueduct, and sewer sectors are not required or obliged to share their infrastructure (pipelines, poles, cables, among others) with the telecommunication sector as it is regularly the case for other OECD countries where infrastructure sharing for telecommunication services is mandated by Law. Hence, an enforceable regulation where other industries are obliged to share their infrastructure with communication operators is required, most importantly in the electricity transmission and distribution sectors as their current networks could reduce deployment costs at fast paces.

Therefore, Chile could benefit from a provision that expressly provides the obligation for all sectors to share infrastructure with other sectors. Such an infrastructure sharing system should be governed by regulations for the use of poles, pipelines, cables, and other infrastructure of the electricity, water and other sectors. This way, communication operators can benefit from already existing infrastructure of other sectors in terms of infrastructure deployment, which would reduce costs and increase the velocity of infrastructure deployment.

Both passive and active infrastructure sharing can produce efficiencies and cost reductions. These provide incentives for new entrants in national markets and local geographic markets, reduce the costs for operators, and, in turn, potentially for their customers. Such efficiencies can enable communication operators to reduce overall costs in network deployment and maintenance.[26] This is particularly relevant for the next generation of mobile networks, 5G, which requires a densification of networks and, often, a large sets of antennas and small cells.

By way of example, in Colombia, infrastructure sharing between different sectors is a permitted practice. Through Article 22 of Law 1341 of 2009, the Colombian Congress gave the Commission for the Regulation of Communications (*Comisión de Regulación de Comunicaciones*, CRC) the power to regulate the conditions through which infrastructure of

24. Through SUBTEL's filing N° 1185/ GN° 29A from 26.01.2018, the President gives instructions on public infrastructure in Telecommunications.

25. The Presidential Decree N° 13 of 24.07.2018 provides the fees for the use of electrical infrastructure.

26. OECD (2019), "The road to 5G networks: Experience to date and future developments", OECD Digital Economy Papers, No. 284, OECD Publishing, Paris, https://doi.org/10.1787/2f880843-en.

other sectors can be used in communication services. This power has been used by the CRC to establish the conditions under which the electricity infrastructure can be used in communication services by Resolution No. 062 of 2013, where the involved parties may freely determine lease prices.

Mexico's system is another example. Pursuant to the Electric Industry Law *(Ley de la Industria Eléctrica, LIE)*, the Energy Regulatory Commission (Comisión Reguladora de Energía) is empowered to issue the necessary provisions to allow access to the facilities and rights of way pertaining to the national electric system to public service providers acting in other industries, such as telecommunication services (LIE, 2014, Art. 12). Such public service providers will be expected to compensate the CRE at a fair rate (LIE, 2014, Art.12 OECD, 2017$_{[4]}$).

3.4 *THE "PROINVESTMENT" WORKING GROUP*

At the beginning of June 2018, SUBTEL, together with the actors of the digital ecosystem, formed the ''proinvestment'' working group in order to identify the best ways to increase both foreign and local investment.

Six months after the launch of the pro-investment Working Group, a document was produced that included different measures aiming at getting back to the pace of investment the sector had in previous periods. One of these measures was streamlining the concession procedures and establishing online procedures for licenses in the future. [27]

Similarly, the need for coordination mechanisms between SUBTEL and municipalities for concession procedures was reflected in the document. This way, SUBTEL could instruct municipal authorities, associations, and the Subsecretariat of Regional and Administrative Development which is in charge of *"promoting and conducting institutional reforms in the field of decentralisation, which contribute to an effective transfer of political, economic and administrative power to regional governments and municipalities"*.[28]

Within this Working Group, operators expressed the need for coordination with government agencies that are responsible for other sectors, which are relevant for the deployment of infrastructure. Those include:

- Energy – to facilitate the eventual use of electrical infrastructure for the deployment of telecommunication networks;
- The Subsecretariat for Crime Prevention and the Ministry of the Interior - to explore measures for the protection of telecommunication infrastructure;
- The municipalities – to clarify plans for cable removals, in coordination with telecommunication companies;
- The Ministry of Environment – to expedite the processing of authorisations; and with
- other government institutions – to expedite and facilitate access to passive infrastructure where SUBTEL has already signed a technical collaboration".

Overall, it seems that, so far, the results of this Working Group have been limited and the measures listed in the document have not been implemented yet. According to industry players, barriers to infrastructure deployment persist.

27. See: https://www.subtel.gob.cl/subtel-y-mesa-pro-inversion-acuerdan-medidas-a-implementar-en-2019-para-el-desarrollo-digital-del-pais/

28. See: http://www.subdere.gov.cl/organización/quienes-somos

3.5 INTERNATIONAL GOOD PRACTICES

Several international practices have been implemented in different jurisdictions with regard to the deployment of telecommunication infrastructure. Most of them are harmonised with the local legal and constitutional system. As has been highlighted in the previous section, the deployment of passive infrastructure is significantly influenced by the constitutional organisation of the powers and competences of local territories. Therefore, in order to implement related best practices, it might be required to promote deep constitutional and legal reforms. A set of different practices are highlighted below.

Infrastructure deployment in the EU

A general guidance on policy implementation for infrastructure deployment can be found in the Directive 2014/61/EU from the European Parliament and the Council. The Directive creates minimum requirements to *"reduce the cost of deploying high-speed electronic communication networks"*. The principal requirements on infrastructure deployment set forth on the Directive are the following:

Article 3 regulates the access of network operators[29] to existing physical structure.[30] Therefore, Section 1 of Article 3 provides that all Member States shall ensure every network operator has the right to offer their physical infrastructure or to provide communication networks access to their physical infrastructure.

Section 2 of Article 3 requires Member States to ensure that every network operator has the obligation, upon request of an undertaking authorised to provide public communication networks, to meet all reasonable requests for access to their physical infrastructure under fair and reasonable conditions. According to this section, network operators shall be obliged to decide with respect to written access requests and their price.

Section 3 of the same Article provides that every refusal of access shall follow objective, transparent, and proportionate criteria. This Section provides a set of non-exhaustive examples of valid criteria for refusals, such as: technical suitability of the physical infrastructure, availability of space to host the elements of high-speed electronic communication networks, safety and public health concerns, the risk of serious interference of planned electronic communications services, or the availability of viable alternatives means of wholesale physical network infrastructure access.

Section 4 provides that all Member States shall ensure that, upon refusals to access, either party is entitled to refer that issue to the competent national dispute settlement body.

Section 5 provides that all Member States shall require the competent national dispute settlement body to issue a binding decision regarding any conflicts brought by any party participating in a refusal to access. According to this Section, all competent bodies shall reach a decision within the shortest possible time without exceeding four months from the date of receipt of the issue at hand.

Article 5 provides minimum requirements to ensure the existence of rights for Coordination of civil works.[31] Within this, Section 1 provides that all Member States shall ensure that all network operators have the right to negotiate agreements concerning the coordination of civil works with undertakings authorised to provide electronic communication networks.

Similarly, Section 2 of this Article establishes that all Member States shall oblige every network operator, directly or indirectly performing civil works, to meet all reasonable requests to coordinate civil works on transparent and

29. According to Section 1 of Article 2 of the Directive, network operator means "an undertaking providing or authorised to provide public communications networks as well as an undertaking providing a physical infrastructure (…)".

30. According to Section 2 of Article 2 of the Directive, physical infrastructure means "any element of a network which is intended to host other elements of a network without becoming itself an active element of the network, such as pipes, masts, ducts, inspection chambers, manholes, cabinets, buildings or entries of buildings, antenna installations, towers and poles; cables, including dark fibre, as well as elements of networks used for the provision of water intended for human consumption (…)".

31. According to Article 2 of the Directive, Civil works means every "outcome of building or civil engineering works taken as a whole which is sufficient of itself to fulfil an economic or technical function and entails one or more elements of a physical infrastructure."

non-discriminatory terms made by undertakings authorised to provide communications networks. This Section also provides that these requests must be accepted provided that the proposed coordination does not entail any additional costs, does not impede control of the civil works, and the request is filed in advance and at least one month before the work is finished.

Section 3 provides that any party is entitled to refer the issue to the national dispute settlement body when a request for the coordination of civil works is not reached within a timeframe of one month from the date of receipt.
On the other hand, Section 4 provides that all Member States shall ensure that the national dispute settlement body reaches a decision regarding the coordination of civil works by taking full account of the principle of proportionality, including the examination to determine if fair and non-discriminatory terms, conditions and charges where included in the request. According to this Section, decision of the national dispute settlement body should be reached in a timeframe within two months from the date of receipt of the complete request.

Nonetheless, Section 5 establishes that Member States may provide for exemptions from the obligations of coordination for those civil works of insignificant importance. These exceptions shall be duly reasoned and parties shall be given the opportunity to comment on the draft exemptions within a reasonable time.

Finally, the permit-granting procedure is set forth in Article 7 of this Directive. Important obligations for Member States include providing electronic means for the application of permits required for Civil Works, ensuring authorities' decisions for the grant or refuse of permits are taken within four months from the date of receipt, and that all requesting parties are compensated for suffered damages for the non-compliance of the deadlines for reaching a decision.

Applying similar guidelines such as those set forth in the Directive could present benefits for infrastructure deployment in Chile. First, applying these guidelines would create clear and efficient processes for co-location and/or for coordination between parties in civil works, as well as a mechanism through which a public national entity would have the faculty of reaching a binding decision regarding co-location or coordination in civil works between network operators.

Such guidelines would also endow the process with legal principles and reasonable justifications that could be used to deny requests or proposals of co-location and civil works coordination. These justifications would also serve as a mandatory guide for the national entities in charge of civil works and co-location issues.

In addition, implementing similar guidelines would substantially reduce the time needed for all relevant processes regarding civil works or infrastructure sharing. In fact, implementing such guidelines would oblige the competent entity to reach its decision regarding the acquisition of a permit in as little as four months. In cases of dispute over co-location or civil works, the entity would be obliged to reach a binding decision within a timeframe of one month.

Moreover, national entities would be obliged to pay for all expenses caused by any government's delay in resolving a dispute or in obtaining permits.

Infrastructure deployment in Colombia

The Colombian case is particularly relevant for Chile, since similar infrastructure deployment barriers existed in Colombia before the OECD's "Review of Telecommunication Policy and Regulation in Colombia".

As stated in the OECD Review, "[a] number of bodies or agencies in Colombia have direct or indirect responsibility over the communication sector". Colombian agencies in charge of policy and regulation of telecommunication included:

- The Ministry of Information and Communication Technology (*Ministerio de Tecnologías de la Información*, MINTIC) which is responsible for telecommunication policy-making and has the main responsibility for overseeing ICT industries. Nonetheless, its role is not limited to policy, but its powers include spectrum assignment or enforcement of regulation.

- The National Planning Agency (*Departamento Nacional de Planeación*, DNP), responsible for universal access policy in conjunction with the Ministry, as well as the power to approve investment projects.

- Colombia's communication regulator, CRC, responsible for promoting competition in communication markets, preventing the abuse of dominant positions, and delivering ex-ante market regulation for networks and services to ensure the efficient provision of services. CRC lacks the faculty or jurisdiction to enforce regulation, due to the lack of sanctioning powers. The Minister is the Chairman of the CRC.

- The Spectrum National Agency (*Agencia Nacional de Espectro*, ANE) in charge of spectrum planning, management, and control.

Similarly to Chile's current regulation, network or communication operators encountered barriers when deploying infrastructure related to requests of rights of way, access to third party facilities, environmental permits, and more. According to the Review, barriers have further been aggravated due to a lack of harmonisation between municipalities with respect to rights of way. In fact, Urban Planning rules ("Planes de Ordenamiento Territorial" in Spanish) in Colombia differ from city to city.

Therefore, the regulator CRC and the MINTIC issued a set of guidelines ("Code of good practice") for municipalities aiming at increasing coordination in urban planning regulations for infrastructure deployment. However, the guidelines are non-binding due to constitutional and legal barriers. Therefore, the voluntary nature of the code unfortunately undermines its attempt to improve harmonisation of Urban Planning Rules. It was also stated in the Review, that CRC should monitor developments to measure the progress of municipalities in implementing these guidelines.

Additionally, municipalities in Colombia could ban tower deployment at will by creating artificial requirements for tower deployment.

However, according to the Review, required infrastructure sharing regulation already existed in Colombia. By way of example, the CRC, in coordination with the Energy Regulator -CREG- issued the Resolution 4245 of 2013 to encourage infrastructure deployment by means of infrastructure sharing. The Resolution established the conditions under which electricity networks and elements, such as poles, ducts and channels could be used by network operators to provide telecommunication services. This regulation also provides rate formulas to determine price caps for compensation for the use of electric grid by network operators.

Another example is the in-building wiring sharing regulation (*Reglamento Interno para Redes Internas de Telecomunicaciones*, RITEL), which led to Resolution CRC 4262 of 2013. This regulation included instructions for building owners and, in general, to all operators providing telephony, Internet access or cable services. In particular, this regulation provides that all operators must have free access to the internal network for telecommunication in buildings. Therefore, as it was stated in the review, barriers in infrastructure deployment focused on the impossibility of coordination between regulatory entities with municipalities regarding Urban Planning Rules and RITEL rules.

These problems were mostly solved with the issuance of a National Law that, despite not giving more power to MINTIC and CRC, enabled these entities to work hand-in-hand with municipalities in the structuring of Urban Planning Rules. By way of example, Law 1978 of 2019 declared infrastructure deployment as a necessity and a means to guarantee constitutional rights such as education, knowledge, science, and culture, as well as the massive adoption of digital procedures.[32] This Law also provides that the Ministry of Information and Communications Technology and the CRC

32. Article 10 of Law 1978 of 2019 establishes the following: "With the purpose of guaranteeing the effective exercise and enjoyment of the constitutional rights of communication, life in emergency situations, education, health, personal security and access to information, knowledge, science and culture, as well as to contribute to the massification of digital procedures and services, in accordance with this Law, it is the Nation's duty to ensure the continuous, timely and quality provision of public communication services, for which it will ensure infrastructure deployment of telecommunication networks (…)"

should in all cases evaluate the possibility of including differential measures or rules that encourage infrastructure deployment and the provision of services in rural areas.[33]

This Law improved infrastructure deployment because it enabled MINTIC and CRC to work jointly with municipalities in the creation of Urban Planning Rules taking into full account the "Code of Good Practices". Therefore, this Law worked as a tool for coordination between authorities for the creation of an effective regulation regarding infrastructure deployment.

As a result of such coordination, MINTIC has stated that *"756 of the 1,103 municipalities on the country adopted the regulations that promote the installation of antennas and network connections by Network and Telecommunication Services Providers in the National Territory."*[34]

Therefore, at least in terms of law and regulation, a better scenario has been created for infrastructure deployment in Colombia.

The Colombian experience demonstrates that Chile could benefit from a National Law that enables SUBTEL to work with municipalities and their Civil Works Directorates in determining Urban Planning Rules for infrastructure deployment and erasing artificial requirements created by municipalities. Working hand-in-hand with municipalities will enable SUBTEL to clarify arguments regarding radiation, and will allow the entity to be at the center of regulation on infrastructure deployment.

Finally, declaring that infrastructure deployment is a necessity and a means to guarantee other constitutional rights, would oblige municipalities to implement the best practices to encourage infrastructure deployment throughout the entire Chilean territory.

Infrastructure deployment in Mexico

Another example of complex regulation regarding infrastructure deployment is Mexico's case which was explained in the OECD Telecommunication and Broadcasting Review of Mexico 2017. According to Article 15 of Mexican's Constitution, state and municipal authorities are designated to manage and oversee the use of public property and rights of way within their jurisdiction. Hence, each local or federal government is in charge of all regulation regarding requirements, condition, and fees. This resulted in the creation of different regimes throughout the nation, and the establishment of several barriers for infrastructure deployment such as a lenghty obtention of rights of way, access to passive infrastructure, the need to incur in complex administrative procedures, and the imposition of subsidising unrelated public facilities and services.

The Ministry of Communications and Transports (*Secretaria de Comunicaciones y Transporte*, SCT) and the Federal Telecommunications Institute recognised the absence of clear rules on the powers of federal, local, and municipal authorities relative to civil works and rights of way, generating barriers to infrastructure deployment derived from the legal uncertainty to service providers. Uncertainty for network operators also increased with the challenge of accurately estimating implementation costs as a result of the unclear and divergent local regulation with respect to related fees. Additional costs could range from 15% to 50% of each project's base cost.

Industry players expressed their concerns regarding permits and fees requested by the local authority which could be excessive. In addition, industry players also stated that local governments usually asked for "in-kind donations" to benefit the local community as a condition for the granting of permits for infrastructure deployment.

33. Article 31 of Law 1978 of 2019 establishes the following: "The Ministry of Information Technology and Communications and the Communications Regulatory Commission must always evaluate, in the development of any type of regulatory project, the possibility of establishing differential measures or rules that encourages infrastructure deployment and service provision in rural areas."

34. See: https://mintic.gov.co/portal/inicio/Sala-de-Prensa/Noticias/124733:En-2019-68-de-los-municipios-se-acogio-a-la-norma-que-regula-el-despliegue-de-infraestructura-TIC-MinTIC

Considering these limitations, the OECD made several recommendations to eliminate barriers to infrastructure deployment. Some of these recommendations are explained below.

First, the OECD recommended that the SCT develops co-ordination agreements with different players, including municipal governments. Under these agreements, municipal governments would implement a model statute that would apply to all infrastructure deployments requests by network operators. By doing this, the regulation would seek to eliminate bureaucratic barriers generated by the legal uncertainty in this area.

Regarding rights of way, the OECD recommended that SCT co-ordinates at the national, state, or municipal level to co-ordinate the requirements and procedures for the access of rights of way on public property. This co-ordination included the determination of fees or prices solely based on factors influencing deployment in order to guarantee the existence of telecommunication infrastructure.

Private network operators and actors highlighted the importance of the creation of a centralised platform to process deployment requests where authorities are obliged to explicitly mention the reasons for every rejection to allow applicants to remedy potential issues.

Chile could benefit from similar policies. Through a co-ordination by SUBTEL with municipalities and their Civil Works Directorate, the same criteria could be applied to all infrastructure deployment requests by the use of a model statute that would apply in all municipalities all over the nation.

Co-ordination with municipalities would also mean defining the national requirements and procedures for the access of rights of way of public property in hands of municipalities. This would encourage network operators to engage in infrastructure deployment since legal certainty is guaranteed.

Infrastructure deployment in the United States

On September 27, 2018, the United States' Federal Communications Commission (FCC) released a compliance guide with the purpose of "[a]ccelerating Wireless Broadband Development by Removing Barriers to infrastructure Investment". The guide provides a set of good practices that can be considered and implemented by the Chilean government and SUBTEL as the government's agency for Telecommunications.

The Addition to Rule 47 to the Code of Federal Rules requires state or local government entities to take timely action on a sitting application or request for infrastructure deployment. By way of example, section 1.6003(C) of Rule 47 provides that the following sitting authorities must act within the timeline of each type of application, as follows:

- Application to collocate a small wireless facility using an existing structure: 60 days.
- Application to collocate a facility other than a small wireless facility using existing structure: 90 days.
- Application to deploy a small facility using a new structure: 90 days.
- Application to deploy a facility other than a small wireless facility using a new structure: 150 days.

In addition, the FCC recognised that local fees and other charges associated with the deployment of wireless infrastructure can effectively prohibit the provision of service. Therefore, the FCC states that *"fees are only permitted to the extent that they represent a reasonable approximation of the local government's objectively reasonable costs and are non-discriminatory."*[35] The term "reasonable costs" refers to administrative costs of local governments incurred for the issuance of a decision regarding infrastructure deployment.

35. See: https://www.federalregister.gov/documents/2018/10/15/2018-22234/accelerating-wireless-and-wireline-broadband-deployment-by-removing-barriers-toinfrastructure

Particularly, the FCC reveals that high fees have relevant effects in the near-term deployment of Small Wireless Facilities. In some cases, high fees in particular jurisdictions will lead to reduced or inexistent near-term deployment. In other cases, high fees in one area may impose a barrier to deploy Small Wireless Facilities elsewhere. Hence, high fees are intrinsically prohibited by Sections 253 and 332(c)(7) of the Communications Act.

Further, the FCC establishes a range of fees for Small Wireless Facilities deployment that are presumably reasonable costs and non-discriminatory and would not be prohibited by Section 253 or Section 332(c)(7): *"(a) USD 500 for non-recurring fees, including a single up-front application that includes up to five Small Wireless facilities, with an additional USD 100 for each Small Wireless Facility beyond five, or USD 1,000 for non-recurring fees for a new pole (i.e., not collocation) intended to support one or more Small Wireless Facilities, and (b) USD 270 per Small Wireless Facility per year for all recurring fees, including any possible ROW access fee or fee for attachment to municipally-owned structures in the ROW."*[36]

Establishing such practices in Chile would be beneficial since municipalities would have a short time frame or *"Shot Clock"* to approve infrastructure deployment, with a maximum of 150 days to approve the installation of tower antenna over 12 meters high.

In addition, requiring a reasonable fee related to local government cost will encourage network operators to engage in infrastructure deployment, particularly in the near-term installation of Small Wireless facilities, which are important for the deployment of 5G.

3.6 IMPLEMENTATION ACTION PLAN

Ensuring Low Barriers to Enter the Telecommunication Market and Facilitate Infrastructure Sharing

POLICY ACTION 1:

Create a mechanism through which operators can file appeals against decisions by Municipal Public Works Departments regarding infrastructure deployment authorisations.

The Law 20 599 ("Antennas Law") grants complete jurisdiction to Municipal Public Works Departments (*Direcciones de Obras Municipales*, in Spanish), to authorise infrastructure deployment projects in municipalities by granting permits. This may create artificial barriers for obtaining permits to roll-out networks.

In addition, there is no mechanism through which operators can appeal against Municipal Public Works Departments' decision in the granting of permits for infrastructure deployment. Hence, decisions from these entities are final, and infrastructure deployment for all operators may be delayed or impeded by them.

An appeal mechanism is necessary for operators and beneficial for the functioning of the sector. Since SUBTEL is the governmental agency in charge of telecommunication services, it can be considered as the competent body to resolve appeals.

Objectives:

- Developing a mechanism through which operators can appeal Municipal Public Works Departments' decisions regarding permits for infrastructure deployment, or where they can identify infrastructure deployment barriers.
- Through this mechanism, operators could file an appeal to SUBTEL indicating the barriers, prohibitions or restrictions that obstruct infrastructure deployment in the respective municipality.

36. See https://www.federalregister.gov/documents/2018/10/15/2018-22234/accelerating-wireless-and-wireline-broadband-deployment-by-removing-barriers-toinfrastructure

- It could be determined that SUBTEL must reach a decision within 30 days and issue its opinion to the respective municipality informing it about the need to guarantee the rights of operators in the aim of eliminating barriers to infrastructure deployment.

- Upon notification of SUBTEL's opinion, the respective municipality would have a maximum period of 30 days to inform SUBTEL of the actions to be taken within six months to remove the identified barrier or restriction.

Actions and timeframe:

- Establish a legal framework through which an appeal mechanism is created. This legal framework can be included as a part of the Antennas Law or could be a regulation issued by SUBTEL (through resolution) in fulfillment of its functions. This should be implemented within one year.

- The issuance of a law that regulates operators' appeals should ideally take no more than one year. If instead this mechanism is adopted through resolution, this process should take a maximum of six months.

Institutions/stakeholders involved:

- SUBTEL – Ministry of Transportation and Telecommunications.
- Chilean Congress.
- Municipal Public Works Departments.

Policy instrument:

- Law that creates a legal framework for appeal.
- SUBTEL Resolution that regulates operators' appeals for decisions regarding infrastructure deployment permits.

Milestones, indicators and evaluation:

- Number of appeals formulated by operators against Municipal Public Works Departments' decisions
- Number of appeals granted by SUBTEL in favour of operators engaging in infrastructure deployment.

POLICY ACTION 2:

Elimination of high fees for cellular sites deployment to ease infrastructure deployment and facilitate market entry.

Chilean regulation regarding infrastructure deployment establishes high fees for obtaining necessary permits. In particular, the Antennas Law establishes that all operators seeking to install cellular sites (i.e. macro tower sites) over 12 meters high must pay an amount of 30% of the project's budget for the improvement of public spaces surrounding the tower.

Therefore, reducing and/or capping these fees would be beneficial to encourage deployment by new players, since potential entrants are less likely to be able to pay high fees. That is, the elimination of high fees could reduce barriers to entry, thus, creating a *"contestable market"*.

Objective:

To reduce or cap the fees that operators pay for antenna site installation in municipalities.

Actions and timeframe:

- Adopt the necessary mechanism in order to amend current laws that stipulate the high fees that operators must pay for infrastructure deployment. Through the amendment, rates in all municipalities shall be equal and oriented to cover the issuance of the permit.

- Maximum amounts of fees could be defined as was done in the United States.
- The amendment of all laws should ideally take no longer than six months to one year.

Institutions/stakeholders involved:
- SUBTEL – Ministry of Transportation and Telecommunications
- National Government
- Municipalities
- Operators

Policy Instrument:
- Law that expressly repeals or amends all provisions that contain high fees for infrastructure deployment and establishes equal fees for all municipalities.
- Governmental action to repeal or amend all laws regarding high fees for infrastructure deployment

Milestones Indicators and Evaluation:
- Time taken for the issuance of a law that repeals or amends
- Time taken for a governmental repeal or amendment
- Statistics regarding entrance of new operators, and/or infrastructure deployed in municipalities.

POLICY ACTION 3:

Create an infrastructure sharing system between sectors through a regulation for the use of poles, pipelines, cables, and other infrastructure of the electricity, aqueduct, and sewer sectors.

In Chile, there is currently no mechanism through which different sectors can share infrastructure. Chilean regulation does not contain a provision requiring sectors to share their infrastructure with other sectors, except those regulating the fees and services associated to the use of parts of the electrical infrastructure. As a result, the electricity, aqueduct, and sewer sectors are not required to share their infrastructure (pipelines, poles, cables, among others) with the telecommunication sector.

Therefore, Chile could benefit from a provision that expressly provides the obligation of all sectors to share infrastructure with other sectors. Such an infrastructure sharing system should be governed by regulations for the use of poles, pipelines, cables, and other infrastructure of the electricity, water and other sectors. Telecommunication operators can benefit from already existing infrastructure of other sectors to deploy communication infrastructure, which would in turn reduce costs and increase the speed of deploying essential telecommunication infrastructure.

Objective:
- To incorporate a rule in the GTL, and other relevant law and/or regulation concerning the aqueduct, electricity, and sewer sectors that requires providers of public services to share their infrastructure.

Actions and timeframe:
- Incorporating a rule of this nature would require the issuance of a law, and or the issuance of regulation (through resolutions) by the competent agency.
- The issuance of a new Law should ideally take no longer than six months to a year.

Institutions/stakeholders involved:
- SUBTEL – Ministry of Transportations and Telecommunications
- Chilean Congress
- Any other competent agency

Policy Instruments:

- Law that incorporates a new rule to the GTL that obliges all operators and providers to share their infrastructure with members of other sectors.
- Resolutions of competent agencies to incorporate a rule of that nature.

Milestones and Indicators:

- Total infrastructure shared between other sectors such as the energy sector and telecommunication operators.

Evaluation:

- Statistics regarding deployed infrastructure in shared infrastructure.
- Telecommunication operators' evaluation on the new legal framework.

POLICY ACTION 4:

Create a simplified licensing procedure through which operators are authorised to provide all types of telecommunication services.

The existing regulation for concessions - an individual concession scheme for each type of service - is burdensome for operators. Currently, public, intermediate, and broadcasting services each require a different authorisation. Chile should consider replacing the individual concession model with a single concession regime, such that there would be one kind of licence for all services. The license would be based on a registry where any company or legal entity interested in obtaining a license would simply report requirements and agree to operate under SUBTEL's regulations.

Objective:

- Creating low barriers to entry for telecommunication markets and providing a simplified procedure through which operators are authorised to provide all kind of communication services.

Actions and timeframe

- Eliminate the existing individual concession model created by Article 8 of the GTL where public, intermediate, and sound broadcasting services are differentiated.
- Creation of a single licensing regime by modifying Article 8 of the GTL. Amendments to the regulation should ideally take place within six months to one year.

Institutions/stakeholders involved:

- SUBTEL – Ministry of Transportation and Telecommunications
- Tribunal for the Defence of Free Competition
- Chilean Congress

Policy instrument:

- Any Law that modifies Law 18.168 (GTL).

Milestones, Indicators and Evaluation

- Legal reform
- Entrance of new operators and/or new services provided by incumbent operators.

Reviewing Power Density Regulation and Addressing Public Concerns

POLICY ACTION 5:

SUBTEL and the competent authorities in Chile could review the current EMF limit regulation to align it with international standards as well as with growing demands for IP traffic.

In light of the increasing demands of IP traffic inherent to the digital transformation, it is important to take into account the potential benefits of deploying network infrastructure, while balancing health concerns. One way to tackle this trade-off would be by harmonising EMF limits to those accepted by the WHO (i.e. as provided by the EMF Guidelines of the ICNIRP).

Objective:
- Review the current EMF limit regulation to align it with international standards as well as with growing demands for IP traffic.

Actions and timeframe:
- Train entities in charge of the authorisation of the installation of towers by SUBTEL. Training should overview the effects of antenna emissions, the EMF and existing international regulation. This can be done by also relying on external experts.
- The development of the training by SUBTEL should take from six months to a year.

Institutions/ stakeholders involved:
- SUBTEL – Ministry of Transportations and Telecommunications
- Ministry of Environment

Policy Instruments
- The aforementioned trainings by SUBTEL

Milestones, Indicators and Evaluation:
- Entities' awareness of the effects of emissions and the EMF Guidelines of the ICNIRP.
- Changes in EMF limit regulation
- Statistics regarding changes in entities knowledge on EMF limits and the effects of emissions.

POLICY ACTION 6:

SUBTEL (or the National Government) could initiate a national campaign with the Ministries of Health and Environment in order to ensure a better understanding of the health concerns generated by non-ionising radiation of antennas, so as to reduce public concerns.

The Antenna Law prohibits the installation of cellular sites near "public or private schools, nurseries, kindergartens, hospitals, clinics, urban premises with high voltage towers, nursing homes, or other sensitive areas of protections so defined", except for cases of antennas between 3 and 12 metres high. In addition, Article 2 of the Antenna Law gives SUBTEL the power to "declare a specific geographical area as a saturated area or radiating telecommunication systems, when the power density exceeds the limits determined by the technical regulations dictated for that purpose by SUBTEL." The scope of the campaign would need to be based on a careful assessment of the number, distribution and content of the complaints filed by citizens.

Objective

- Better inform and educate the population regarding concerns on EMF

Actions and timeframe

- Develop a campaign by SUBTEL with the Ministry of Health and the Ministry of Environment in order to educate the population on EMF issues.
- This campaign will further result in the recommendation of a modification of the Antennas Law.
- The issuance of the campaign should take from six months to a year.

Institutions/stakeholders involved

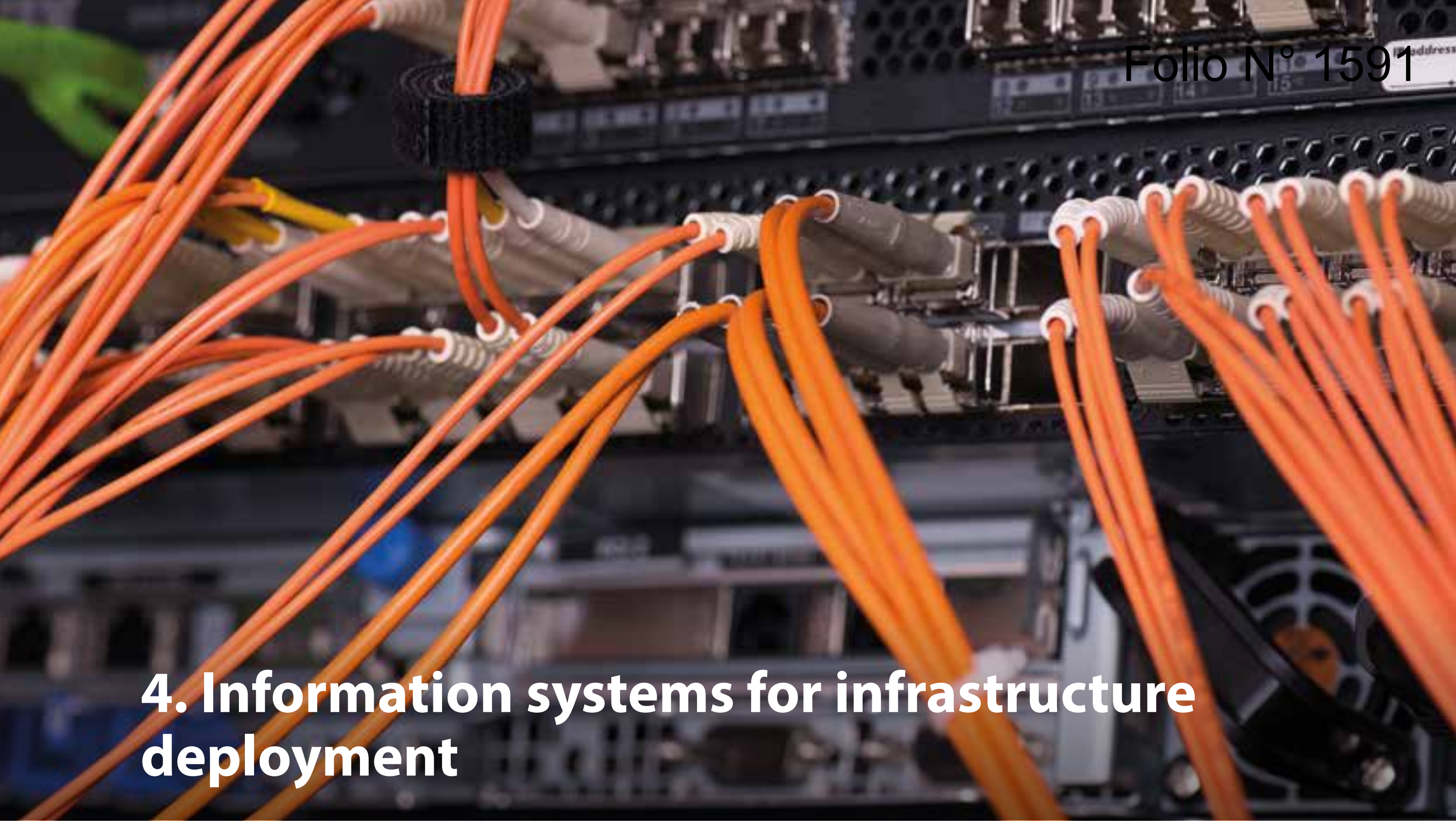
- SUBTEL – Ministry of Transportations and Telecommunications
- Ministry of Health
- Ministry of Environment
- Chilean Congress

Policy Instruments

- The aforementioned campaign by SUBTEL with the Ministry of Health and the Ministry of Environment

Milestones, Indicators and Evaluation:

- Number of complaints filed by citizens against the installation of antennas and towers.
- Statistics that demonstrate the reduction in the denials of all Municipal Works Directorates through the application of the precautionary principle.



4. Information systems for infrastructure deployment

4.1 THE CHILEAN INFORMATION TRANSFER SYSTEM (STI): LIMITATIONS

The general regime of information management in Chile is based on Resolution No. 159. This resolution creates the Information Transfer System (Sistema de Transferencia de Información, STI), a platform that allows telecommunication operators to electronically submit the information they are required to report. STI was created by SUBTEL in 2006 and directly derives from the powers of SUBTEL, set in letter K of article 6 of Decree Law No. 1,762 of 1977 and subsection 2 of article 37 of the GTL.

The STI is *"an application supported by an Internet platform through which telecommunication service providers send the required information to SUBTEL in a simple, expedited and secure manner."*[1] Under the STI, providers of Voice and pay-tv services must report the information specified in the annexes of the Resolution. The annexes also include the periodicity with which concessionaires must report and clarifies how the requested information should be disaggregated.

The information that must be reported by concessionaires includes:

- Information about communication access lines
- Traffic (voice and data)
- Number of mobile subscribers
- Prepaid services
- Blocking and unlocking mobile terminal devices
- Quality of the Mobile Network
- Assigned Numbers
- Internet Network Quality and Availability
- Internet connections
- Subscribers
- Other characteristics SUBTEL may define

1. See: http://sti.subtel.cl:8080/sti/jsp/login.jsp

However, STI does not work as a mechanism or platform where operators can share the number of sites or buildings that could be suitable for infrastructure deployment. Thus, operators have limited resources to know the possible sites suitable for this purpose.

In conclusion, the STI is mainly a mechanism to provide SUBTEL with data on the sector, including some quality indicators. This system could be complemented by an information transfer system containing an inventory of the State's assets that could be used for communication infrastructure deployment, as well as private assets and operators' infrastructure available for co-location. Access to the exact location of said national and private assets would eliminate search costs and administrative processes for infrastructure deployment.

International good practices

A good practice with regard to information systems for infrastructure deployment is the ARES[2] platform in Mexico. ARES allows nearly 110 000 state-owned structures to be used and shared by concessionaires (licensees), permission holders and infrastructure developers as passive infrastructure for communication networks under non-discriminatory, equal-access and non-exclusive conditions. Information pertaining to the relevant properties, including geo-referenced location as well as physical, economic, technical, safety and operational conditions, is available on this online platform since May 2017. The information on economic conditions (i.e. price of the space to be leased) aims at fostering competition in the sector and encouraging more operators to use the infrastructure. The leasing price depends on the municipality, but on average, operators will only pay around USD 160 for a maximum rented area of 190 square metres. Interested parties can use the platform as a search engine and indicate their interest for a particular building and the platform will serve as a one-stop portal for all the requests. Apart from the 110 000 federal buildings, other interested public institutions, for instance at the municipal level, can become a member of the portal and present their properties that fulfil the necessary technical conditions (OECD, 2017[4]). This portal is an innovative approach for shortening administrative processes, keeping fees at moderate levels and thus easing infrastructure deployment. It further facilitates locating properties that are suited for deploying infrastructure (OECD, 2017[4]).

The Mexican law further includes the National Infrastructure Information System (*Sistema Nacional de Información de Infraestructura*, SNII). This system includes useful information on rights of way geared towards allowing concessionaires to deploy telecommunication infrastructure within those assets. Regulations in Mexico oblige both concessionaires and public agencies to inform the telecommunications regulator, IFT, of all relevant information on the federal public sites, ducts, posts and rights of way for their registration in the SNII and its eventual availability to telecommunication and broadcasting operators to expedite the deployment of their networks.

The OECD further advised the Mexican Government (OECD, 2017) to deepen their passive infrastructure project and the National Infrastructure Information System, so that it is available to all operators, under equal-access conditions, federal real estate and rights of way that can be used for the deployment of telecommunication networks and equipment.

This good practice is also applicable to the Chilean legal system. The Government could include recommendations to states/municipalities to standardise and simplify requirements for infrastructure sharing, lease of government real estate for telecom infrastructure, and authorisations needed to expedite the deployment of infrastructure, under SUBTEL's guidance. SUBTEL should therefore be empowered, as the IFT, to determine the infrastructure deployment policies across the country and establish guidelines to access information on public infrastructure, jointly with other government agencies, including the Administration of National Property or the Energy Regulatory Commission when information regarding the electrical infrastructure is required.

Another good practice is Directive 2014/61/EU of the European Parliament and the Council which also includes provisions regarding information sharing. Article 4 provides that all Member States shall be transparent regarding information on physical structure. Therefore, Section 1 provides that all Member States shall ensure an information system through

2. At the time of writing, the webpage ARES is currently reworked by INDAABIN, but soon available again.

which, when information of physical infrastructure is requested by Network Operators, the following minimum information shall be given:

a. location, and route;
b. type and current use of the infrastructure; and
c. a contact point.

Sections 2 and 3, although not obligatory, recommend Member States to implement a unique (or single) electronic information system that ensures all network operators have access to such information promptly.

In absence of an electronic transformation system, Section 4 of Article 4 requires Member States to ensure that competent bodies give access to such information to the requesting party in a period of no more than two months from the receipt of the information request. Such access shall be given under proportionate, non-discriminatory and transparent terms.

In addition, Article 6 provides that Member States may require the following information regarding current civil works or related to future physical infrastructure for permits granted, where a permit granting procedure is pending or for a first submission to the competent authorities that is envisaged in the following six months:

a. the location and the type of works,
b. the network elements involved,
c. the estimated date for starting the works and their duration; and
d. a contact point.

Network operators shall answer this request within two weeks from the date of receipt of the written request under proportionate, non-discriminatory, and transparent terms.

Finally, the Directive provides for a dispute settlement mechanism where parties can refer the dispute to a national dispute settlement body which shall issue a binding decision within two months, except in exceptional circumstances.

Applying similar information sharing rules would benefit Chile. First, applying these rules would mean creating a centralised and efficient information sharing system where network operators have access to a National Inventory of public property where infrastructure can be deployed within a short time frame.

Such guidelines would also oblige network operators to share information regarding their existing or future physical infrastructure, with the aim of informing other network operators about possibilities for co-location.

Finally, such guidelines would provide a dispute resolution mechanism regarding information sharing for infrastructure deployment and Civil Works. This guarantees information sharing between national and local authorities with existing and incumbent network operators.

4.2 ANTENNAS LAW

The Antennas Law is relevant for information platforms as it aims at enabling both the community and the operators to know the state of the existing infrastructure throughout the entire national territory.

With respect to this and in accordance with article 116 bis F, municipalities shall determine the *"areas with municipal or national public goods where operators preferably will have the right of use for the location of antenna support towers of more than twelve meters."*

Thus, municipalities are obliged to define the preferred, but not exclusive, places for companies to build antenna support towers between three and twelve meters. Operators can thus access information about areas where they can preferably deploy their infrastructure.

However, municipalities do not have the obligation to share the information with other authorities, including at the national level, such as SUBTEL, the Ministry of Transportation and Telecommunications, or the Ministry of Housing and Urban Planning.

Therefore, operators who want to deploy their infrastructure in a specific place need to look for respective ordinances of the municipality where they plan to deploy their infrastructure. In addition, municipalities do not necessarily have a digital and effective publication system for information sharing, which can make it very hard for operators to obtain the relevant information. Indeed, more than 50% of the overall 345 municipalities in Chile may be classified as semi-urban with low or medium development (see http://www.dipres.gob.cl/598/articles-114713_doc_pdf.pdf).

Article 2 of the Antennas Law, which modifies Article 7 of the GTL, provides for a second mechanism through which information is transmitted. The article obliges SUBTEL to maintain an information system on its website "that allows citizens to know the state of authorisation procedures in progress, the cadastre of antennas and authorised radiating systems, the levels of exposure to electromagnetic fields in the vicinity of said systems, and the certifying companies that perform said measurements and used protocols" . However, this system is not aimed at facilitating infrastructure deployment or the extension of information services for operators, but informing consumers whether an antenna is about to be authorised.

4.3 PROMOTE INFORMATION MANAGEMENT AND SHARING IN CHILE TO FOSTER INFRASTRUCTURE DEPLOYMENT

As explained above, information sharing regarding co-location and possible shared infrastructure for deployment needs to be increased, in particular regarding the access to passive infrastructure, information on passive infrastructure location and obligations for both public and private undertakings to publish such information. If such information is available, operators can negotiate to get access to the terms and conditions to access said infrastructure.

SUBTEL should also be empowered to intervene when infrastructure sharing is essential to provide telecommunication services. Thus, all concessionaires and authorised entities should be obliged to inform SUBTEL on their active infrastructure and transmission means, as well as on their passive infrastructure and rights of way in order to be able to develop their Information System.

Currently, information regarding infrastructure deployment is not shared and made available in the Information Transfer System managed by SUBTEL. Only information regarding the quality of telecommunication services is shared. Although Article 116 bis F of the Antennas Law requires municipalities to determine the best areas to deploy infrastructure, there is no legal obligation that binds municipalities to report their preferential areas to SUBTEL, the MTT, nor to the Ministry of Housing and Urban Planning. As a result, the current system creates excessive search costs for interested agents, which may prevent investments in new infrastructure. Therefore, a National Information System containing all information for deployment would help network roll-out efforts.

Therefore, the creation of an information platform to ease market-oriented transactions that promote contractual agreements between operators and public and private owners of properties would complement existing measures, when made available on a public and non-discriminatory basis to telecommunication licensees.

In addition, Chile should take advantage of state-owned infrastructures to deploy telecommunication networks, by providing space that could be used for infrastructure deployment in state-owned and state-operated buildings to operators and licensees at market prices. For both initiatives, information systems should be implemented, as done in Mexico.

4.4 IMPLEMENTATION ACTION PLAN:

Creation of a National Information System that facilitates Infrastructure Deployment

POLICY ACTION 7:

Consider the creation of a provision that obliges Municipal Public Works Departments to share land registry information regarding preferential zones for infrastructure deployment with relevant Ministries and national authorities.

Although Article 116 bis F of the Antennas Law requires municipalities to determine the best areas to deploy infrastructure, there is no legal obligation for municipalities to report their preferential areas to SUBTEL, the Ministry of Transport and Telecommunications (MTT), nor to the Ministry of Housing and Urban Planning. In addition, municipalities do not necessarily have a digitalised and effective publication system for information sharing, which can make it very hard for operators to obtain the relevant information. As a consequence, the current system creates excessive search costs to interested agents, which may prevent investment in new infrastructure.

The Antennas Law – and other relevant legislation – should be amended in order to include an obligation for Municipal Works Directorates to periodically share cadastre information about the preferential zones for infrastructure deployment with SUBTEL, MTT, the Ministry of Housing and Urban Planning, or other national authorities. This would increase operators' incentives to verify preferential areas for infrastructure deployment throughout the national territory and rural zones.

Objective:
- Create an information transfer system that obliges all Municipal Public Works Departments to share information regarding land registry where preferential zones for infrastructure deployment are determined.

Actions and timeframe:
- Incorporate a rule, either in the GTL or in the Antennas Law, that obliges all Municipal Public Works Departments to share land registry information regarding preferential zones.
- The incorporation of a new rule in a law should take from six months to a year since the only way to do it is by means of a new law.

Institutions/stakeholders involved:
- SUBTEL – Ministry of Transportations and Telecommunications
- Chilean congress
- Municipal Public Works Departments

Policy Instruments:
- A law that incorporates a new rule either to the GTL or the Antennas Law, regarding the obligation of all Municipal Public Works Departments to share cadastre information determining preferential zones.

Milestones, Indicators and Evaluation:
- Statistics regarding a number of municipalities sharing information and/or operators' ease to access such information.

POLICY ACTION 8:

Implement a National Information Transfer System with an inventory of all State's assets (e.g. public buildings) that can be used for communication infrastructure deployment. Ideally, this system would also include private real estate with geolocation details.

Even though the GTL establishes the right for all operators to use State owned infrastructures to deploy telecommunication networks, no information regarding public assets is shared. Therefore, a National Information Transfer System where information pertaining all State's assets (inventory) is shared is desirable, ideally in a digital way which is easy to access.

Objective:

- To develop a national, one-stop portal to share all information regarding public assets where infrastructure can be deployed, and at what price. The Mexican ARES portal, launched in May 2017, which geo-references public buildings with respective leasing prices can serve as good practice.
- Also include private buildings on the one-stop portal as well as private infrastructure that could be used for colocation.

Actions and timeframe:

- If required, modify SUBTEL's regulation regarding the National Information System (Exempt Resolution No. 159 of February 28, 2006).
- If a new resolution is to be issued, it should be ideally be done within six months to a year.
- Develop an online one-stop portal.

Institutions/stakeholders involved:

- SUBTEL – Ministry of Transportations and Telecommunications
- Ministry of Housing and Urban planning
- Ministry of National Infrastructure

Policy Instrument:

- If required, a SUBTEL Resolution that modifies the Exempt Resolution No. 159 of February 28, 2006.

Milestones, Indicators and Evaluation:

- One-stop portal is live on the government's website.
- Quality measures of the portal
- Statistics regarding the number of private and public assets in the one-stop portal and their location.

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5. Spectrum management

5.1 SPECTRUM POLICY AND REGULATORY FRAMEWORK

Radio spectrum management

The GTL mandates that concessions and licenses for spectrum use by public and intermediate telecommunication services are authorised for a fixed 30 years period, renewable for an equal amount of time, besides setting the principles of free and equal access to the radio spectrum and the criteria for the allocation of this resource. The law does not provide for the possibility to trade spectrum in a secondary market.

The GTL also determines that SUBTEL is in charge of ensuring that telecommunication services, depending on their specific characteristics, are subject to a technical regulatory framework, and of defining the *Plan for Radio Spectrum Use* for this purpose.

The first *General Plan for Radio Spectrum Use* was approved in 1983 by the Supreme Decree 15. Subsequently, a new plan was approved by Supreme Decree 127 of 2006.[1] The GTL also determines that concessionaires, permit holders and telecommunication licensees that require the use of radio spectrum to provide their services, need an official authorisation. In addition, they are subject to the payment of fees related to this resource according to the specific characteristics of each service (Articles 31 and 32).

Spectrum and national ICT policies

Consistent with the liberalisation of the telecommunication sector, the use of spectrum has become a key factor for mobile communication services. As such, spectrum allocation has become an important mechanism for public policy to expand access to telecommunication and promote network deployment and digital transformation in the country. In addition, spectrum allocation is an important tool to foster competition in the market.

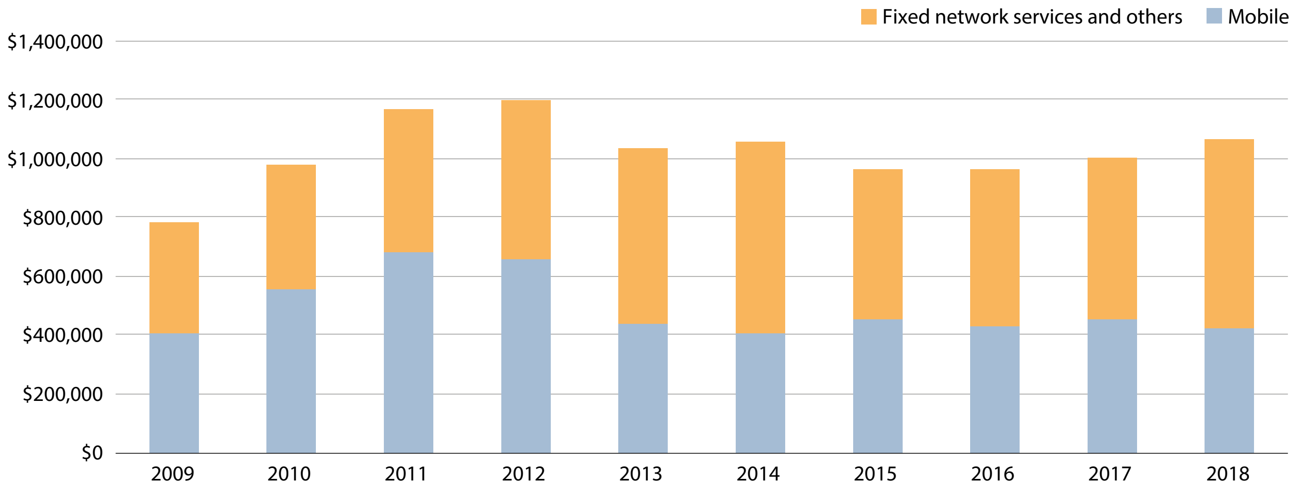
In light of the importance of spectrum for telecommunication services, the Chilean government introduced the digital agenda “Chile Towards the Information Society” in 1999. In this context, the government expressed the need to reallocate the spectrum bands occupied for broadcasting to digital transmission services, and to guarantee that operators entering the market could use this resource in transparent and non-discriminatory terms.

The central role of spectrum is also reflected in the *Imagina Chile 2013-2020 Digital Agenda*, which aims at an evolution towards a new generation of higher quality communication services at lower cost and greater coverage. In the same Agenda, the Chilean government defined that mandatory coverage in rural or isolated areas must be considered in spectrum assignment processes.

1. Modified in specific parts by Decree 956/2008, Decree 31/2009, Decree 156/2010, Decree 240/2011, Decree 141/2012 and Decree 19/2016.

Figure 5.1. Total investment in telecommunication in Chile has been stable between 2009 – 2018

Million CLP



Source: *SUBTEL. Documento Sector Telecomunicaciones 2018.*

The *Digital Connectivity* axis of the *Digital Agenda 2020 - Chile Digital para Tod@s* targets the deployment of high-speed mobile networks throughout the country. It also considers coverage obligations when assigning spectrum frequency bands, in accordance with the development and territorial integration of the country. For this purpose, a specific action includes the deployment of telecommunication services in the 700 MHz and 2.6 GHz bands in order to offer high-speed mobile broadband services and voice communications.

In addition, the *Digital Matrix 2018-2022*[2] initiative envisages the implementation of the fifth generation (5G) mobile technology, as well as a projected 30% increase in national investment in telecommunication. According to SUBTEL[3], the estimated value of mobile services investment has been stable since 2013, reaching around CLP 400 billion (USD 570 million) (Figure 5.1).

The evolution of spectrum assignation for mobile communication services

In Chile, spectrum assignation for mobile communication has experienced significant evolutions over the past 30 years. This section provides an overview of how this evolution unfolded over time and discusses how this has led to the spectrum-related challenges that Chile faces today. Overall, Table 5.1 portrays the current state of International Mobile Telecommunications (IMT) spectrum assignment in Chile.

The operation of mobile communication services in Chile began in the early 1990s. Initially, following the first spectrum assignments, specifically in the 850 MHz band. At the time, two concessions were granted, which are currently held by the operators Telefónica and Claro.

As technological advances were made towards the digitalisation of communication services, SUBTEL worked on allocating blocks in the 1900 MHz band. As a result, in 1997, the authority assigned spectrum to Chilesat (currently Claro), Entel PCS and Entel Telefonía Móvil[4], allowing these operators to have the spectrum for the implementation of 3G technology during the following years.

In 2009, the process for assigning spectrum in the AWS bands (1700 MHz paired with 2100 MHz) was undertaken, with the objective to facilitate the entrance of new competitors to the market, granting 60 MHz to Nextel (today WOM) and

2. National Plan that will allow Chile to position itself at the technological forefront of the region and that will shorten the existing digital and telecommunications gap in the country. Source: https://www.gob.cl/matrizdigital/
3. SUBTEL. Documento Sector Telecomunicaciones 2018. https://www.subtel.gob.cl/wp-content/uploads/2018/09/PPT_Series_JUNIO_2018_V1.pdf
4. In the first decade of the 21st century, Telefónica participated in a new bidding process, obtaining a portion of 30 MHz in the 1900 MHz band.

30 MHz to VTR. This process restricted the participation of the three existing operators by fixing spectrum caps. On 27 January 2009, the Supreme Court determined that *"if the amount of radioelectric spectrum held by any of the current operators exceeds the fixed limit of 60 MHz, spectrum must be released in ways allowed by the law in the necessary amount to adjust to the established limit"*.[5]

Since 2010, Entel is authorised to use the spectrum in the 900 MHz band, which was granted for the operation in the metropolitan area of Santiago and other regions of the country.[6]

Subsequently, the first process to assign spectrum for 4G technology took place in 2012 in the 2.6 GHz band. In addition, in response to the coverage arrangements proposed by the participants in the bidding process, SUBTEL included the obligation to provide mobile broadband service for 543 isolated localities, and subsidies were included for mobile telephony and data expansion projects for 360 such locations, with an aim to increase the connectivity of the country to 98% of the population. Given a condition of equality in the technical qualification score[7], the operators underwent a bidding process. Finally, three blocks of 40 MHz each were awarded to Claro, Movistar and Entel. This process meant that these operators, in addition to complying with the required conditions, had to make payments for each of their respective spectrum blocks.

Thereby, in 2012 Movistar, Claro and Entel had a 98.75% market participation in terms of number of subscribers, positioning themselves as the companies with the greatest presence in the Chilean market.

The most recent spectrum assignment for mobile services was in 2014 for the 700 MHz band. As a result of the process, 30 MHz were assigned to Entel, 20 MHz to Movistar and 20 MHz to Claro.

Table 5.1 Current state of International Mobile Telecommunications spectrum assignment in Chile

Assigned spectrum by operator

Operator	700 MHz	850 MHz	900 MHz*	1.7 GHz	1.9 GHZ	2.6 GHz	TOTAL
ENTEL	30 MHz	–	20 MHz	–	60 MHz	40 MHz	150 MHz
MOVISTAR	20 MHz	25 MHz	–	–	30 MHz	40 MHz	115 MHz
CLARO	20 MHz	25 MHz	–	–	30 MHz	40 MHz	115 MHz
WOM	–	–	–	60 MHz	–	–	60 MHz
VTR	–	–	–	30 MHz	–	–	30 MHz

Source: SUBTEL and communication operators.

In 2014, the National Consumer and User Corporation (Corporación Nacional de Consumidores y Usuarios, CONADECUS) filed a lawsuit calling into question the effectiveness of spectrum caps of 60 MHz which were defined in 2009. In 2018, the Supreme Court ordered the three companies that had been assigned spectrum in the 700 MHz band (Entel, Movistar and Claro) to return the spectrum which exceeded the referred caps.[8]

In response to this decision, SUBTEL proposed a modification to the National Spectrum Plan in 2018, recognising spectrum caps that reflect the needs for mobile services. After that, in March 2019, SUBTEL presented a new proposal to TDLC based on a dynamic approach, which determined a cap of 32% per operator per spectrum band. By the end of 2019, TDLC issued Resolution 59, in which it defined new spectrum caps based on percentages assigned for five macrobands, as follows:

5.. The Supreme Court established that on the basis of the AWS contest "it should be noted that, if the amount of radio spectrum held by any of the current operators arrives in the same way to exceed the limit set at 60 MHz, they must be released in any of the ways that the law allows for the amount of spectrum that is necessary to adjust to the established limit ".

6.. Through the acquisition of Transam and Will.

7.. According to Title X, related to concessions awarding, this condition would occur when the difference between the qualification achieved by the applicant who obtained the highest score and that obtained by other applicants differed by less than two points.

8.. This decision mandates Movistar, Claro y Entel to revert the same amount of radio spectrum that was acquired by each one in the 700 MHz band contest, having the possibility the spectrum bands for those returns (Causa 73923/2016. Resolución 113 - Corte Suprema, Sala Tercera (Constitucional), June 25th 2018)

Table 5.2. TDLC Resolution 59 / 2019: spectrum caps rules

Spectrum band	Spectrum cap	Remarks
Low < 1 GHz	35% per operator.	--
Low-Medium 1 -3 GHz	30% per operator.	--
Medium- 3 -6 GHz	Short Term	Blocks at a size of >40 MHz per operator (in a first assignment process, at least 80 MHz should be offered to two operators)
	Medium Term	SUBTEL shall ensure at least four operators with a minimum of 40 MHz contiguous blocks each.
	Long term	Spectrum cap of 30%, with a minimum of 80 MHz contiguous blocks each.
Medium-high 6 -24 GHz	No	No current International Mobile Telecommunications (IMT) spectrum allocations and assignments for mobile services in this macroband. SUBTEL must consult TDLC regarding the maximum spectrum limit by each operator, when decides to open a process into these bands.
High >24 GHz	Short Term	SUBTEL shall ensure blocks at a size of >400 MHz per operator (in a first assignment process, at least 800 MHz for two operators should be offered)
	Medium Term	SUBTEL shall ensure at least four operators with a minimum of 400 MHz contiguous blocks each.
	Long term	Spectrum cap of 25%, with a minimum of 800 MHz contiguous blocks each.

Source: TDLC9

Based on the TDLC decisions, in January 2020, SUBTEL opened a public consultation in order to assign spectrum for 5G services for separate bands (Table 5.3), and announced the timelines on 1st of August of 2020 for the public tender.

Table 5.3. SUBTEL 4-processes proposal for 5G Spectrum assignment

Process	Available spectrum	Number of blocks	Block size	Total spectrum offer
700 MHz	703-713 and 758–768 MHz	1	20 MHz	20 MHz
AWS	1.755-1.770 and 2.155-2.170 MHz	1	30 MHz	30 MHz
3.5 GHz	3.300-3.400 and 3.600-3.650 MHz	15	10 MHz	150 MHz
26 GHz	25.900-27.500 MHz	2	400 MHz	800 MHz

Source: SUBTEL10

For the first two processes (700 MHz and AWS), SUBTEL proposed the use of LTE advanced or 5G or higher technologies. For the bands in the 3.5 GHz and 28 GHz spectrum bands, the regulator proposed only 5G or higher technologies. The consultation process was closed in February 2020.

As a final remark, there were two specific challenges that needed to be overcome in order to have more clarity for the overall spectrum assignment and spectrum holdings by different operators and thus the future provision of the different voice and data services and the market structure: (i) the current availability of the AWS band; and (ii) the conditions to be applied for the 3.5 GHz band for the 5G spectrum assignment.

First, the VTR operator stopped using the spectrum assigned to it in the AWS band since 2014, because the operator became a Mobile Virtual Network Operator (MVNO) using Movistar's network. SUBTEL should thus consider options to get this spectrum back and whether the block could be included in the new spectrum assignments in the near future or whether it should be defined for other uses.

9. Adapted from TDLC: https://www.tdlc.cl/nuevo_tdlc/category/lexsoft/resoluciones/

10. https://www.subtel.gob.cl/wp-content/uploads/2020/01/20200113_Texto_Ficha_Tecnica_consulta_ciudadana_5G.pdf

Second, in 1999, SUBTEL issued technical regulation applicable to fixed wireless local telephone services in the 3,400 – 3,600 MHz band (3.5 GHz).[11] Consequently, assignments for fixed wireless services were given to some operators during the first decade of the 21st century[12]. Additionally, in 2011, SUBTEL determined that the 3.5 GHz band could be used to provide both fixed and/or mobile services, and that current fixed concessionaires interested in providing mobile services should update their frequency band concessions.[13]

In 2018, SUBTEL studied whether spectrum is used in an efficient way in the frequency range between 3400 and 3800 MHz, and the results indicated that operators were not making an efficient use of this band.[14] Based on that study, SUBTEL stopped the operations of all telecommunication services that have previously been authorised in this band and suggested the use of the 3.5 GHz band for the development of 5G mobile services in its National Spectrum Plan. [15]

After a long discussion, SUBTEL proposed a mandatory obligation for operators in the 5G spectrum assignment processes to return current assigned blocks in this band in order to be able to participate in the process and obtain a new 30 years license. Furthermore, the bid proposal for this specific process was based on a combinatorial model, in which the participants need to indicate the number of blocks in which they are interested, and the price offered for the sum of these blocks.

Several groups and companies, including the consumer protection group CONADECUS and the companies Netline and WOM, had filed claims at the Supreme Court, questioning the new spectrum caps. On 13 July 2020, a new Supreme Court's ruling confirmed the spectrum caps of TDLC's Resolution 59 almost entirely, with the exception of spectrum caps in the low frequency band, with the aim of allowing for more operators to hold spectrum in this band. The Court further ruled that the gradual procedure in differentiating between the short-, medium and long-run in two spectrum bands was not required. Table 5.4 shows the determined spectrum caps for the different spectrum bands:

Table 5.4. Spectrum caps based on the Supreme Court decision (July, 2020)

Spectrum band	Spectrum cap	Remarks
Low < 1 GHz	32% per operator	
Low - medium 1 -3 GHz	30% per operator	no differentiation between short- medium and long-term
Medium 3 -6 GHz	30% per operator	
Medium-high 6 -24 GHz	No spectrum caps	
High >24 GHz	25% per operator	no differentiation between short- medium and long-term

Source: Supreme Court, Decision July 13, 2020.

In addition, according to the Supreme Court ruling[16], adjustments in the overall spectrum holding limits should be implemented in connection with future auctions, such as the one proposed by SUBTEL above. The ruling further states that incumbent operators shall prove that they do not exceed the spectrum caps at that time or "within a period that will not exceed six months" in each of the spectrum bands (c. 17). As a consequence, SUBTEL is required to modify its proposal for the 5G spectrum allocation contest following the rules and instructions established by the judiciary.

11. Adopted by Resolución Exenta 1498 / 1999.

12. Entel has currently assigned 100 MHz and Claro 50 MHz for nation-wide operation. Also, VTR has 50 MHz assigned for operation in regions RM, IX, VIII, VII, VI, V, IV, III, II y I. Movistar has 50 MHz assigned for regions XI y XII, and also other 50 MHz for region X through its subsidiary Telefónica del Sur.

13. Change adopted by Resolución Exenta 6554 / 2010

14. This determination by SUBTEL was based on the measurements made by the inspection department which found that, for each 60 municipalities in Chile, nearly a 73% had no signal. According to the report, anomalous situations were happening; technical samples proved some companies were operating with a greater power than the authorised, or commercially exploiting it irregularly.

15. Adopted by Resolución Exenta 1289 / 2018.

16. Corte Suprema, Sentencia de 13 de julio 2020, Rol 181-2020. Justices: Jorge Dahm, Sergio Muñoz y Leopoldo Llanos (concurrent opinion); María Eugenia Sandoval y Ángela Vivanco (dissenting opinion).

The Supreme Court's decision also made significant changes to infrastructure and spectrum access regulations. These orders, although considered complementary measures, produce an important set of changes in spectrum and infrastructure regulation in Chile. These measures include:

a) the obligation for so called "incumbent operators" to provide national, compulsory and temporary roaming to operators that are still in the deployment stage of the necessary infrastructures to compete fully with the former (see section 5.1.1).

b) the obligation for incumbent operators that have a national coverage network to publish a "viable" reference offer including access to facilities and resale plans for MVNOs so that they can provide to the public all the services that are provided by the incumbents. These offers and their modifications must be approved by the FNE, after a report from SUBTEL. As for the national roaming obligation, it will be important for subsequent regulation to define the term "incumbent", as well as to specify how the term "viable" should be interpreted, as this will be crucial for the effectiveness of such a measure.

c) The Court mandated SUBTEL and FNE to permanently and independently monitor the roaming and network sharing obligations above, and to sanction non-compliance as needed. The monitoring should be similar to FNE's supervision of merger control matters, through an independent auditor that reports to FNE and SUBTEL.

d) In the context of spectrum allocation processes, all assignees will be required to present and commit to an effective ("real") use plan and efficient use of spectrum (optimal) which must be valid for the entire duration of the auctioned concession. In addition, the requirement of effective use also includes all other frequencies that were previously allocated to the operators. The spectrum use plans needs to be approved by SUBTEL. Frequencies that are not effectively used in accordance with the committed plan must be made available to interested third parties, in various ways:

   i. Assignment of use to other (preferably new) entrants or smaller mobile network operators, through non-discriminatory mechanisms that allow the transferor to only recover efficient costs.

   ii. Divestment to third parties or return to the State of concessions for non-compliance with the use plan.

e) A final rule consists in an obligation for the regulatory authority to analyse whether the incumbent operators can – either immediately or after network optimisation undertaken in a reasonable time and costs – reasonably offer new services or technologies using their current spectrum holdings. If so, the new market entrants or smaller operators should be privileged in spectrum allocation processes.

The additional measures d) and e) entail several challenges: Determining the efficient use of spectrum is a complex task and will not only require an in-depth analysis of historical, geographical and granular data from incumbent operators, but also significant preparations for the establishment of such plans before new spectrum allocations can take place. The efficient use of spectrum, a scarce resource, is an important policy objective. One method to achieve this objective from the start is to move from a comparative selection assignment model to an auction model, in order to allocate this scarce resource in an efficient way (see also Policy Action 13). In addition, this decision introduces a retroactive regulation as it applies to all spectrum holdings of an operator and not just the new frequencies that will be allocated. The spectrum divestment to smaller operators on the secondary market might allow for more players to have spectrum in the different frequency ranges, but it can be questioned whether this will automatically translate to a globally more efficient spectrum use.

Additionally, defining whether an operator can offer new mobile services with existing spectrum, as determined in e), is another complex task as this depends on multiple factors. It will be important to further clarify this measure to ensure that operators with significant customer bases can participate in future allocation processes, i.e. that the measure is designed in a way that ensures continued innovation by all players in the market, while, at the same time, also fostering competition in the market.

Overall, this new set of measures and obligations, including the asymmetric measures for new entrants and smaller operators, has an important effect on the design of the rules applicable to the forthcoming spectrum allocation processes. In line with OECD practices, this allocation processes should be designed carefully to avoid a high level of market concentration, and the Supreme Court rules contribute to this. New allocation processes should be designed with careful attention to what has been stated by the Supreme Court, in order to avoid further litigations. At this stage, the decision by the Supreme Court is very open to interpretation, given its wide sets of concepts. Some additional clarifications might be necessary – through decrees or resolutions – so as to ensure investment certainty for operators, while also ensuring that the regulator is not further limited in its independency, technical analysis and capacity to effectively structure future spectrum allocation processes. Overall, further efforts should work to ensure continued innovation in the mobile market and to avoid creating a less competitive mobile communication market by only allocating spectrum to companies that may be less efficient players.

5.2 ANALYSIS OF THE CHILEAN SPECTRUM ALLOCATION FRAMEWORK

Priority actions for spectrum bands

In order to create a stable and business-friendly market environment, it is fundamental to apply the recently defined criteria for spectrum caps. In general, that definition of caps reflects the position of many actors in the market related to the use of groups of spectrum bands and the model has proven to be effective in several Latin American and Caribbean countries.[17]

In that sense, another important competition aspect for Chile is the determination of the future use of the 3.5 GHz band. This is because the assignments originally granted for fixed services have been extended to mobile services in recognition of technological developments and subsequently, SUBTEL temporarily limited its use as a regulatory measure. As the 3.5 GHz band represents a strategic band for the development of 5G, and considering the proposal for discussion issued by SUBTEL on January 2020 and SUBTEL's 1 August 2020 announcement on the timelines for the public tender, it is essential to adopt an effective transition regime for the use of the blocks by the current assignees, as well as for the adoption and execution of possible rearrangement schemes to be applied within this band. In addition, the tender will need to be amended in line with the Supreme Court's decision of 13 July 2020.

Spectrum assignment and management

In Chile, the spectrum allocation for mobile technologies has been timely and kept pace with technological developments. The adoption of 2G technology was carried out in the 90s, while 3G technology was deployed in the country since the middle of the first decade of the 21st century in the previously assigned spectrum. Likewise, the implementation of 4G technology began around 2013 with first spectrum assignments for 4G in the 2.6 GHz band.

Although these spectrum assignment processes have been developed in a timely manner, it does seem that the planning lacked a long-term vision. In some OECD countries, both short- and long-term technological developments have been taken into account in order to anticipate spectrum needs for different types of users. [18]

Although these assignments have allowed Chile to become the Latin American country with the third largest amount of spectrum assigned to operators, this is still smaller than developed telecommunication sectors such as Canada and the United States (Figure 5.2).

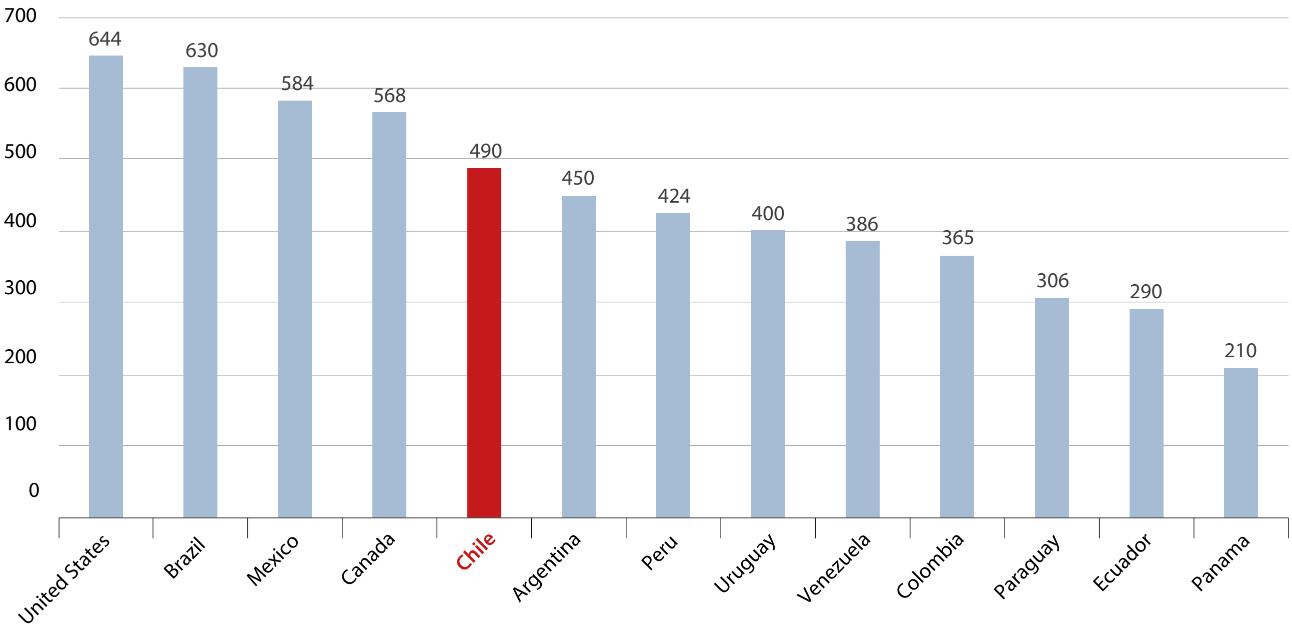
17. The OECD, in its document of Broadband Policies for Latin American and Caribbean countries, establishes that the use of spectrum caps is common among the countries that make up the organisation, focusing its use on facilitating the entry of new agents and on the management of situations related to dominance

18. As a reference, the document Spectrum Management The Key Lever for Achieving Universality published by IDB in 2015, shows that countries like Australia, Germany, the UK, and the United States, had high percentage of wireless broadband penetration, as well as advanced mobile technologies in comparison to most, being ahead in terms of innovative approaches in the use of spectrum. For this purpose, these countries determined their spectrum availability, and also applied innovative policies like TVWS. All these countries also included recently 5G technology into their spectrum plans.

In the same way, the European Union, in the Directive (EU) 2018/1972 referred to the European Electronic Communications Code, describes that "it should be possible to adopt multiannual radio spectrum policy programmes, where appropriate. The first such programme was established by Decision No 243/2012/EU of the European Parliament and of the Council (19), setting out policy orientations and objectives for the strategic planning and harmonisation of the use of radio spectrum in the Union. It should be possible for those policy orientations and objectives to refer to the availability and efficient use of radio spectrum necessary for the establishment and functioning of the internal market, in accordance with this Directive"

Figure 5.2 Allocation of spectrum in Chile is significant but still lagging behind more advanced communication markets

Assigned Spectrum (MHz) allocated in selected American countries as of June 2019

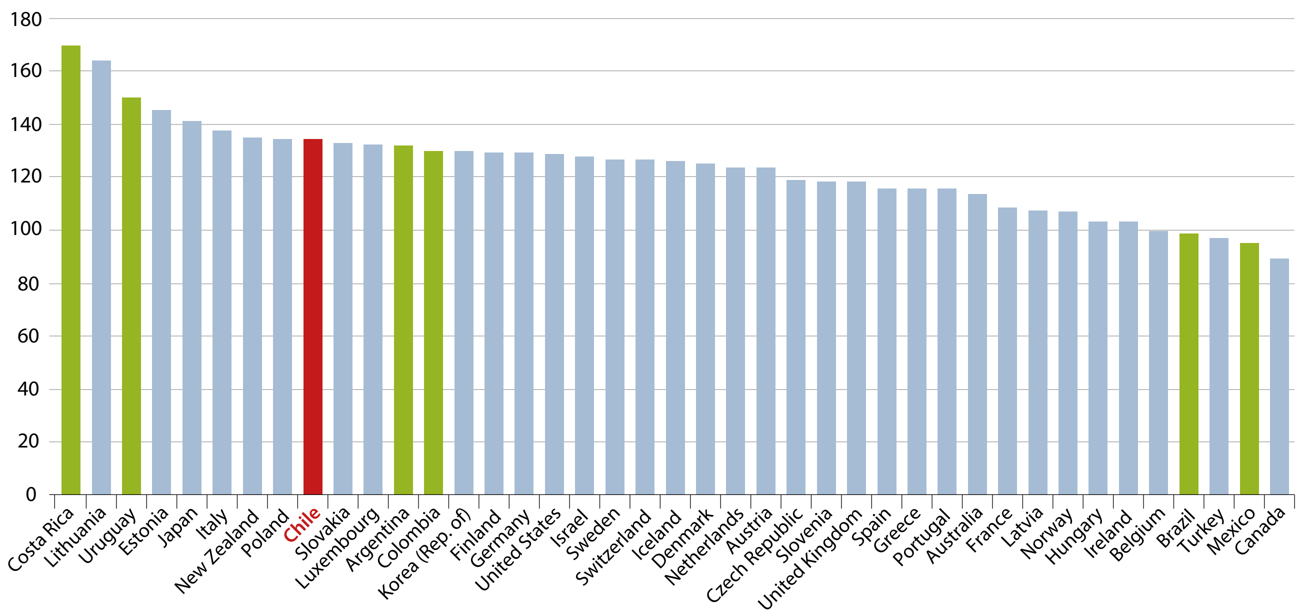


Source: 5GAmericas.

In terms of market performance, the mobile penetration in Chile is higher than in other Latin American countries as of 2018 and even higher than in some OECD member countries. This phenomenon is evident both in terms of voice and, to a lesser degree, data, as set out in Figure 5.3 and Figure 5.4. Chile also has a higher monthly per user consumption of mobile data than the OECD average (Figure 5.5).

Figure 5.3. Subscriptions to mobile services in Chile are high

Mobile subscriptions per 100 inhabitants in OECD countries and selected Latin American Countries – 2018



Source: ITU World Telecommunication/ICT Indicators Database 2019, http://www.itu.int/pub/D-IND-WTID.OL.

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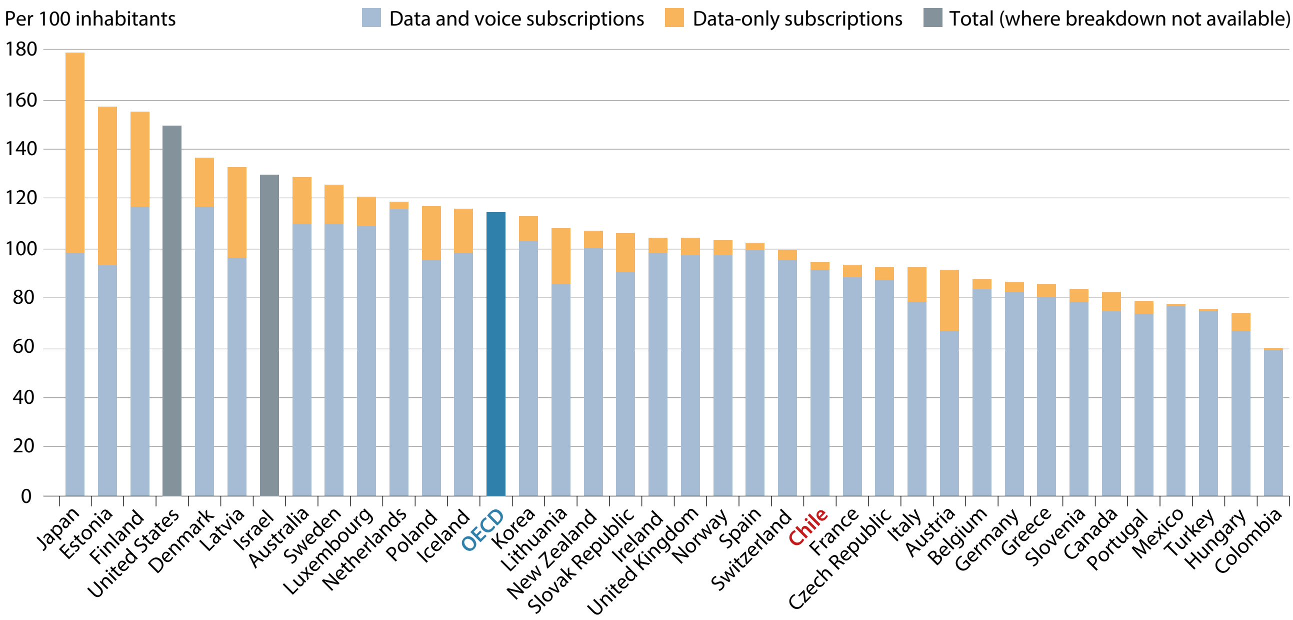
Figure 5.4. Mobile broadband subscriptions are high in Chile compared to other American countries but below OECD average

Mobile broadband subscriptions per 100 inhabitants, December 2019

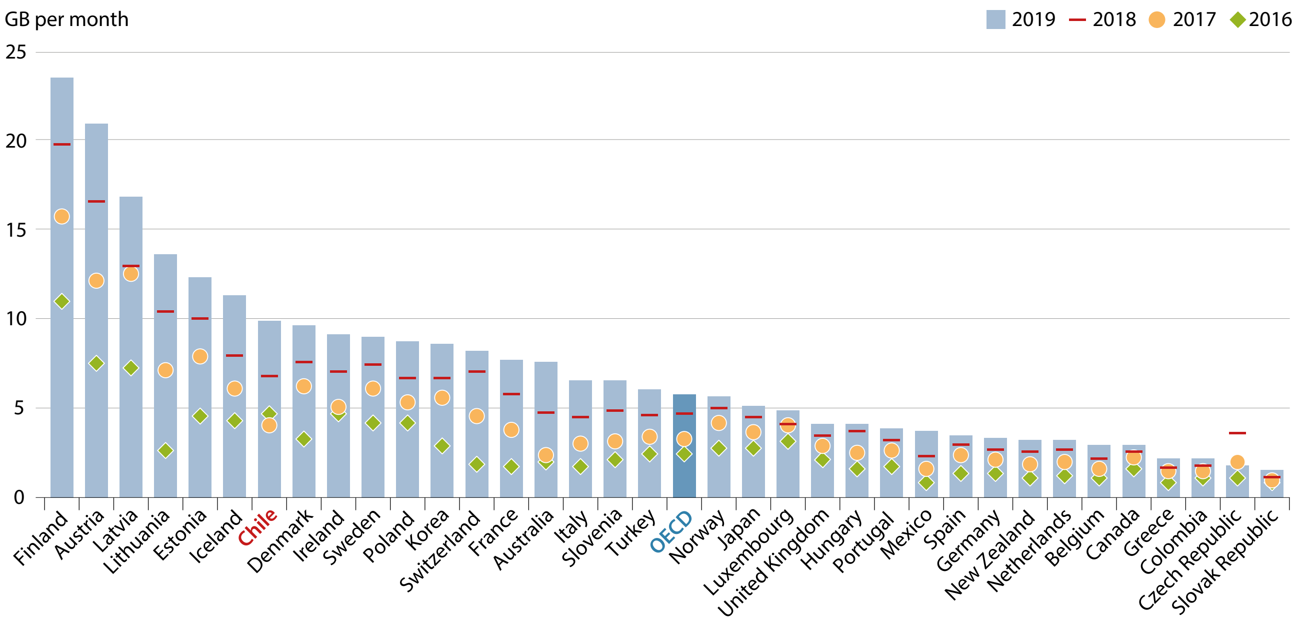


Notes: Australia: Data reported for December 2018 and onwards is being collected by a new entity using a different methodology. Figures reported from December 2018 comprise a series break and are incomparable with previous data for any broadband measures Australia reports to the OECD. Data for Canada and Switzerland are preliminary. Data for United States are OECD estimates.

Source: OECD, Broadband Portal, http://www.oecd.org/sti/broadband/broadband-statistics/

Figure 5.5. Consumption of mobile data in Chile is above the OECD average

Average monthly mobile data usage per mobile broadband subscription, 2016-2019.

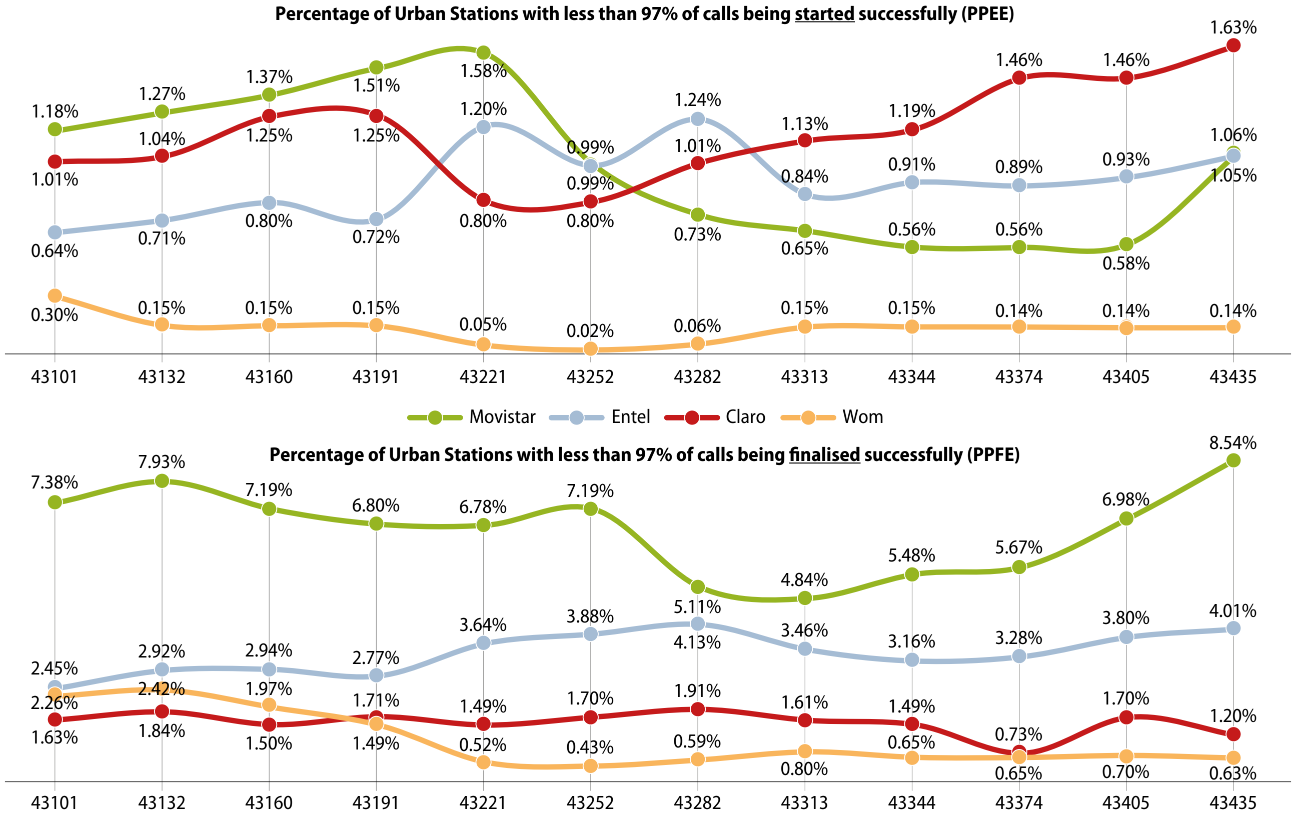


Notes: The multiplier 1024 is used to convert TB into GB; the total amount of GB is divided by the yearly average number of Mobile broadband subscriptions. Australia: Data reported for December 2018 and onwards is being collected by a new entity using a different methodology. Figures reported from December 2018 comprise a series break and are incomparable with previous data for any broadband measures Australia reports to the OECD. Data for Canada and Switzerland are preliminary. OECD average includes estimates.

Source: OECD Broadband Statistics http://www.oecd.org/sti/broadband/broadband-statistics

Figure 5.6. Quality of voice calls is on average relatively high in Chile

Failed calling attempts and dropped calls in urban stations. January – November 2018.



Source: SUBTEL (Information only available until November 2018).

Despite the high mobile penetration, there are differences in coverage with respect to different mobile technologies in each geographical market. This phenomenon is evident when reviewing the coverage maps published by different operators. The technologies available in each city or area and the signal levels differ depending on the region of the country.[19] For example, there are still areas that do not dispose of LTE or have poor coverage in general.

In terms of quality, voice calls have been established successfully, with a relatively high and stable rate in urban areas in 2018. This contrasts with the statistics for successfully terminated calls for some operators, which reflects a lower performance of their networks (Figure 5.6). It should be noted, however, that the measurement unit used is base stations instead of single calls. With respect to mobile broadband services, download speeds show levels below the OECD average, and even lower than those reached by other reference countries in Latin America (Figure 5.7).

Overall, while Chile shows a better performance for some indicators than some of its peers, with respect to the penetration of voice services and the average usage of mobile data, there is room for improvement when it comes to 4G coverage and download speeds.

While multiple factors influence market performance, the way spectrum as a scarce resource is allocated in the market can be considered as a key factor. Therefore, spectrum management should follow a broader vision that focuses on strategic aspects such as extending coverage, ensuring its efficient use and fostering competition in the market, as it is not only relevant for the telecommunication sector but also for the digitalisation of all sectors of the economy and the society.

19. Data from operator websites accessed on June 22, 2020: https://www.clarochile.cl/personas/servicios/servicios-moviles/consulta-tu-cobertura/; https://www.movistar.cl/cobertura-movil-4g; http://www.wom.cl/cobertura/; https://www.entel.cl/landing/cobertura/movil/

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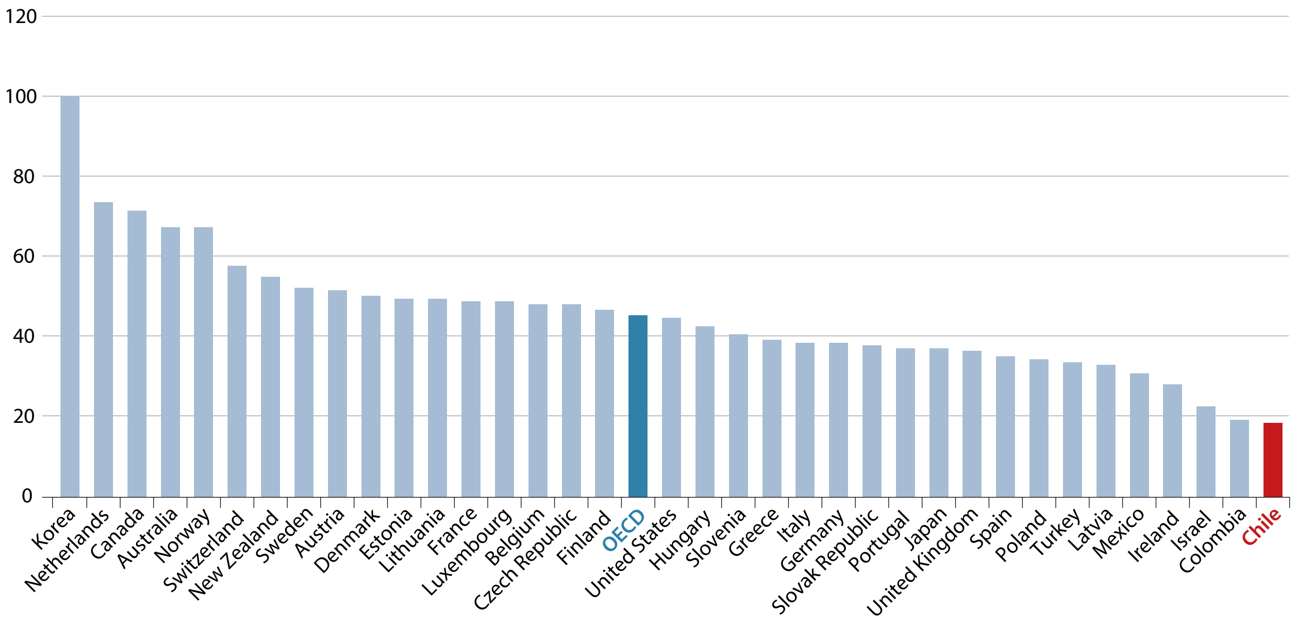
Figure 5.7. Mobile download speed is low in Chile

Average mobile download speed in OECD countries May 2020 (Mbps)



Source: Speed Global Index – Speedtest, https://www.speedtest.net/global-index

This approach has been recognised in the *Digital Agenda 2020 – Chile Digital for Tod@s*, which determines that spectrum management should be aligned with the development of the country and the integration of different demands. The agenda also points to the need to ensure the effective deployment of high-speed communication networks, in order to offer improved voice communications and mobile broadband services. An overarching vision is a prerequisite from a digital transformation perspective and there is the need to implement public policies that not only improve access conditions and reduce digital divides, but also contribute to strengthening other capacities required for the digital economy (OECD, 2019[31]). Transformation strategies should therefore include ways to promote investments in digital tools to increase productivity, the availability of open data and the dissemination of knowledge.

This topic is highly relevant, because in Chile, the spectrum allocation model and the mechanisms available for spectrum block assignments are currently determined by the GTL and are mainly focused on a "comparative selection" scheme. For this reason, these mechanisms have been mainly focused on general *"optimal transmission or excellent service"* criteria and are only considering the possibility of applying an auction model if two or more agents *"offer similar conditions"*. This reduces the possibilities of policy makers to design and develop alternative models of spectrum allocation that have been proven to be successful in other OECD countries, where spectrum auctions are considered the gold standard.

In general, the limitations imposed by law and by the Supreme Court decision, strongly reduce the policy options. Regularly there are four typical approaches for spectrum allocation, namely: (i) auction; (ii) comparative selection; (iii) tender; and (iv) direct assignment. Table 5.5 provides a comparative overview of the former two approaches, given the use of auctions in OECD countries and the comparative selection approach used in Chile.

To date, most OECD countries use spectrum auctions to allocate spectrum. One of the reasons OECD countries introduced auctions for assigning spectrum was to obtain transparent and explainable outcomes. A second reason was to use this as a discovery tool given that, due to their knowledge and experience, industry players are better placed to assess market value. A third reason was that alternative mechanisms for assigning spectrum, such as comparative selection or lotteries, often led to suboptimal outcomes, both in terms of the value captured by successful parties relative to policy objective and due to the fact that sometimes the targets specified in the proposal by the winning party were not always realised (OECD 2014; OECD, 2017). Possible disadvantages include the risk of excessively high fees, which may hinder a faster deployment of communication networks due to limited financial resources of operators.

Table 5.5. Comparison between spectrum allocation mechanisms

Scheme	Characteristics	Potential advantages	Possible disadvantages
Auction	• Definition of blocks and base prices: • Open to multiple qualified actors; • Bid based on economic criteria; • Competitive prices are necessary; • The bidder is financially responsible for their offer, which generates incentives to develop realistic offers.	• Prices defined by the market; • maximization of economic income for the State; • Since supply depends on internal predictions about profitability and market demand, bidders have an incentive to ensure that their predictions are as accurate as possible. • An auction obliges the participants to reveal, via their bids, the future expected stream of profits. Their bids reflect this information. If well designed, the auction will give a clear ranking of operators (OECD, 2001); • Based on relatively simple and transparent rules that apply in the same way to all participants; • Corruption is avoided as final offers are the only thing that matters for the final assignment.	• It can lead to high license fees, hindering a rapid spectrum use; • Increased chance of "winner's curse"* • Increased probability of unassigned blocks; • Risk of transfer of spectrum costs to end user; • Money collected can be used for purposes other than for the telecommunication sector; • Risk of a single company dominating the market if auction is not carefully designed.
Comparative selection	• Definition of minimum conditions to participate; • Open to multiple qualified agents; • Bid based mainly on technical criteria.	• Resources focused on the telecommunication sector priorities; • All participants are obliged to provide the same information and, in theory, the same criteria are used to value offers.	• Spectrum value depends on the State and not on the market; • Information asymmetry can underestimate the resource; • A lower degree of transparency compared to auctions • Past experience has shown that technical targets of the winning proposal were not always realised.

Note: *Situation in which the assignee allocates such a significant volume of resources across the spectrum, which leads him to limit his investment possibilities in the deployment of networks, putting his business model at risk.

Source: OECD.

While the approach of a comparative selection ensures that the resources are typically devoted to the communication sector, the overall price paid for the spectrum tends to be low (or non-existent) under the scheme, which implies that the state is granting a subsidy to private actors (OECD/IDB, 2016[5]). Likewise, comparative selections do not allow a true estimate of the economic value of spectrum resources, since the information between regulatory authorities and operators is asymmetric. In general, auctions are on the rise in Latin America, even though comparative selections have been frequent in the past.

Overall, it is important to highlight that auctions can include coverage obligations and, in an extreme case, can be the only decisive factor such as in the case of the auction of the 700 MHz band for the mobile wholesale network in Mexico, the *Red Compartida*. Several recent auctions in OECD countries have been designed to include important coverage obligations such as the 2018 auction in Mexico and the 2019 auction in Germany (Box 5.1). The last auction in Germany, for example, also included the obligation to connect strategic infrastructure such as major highways, railways and main waterways.

In the specific case of Chile, one factor to be considered is the current legal definition of the spectrum assignment period for 30 years. Such a period is relatively long which makes a comparative selection process complex, in particular with respect to the valuation of the spectrum and the applied technical criteria for a 30 years use, considering the technological changes during this period. The current challenge and discussion around the assignment of the 3.5 GHz band which was initially allocated for a fixed-wireless use, but is now an important band for 5G services is an illustration

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of the complexity. Therefore, the establishment of the criteria that determine the rationale and proportionality of the obligations in a comparative selection process, whether economic or in kind, may be complex.

An additional consideration for spectrum policy is its role in competition policy. Although the mobile telecommunication market in Chile is considered to be competitive, the influence that radio spectrum management has on competition should be paid attention to. Spectrum allocation and management plays a fundamental role for competition, mainly because of three reasons:

1. Being a limited resource and considering that a minimum amount is required to operate, the number of licenses to be granted is very small, which in turn tends to lead to market concentration;
2. Since all spectrum bands are not equal in terms of their technical characteristics, a larger number of base stations is required for higher operating frequencies. This implies larger investments and an impact on costs which might, in turn, affect prices to the end user; and
3. In general, incumbent operators tend to have higher valuations of spectrum compared to new operators, due both to potentially higher returns on investment and higher financing capabilities. This means that if auctions are not appropriately managed, their effectiveness in terms of competition policy may be limited.

An auction should be designed carefully to prevent a single company from dominating the market, and the new spectrum concessions should be designed with the aim of creating a more competitive mobile communication market (see also OECD, 2017[4]). Likewise, all actors involved in this kind of processes should work closely with the competition authority to ensure that the usage of spectrum fosters effective competition. In this regard, the relationship that SUBTEL maintains with Chile's *National Economic Prosecutor's Office*, (Fiscalía Nacional Económica) can be considered a good practice.

Finally, it is necessary to consider the introduction of flexible models for the usage of spectrum. These include spectrum trading, secondary markets and spectrum sharing. In particular, the development of *secondary markets* and *spectrum sharing* rules brings more flexibility and allows for improved market structures and for a more efficient use of spectrum. This process implies the evaluation of possible legal and competition restrictions, as well as technical issues (e.g. interferences) (OECD/IDB, 2016[5]). OVUM Research shows that as of 2018 a number of countries such as USA, Canada, Australia, New Zealand, India have already adopted the secondary markets model and that this is also planned in the Latin American region for Mexico, Guatemala and Dominican Republic.[20]

20. https://static.pisapapeles.net/uploads/2018/07/Asignaci%C3%B3n-y-uso-eficiente-del-espectro-en-Chile-prioridad-en-la-agenda-de-pol%C3%ADtica-p%C3%BAblica-hacia-la-conectividad-total-OVUM-2018.pdf

BOX 5.1 REFERENCE CASES REGARDING AUCTION-BASED SPECTRUM ALLOCATION PROCESSES

Mexico. Based on the auction design developed by the Federal Telecommunications Institute (IFT) in 2018, 6 blocks of 20 MHz in the 2.5 GHz band were auctioned for a 20 years period. As a result of this process, four blocks were awarded to AT&T, while the remaining two were assigned to Telefónica . In this auction, América Móvil, the operator with the largest market share, did not participate due to applicable restrictions of spectrum caps, and because it is currently authorised to use spectrum it has been originally granted in the same band.

Mexico collected MXN 2 100 million (approximately USD 115 million) and managed to balance the available spectrum between operators. Three main mobile market players have now access to the referred band.

Germany. In March 2019, the German regulation authority Bundesnetzagentur opened an auction that included 41 blocks located in the 2.1 GHz (120 MHz) and 3.5 GHz (300 MHz) bands, all intended for the provision of 5G services for a 20 years period.

Among the conditions, participants were required to have coverage with a minimum speed of 100 Mbps at the end of 2022 for 98% of the country's households and on all federal highways, major highways and railways. Likewise, by the end of 2024, service coverage should be extended with the same reference speed in the rest of the country's highways, and at the same time, coverage at 50 Mbps on all regional and federal highways should be offered for the same date, as well as for ports, the main waterways and the rest of the railways. The spectrum auctioned in the 2.1 GHz band will only be available from dates ranging between 2021 and 2026.

By June 2019, and after a 497 rounds process, Deutsche Telekom paid EUR 2 175 million (USD 2 456 million, 130 MHz), while Vodafone's investment reached EUR 1 880 million (USD 2 123 million, 130 MHz). Telefónica paid EUR 1 425 million (USD 1 609 million, 90 MHz), and the entering operator 1 & 1 Drillisch paid EUR 1 070 million (USD 1 208 million, 70 MHz).

5.3 IMPLEMENTATION ACTION PLAN

Reference Framework for Spectrum Management and Spectrum Allocation

POLICY ACTION 9:

Adapt the conditions for future use of the 3.5 GHz band, considering possible reallocation and refarming schemes.

Based on the obligation established in 2018 by the Supreme Court in response to the lawsuit filed by CONADECUS, and also the decision related to spectrum caps by the Supreme Court in July 2020, actions are expected regarding the return of parts of the assigned spectrum by operators in the 3.5 GHz and 900 MHz bands. Given the effect this measure may have on the provision of services by the current assignee operators in both bands, and especially for the 3.5 GHz band, a coordinated action between operators, the Chilean government and the users is required, in order to minimise the expected impact of said measure, taking into account technical and economic aspects.

Regarding the current spectrum assignments in the 3.5 GHz band, considering that SUBTEL has adopted measures aimed at a temporary restriction in its use, it is essential to determine, confirm and applythe criteria established in an effective way in order to reorganise the spectrum as soon as possible and before the next allocation processes related to this band. For the above, the criteria proposed within the last document published for discussion on the spectrum allocation for 5G were specified and quantified.

In addition, SUBTEL's proposal will need to be amended to fully include the provisions of the Supreme Court decision and avoid further litigations. Some legal and regulatory measures that specify terms and approaches might further be needed for an adequate implementation of the decision by the Supreme Court.

The design of the allocation process should strive to foster competition, to also serve as a reference for future spectrum allocations, while also ensuring continued innovation in the market and an allocation of spectrum to multiple operators, promoting that each agent shall use it in the most efficient way. Overall, the spectrum allocation of this important band with a 30 years licence duration should ideally be conducted through an auction, as specified in Policy Action 13.

Objective

Provide and apply clear rules about the future use of strategic bands to close connectivity gaps and provide services under 5G technology.

Actions and Timeframe

- Determine, along with the operators involved, the possible effects of the return of the spectrum in the 3.5 GHz and 900 MHz bands, and evaluate technical alternatives that allow mitigating potential risks.
- If needed, adopt and develop transition plans that minimises the impact on operators affected by the mandatory return of the spectrum in the referred bands, formalising its application by issuing the regulations with the applicable modifications.
- If needed, apply reference parameters for the concrete spectrum reorganisation and potential reallocation proposals with each of the current assignees in the 3.5 GHz band, and advance approaches with these agents to adopt the measures that may take place, if possible, through consensus mechanisms.
- Amend the proposal for the allocation process for the 3.5 GHz band, based on the Supreme Court's decision of 13 July 2020. Prior to the publication of the allocation conditions associated to the 3.5 GHz band, assess the need for further legal or regulatory measures to specify some terms of this decision (for example roaming and spectrum efficiency), in order to provide clarity and investment certainty to the market.

Institutions/stakeholders involved

- SUBTEL – Ministry of Transportation and Telecommunications
- Assigned operators in the 3.5 GHz and 900 MHz bands
- Tribunal for the Defence of Free Competition
- Supreme Court
- User associations

Policy instruments

- Resolutions regarding spectrum assigned, recovered, refarmed and reallocated.

Milestones, Indicators and Evaluation

- Available and assigned spectrum in the 900 MHz and 3.5 GHz bands
- Quality of service offered to users
- Verification of the release of the bands in the different regions within the timeframe
- User surveys regarding the perception of services

POLICY ACTION 10:

Establish transparent and clear strategic guidelines regarding the current and future availability of radio spectrum for mobile telecommunication services in the country, based on projected needs and technological developments.

The development of mobile communication services implies the need to allocate an increasing amount of spectrum to operators offering their services in the country. In order to achieve allocation levels comparable to those observed in other OECD countries, it is necessary to have strategic guidelines that complement the current spectrum planning exercise, which focuses mainly on strictly technical aspects. These guidelines could start by considering the state of the use of frequencies in Chile, and the projection of future demand for additional bands; together with a planning of which bands could be freed for the use by commercial mobile communication services in the next five to ten years. Where possible, the guidelines should also seek to facilitate the processes of migration of other services for which spectrum is used in order to be able to undertake spectrum refarming and freeing additional frequency bands.

Objective

- Have a long-term reference guide for spectrum management that allows the future uses of the radio spectrum to be managed appropriately and with due anticipation, with a focus on the resources required for mobile telecommunication.

Actions

- Develop a diagnosis to assess the current state of use of radio spectrum bands that can be used in mobile telecommunication in a long-term perspective, in the coming five to ten years and beyond, if possible. The analysis should consider a detailed benchmark of best practices of leader developed countries on spectrum assignment. This should become an ongoing exercise after the publication of the first report.
- Develop strategic guidelines that provide an overview of future spectrum needs, possibilities to free spectrum as well as information on future allocations and spectrum assignments, with an emphasis on the spectrum required for mobile telecommunication services. Identify the relevant bands for future mobile technologies in alignment with international developments. Incorporate also the relevant bands for high capacity transport networks.
- Make regular updates to the guide, based on the assignments that are carried out and with the new definitions of bands that can be used in mobile telecommunication in the future (starting in 2024).

Timeframe

- The studies and the development of the initial guidelines document for long-term spectrum planning should be carried out over a period of one year.
- Subsequent updates should be made, at least every time modifications are adopted based on the decisions taken at the ITU World Radiocommunication Conferences.

Institutions/stakeholders involved

- SUBTEL – Ministry of Transportation and Telecommunications
- Telecommunication operators and other possible organisations of spectrum users
- Academic Organisations that address issues related to spectrum use
- International Organisations related to spectrum management, such as the International Telecommunications Union - ITU and the Inter-American Telecommunications Commission CITEL of the Organization of American States (OAS)

Policy instruments

- Long-term strategic spectrum planning guidelines for Chile. If necessary, some specific measures may be adopted by resolution or decree.

Milestones, Indicators and Evaluation

- First version of the guidance document for spectrum planning for mobile services and high capacity transport networks
- Amount of spectrum available for the allocation to mobile services
- Amount of spectrum allocated for mobile services
- Compliance with the allocation plan as defined in the guidance document
- Number of updates of the guidance document

Adjusting the criteria for allocation and use of the spectrum to the needs of a digital economy

POLICY ACTION 11:

Define technical and economic criteria, in order to contribute to the determination of reasonable obligations for the assignees in future spectrum assignment processes for mobile telecommunication services.

According to the General Telecommunications Law, and considering the Supreme Court decision of 13 July 2020, spectrum assignments for mobile telecommunication services have been supplied under the comparative selection model. The reviews of the processes show that, in general terms, coverage obligations are established for geographical areas, as well as the quality of the services offered, which are defined based on the reference technology that is being implemented.

The determination of these types of conditions is based on a direct interpretation of the provisions of the GTL. However, these allocation processes do not involve conducting reference studies for the establishment of the respective conditions, through which it is feasible to estimate, from a technical and economic approach, the cost of such obligations.

Because these studies are not conducted, it is not possible to estimate the impact of these obligations on the business models of the operators. Considering that the respective allocation period is rather long (30 years), this could potentially generate surplus income to the agents which would mean a general subsidy of telecommunication services by the State. It is thus necessary, before each specific allocation process, to have a set of criteria that can be

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applied by the regulator to develop the conditions for the comparative selection model based on a sound technical and economic analysis. In addition, if the comparative selection model is kept in the short run, the regulator should carefully analyse and verify whether the coverage obligations are implemented by operators. In the longer run, however, it is recommended to move to auctions as the main spectrum allocation model (Policy Action 13).

Objective

- Establish bases and criteria to better develop and evaluate the obligations to be imposed on operators in comparative selection processes for the assignment or renewal licenses of spectrum for mobile telecommunication services.

Actions

- Undertake a study analysing the criteria and best practices used internationally for the assessment of spectrum bands for mobile telecommunication services.
- If needed, incorporate the regulations required into the regulatory framework for the implementation of the identified criteria, so that the established rules can be applied on a case by case basis to future allocation processes.
- Strengthen the technical capabilities of the regulatory authority/ies, so that they have the necessary training for an appropriate assessment of the radio spectrum and its value, with an emphasis on mobile telecommunication.

Timeframe

- The definition of the general criteria should be available for all future spectrum assignments in the medium/ long term.
- If it is necessary to design one or several allocation processes in the short term, they must be preceded by specific studies that allow the assessment of the spectrum to be assigned.
- Capacity building must begin as soon as possible and a periodic skills upgrading based on new developments, both nationally and internationally must be undertaken.

Institutions/stakeholders involved

- SUBTEL – Ministry of Transportation and Telecommunications
- Ministry of Economy, Development and Tourism
- Tribunal for the Defence of Free Competition

Policy instruments

- Resolution / Decree with general guidelines
- Future process documents for spectrum allocation

Milestones, Indicators and Evaluation

- Number of sites deployed by technology and by spectrum sub-band
- The existence of guidelines for the evaluation of criteria to design the spectrum allocation
- Variation of annual investment amounts in the mobile telecommunication sector.

POLICY ACTION 12:

Include connecting strategic infrastructure (such as highways and ports) and industrial areas as additional criteria for future spectrum assignment processes.

The spectrum allocation processes for mobile telecommunication in Chile have been characterised by prioritising the geographic expansion of **coverage**, as well as the **quality** of the services offered. These two criteria have been highly relevant and continue to be important, but in light of preparing the digital transformation of the country, additional weight could be given to increasing connectivity for industrial applications and the Internet-of-Things, given that 5G is the first standard that has been created with the Internet-of-Things in mind.

To achieve this goal, it is necessary to consider at least two perspectives. The first one focuses on a greater transversality of telecommunication as a driver for the digital transformation of other sectors of the economy. And the second is that, beyond the basic functionalities of telecommunication, its main value is increasingly reflected in the ability to support a growing number of specific applications. Therefore, it is imperative to ensure that industrial areas and strategic infrastructure such as highways, national roads, ports etc. dispose of high-speed, high quality connectivity. It is thus necessary to implement measures that make it possible to broaden the perspective for obligations in future spectrum assignment processes.

Objective

Connect strategic infrastructure such as highways, national roads and ports that boost Chile's digital transformation. Incorporate specific obligations into future spectrum allocation processes.

Actions and timeframe

- Develop or update studies that determine the level of connectivity in strategic industrial areas and along strategic national infrastructure. Identify existing gaps.
- Incorporate into future spectrum allocation processes, and particularly those related to 5G technology, conditions for the ubiquitous connectivity of national infrastructure and industrial areas in the country.
- Determine the baselines that allow for a clear reference to measure the improvements introduced through digital transformation processes.
- The studies for the prioritisation of strategic sectors should be carried out by SUBTEL and the Ministry of the Economy.
- If it is necessary to design one or several allocation processes related to 5G, it should be ensured that they include a preliminary analysis that identifies, in a general way, which main infrastructures should be given priority in the short term.

Institutions/stakeholders involved

- Ministry of Economy, Development and Tourism
- SUBTEL – Ministry of Transportation and Telecommunications
- Ministry of Public Works (Use of strategic infrastructure projects)

Policy instruments

- Base documents for new spectrum allocation processes

Milestones, Indicators and Evaluation

- Number of connected highways, industrial areas, ports etc by 4G and 5G networks
- Evolution of the state of connectivity of highways, ports, and other infrastructure as well as strategic industrial areas

POLICY ACTION 13:

Create new rules in order to achieve more flexible spectrum assignment and use mechanisms, adapted to future requirements of the society and productive sectors in the country. Ideally, spectrum allocations should be based on auctions.

According to the General Telecommunications Law, spectrum assignments in Chile for mobile telecommunication services are based on a comparative selection scheme. Likewise, the legal framework limits the use of the spectrum to those agents to whom it has been assigned by the regulator.

Although this scheme has addressed coverage and quality needs in the past, it is not the most efficient assignment model for spectrum. Ideally, spectrum allocations should be made based on auctions which can be designed in a more flexible way for each allocation process and according to the country's needs, also in light of the developing Internet-of-Things and the need to collect an ever growing number of devices, besides people. Auctions also allow for a closer determination of the value of the spectrum and for a more efficient spectrum allocation. It is important to highlight that coverage obligations can be a main part or even the main part of an auction, depending on a country's need. For this reason, it is advisable that the government has the possibility to conduct spectrum auctions. In addition, more flexibility should be granted for the allocation of spectrum for the different types of use.

Overall, it is necessary to adapt the rules of spectrum allocation, so that they meet the reality of the country's needs, in order to promote the development of the Digital Economy and contribute to the transformation of strategic sectors.

Objective

Make spectrum allocation schemes more flexible, so that they meet the future needs of the country. Allow for the possibility to undertake spectrum auctions. Additional measures can include, for example, a secondary market for spectrum, spectrum trading and innovative spectrum sharing models etc.[1]

Actions and timeframe

- Advance a review that allows a comparison between the different commonly used spectrum allocation mechanisms and the potential impact of their use for the specific case of Chile, as well as the potential demand for secondary spectrum allocations and use by specific agents. This would be implemented with the purpose of having a reference for the use of these schemes, according to the objectives set by the State.
- Based on the results obtained in the aforementioned study, develop and discuss a draft Law in Congress aimed at allowing for more flexible future spectrum allocation schemes, as well as strengthening the technical capacity of the regulator in this matter.
- The time of approval by the legislature of the bill will depend on the priority with which this initiative is processed in Congress.

Institutions/stakeholders involved

- SUBTEL - Ministry of Transport and Telecommunications
- Ministry of Economy, Development and Tourism
- Spectrum assignee operators for mobile telecommunication
- Potential interested in secondary use of the spectrum
- Congress of the Republic

1. As a reference, in terms of OVUM Research, (https://static.pisapapeles.net/uploads/2018/07/Asignaci%C3%B3n-y-uso-eficiente-del-espectro-en-Chile-prioridad-en-la-agenda-de-pol%C3%ADtica-p%C3%BAblica-hacia-la-conectividad-total-OVUM-2018.pdf) by 2018n countries like USA, Canada, Australia, New Zealand, India were using secondary markets model. Also, in Latin American region, it was planned for Mexico, Guatemala and Dominican Republic.

Policy instruments

- Modify the General Telecommunications Law

Milestones and Indicators and evaluation

- Approval of the Law to make spectrum allocation schemes more flexible
- Quantification of obligations arising from future allocation processes
- Increase in the efficiency of the use of the assigned spectrum, based on the methodology established for this purpose.

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6. Governance of Chile's telecommunication regulator

Regulatory authorities play a crucial role in ensuring that markets function properly and the public interest is safeguarded. Regulators should act as 'market referees' in the relations between political authorities, businesses and citizens. Regulators' ability to fulfil this function is conditioned by having robust governance arrangements, in particular with regard to safeguarding objective, technical and impartial decision-making. Regulators can fail to deliver essential public services if they are unfairly influenced, and any perception of partiality will hinder their capacity and credibility in acting as referees that mediate between actors and their interests. Impartiality and independence come hand in hand with strong accountability and transparency measures for decision-making, which reinforce legitimacy and trust.

This section provides an overview of the governance of Chile's telecommunications sector regulator, the Undersecretariat of Telecommunications (*Subsecretaría de Telecomunicaciones*, SUBTEL). The analysis benchmarks SUBTEL's governance arrangements to other economic sectors in Chile and e-communications regulators across OECD countries. Based on an assessment of the challenges of the current institutional arrangements and sector requirements, it proposes a way forward that includes the creation of an independent technical and economic regulator for the sector and presents avenues to pave the way for its establishment by strengthening the regulatory capacities of the current ministerial regulator. Robust and effective governance of Chile's telecommunications sector will be key for ensuring the efficiency of the sector, in particular in deploying new technologies and infrastructures, such as future 5G connections.

6.1 STATE OF PLAY AND INTERNATIONAL EXPERIENCES

Overview of the governance of SUBTEL

As discussed in section 3.1., SUBTEL's performs a wide range of functions aimed at developing Chile's telecommunications sector. These range from developing and implementing policy for the telecommunications sector to supervising public and private sector operators and monitoring compliance with laws, regulations and standards of sector actors. This gives SUBTEL both policy-making and regulatory enforcement responsibilities over the sector. SUBTEL holds a variety of powers under its regulatory scope of action, including: issuing / revoking licenses; regulating prices (for access charges in fixed and mobile voice calls and other services or activities defined as monopolies by the Competition Court); providing binding guidance on contract terms; issuing industry and consumer standards (technical regulations); enforcing compliance with standards through legal punitive powers for non-compliance and issuing sanctions and penalties. (OECD, 2019[6]) Table 6.1 illustrates which of these functions are conducted jointly with other public entities.

The objectives and functions of the regulator are set in the 1977 Law Decree and SUBTEL updates its strategic programming according to the policy defined by the Presidency of Chile. The priorities of the current administration are put forth in the 2018-2022 strategic plan "*Matriz Digital 2018-2022 Por un Chile Conectado*". They are: to bridge the digital gap and strengthen citizen inclusion; protect consumer rights; increase quality of services; drive market competition in favour of developing the information society; and promote innovation and development of information and communication technologies (Government of Chile, 2019[7]).

Table 6.1. SUBTEL areas of joint competences and action

Public body	Joint area of competence / action
Ministry of Economy, Development and Tourism *(Ministerio de Economía, Fomento y Turismo)*	Joint work on tariff setting Joint work on setting regulation
Competition authority *(Fiscalía Nacional Económica)*	Joint work on definition of areas for regulation
Consumer protection agency *(Servicio Nacional del Consumidor)*	Joint work on resolution of consumer complaints
National television authority *(Consejo Nacional de Televisión)*	SUBTEL supervises television services
Competition tribunal *(Tribunal de Defensa de la Libre Competencia)*	The Tribunal makes rulings on the application of tariff regulation, competition, mergers, etc.
Supreme Court	The Court makes rulings that are relevant to both short and long term policy issues, such as infrastructure and spectrum access regulations, spectrum allocation and competition

Source: Information provided by SUBTEL, 2019

As a centralised organism of the Ministry, SUBTEL is headed by the undersecretary of telecommunication, who is directly appointed by the President of Chile. The President also has the power to dismiss the undersecretary. The appointment process follows practice for ministerial and political appointments in Chile's public administration and takes place without the input of an independent panel. There are no restrictions regarding the employment history of the head of SUBTEL, and technical requirements or competences are not defined in legislation, aside from high level requirements for the position of undersecretary that are not sector-specific. The public administration law (*Ley orgánica constitucional de bases generales de administración del estado*) instates a six month cooling-off period for all senior public officials that also applies to SUBTEL.

The Undersecretariat is entirely funded by the central government budget. Its budget is defined annually in collaboration with the Budget Directorate of the Ministry of Finance (*Dirección de Presupuestos*, DIPRES) and is approved by Chile's National Congress as part of the annual government budgeting process. The funds of Chile's Telecommunications Development Fund (a public financial instrument aimed at promoting coverage of telecommunication services in rural and poor urban areas) are included in the overall budget of SUBTEL, perhaps explaining the wide fluctuations in SUBTEL's overall budget over the years (Table 6.2). While the proportion has tripled since 2016, the budget of SUBTEL in the overall budget of the Ministry remains below 5%. SUBTEL reports that its regulatory enforcement functions (inspections) are largely underfunded. Currently, income from public tenders or any fines or sanctions paid by the industry are not directly used to fund regulation of the sector and is considered as income to the General Treasury of the Republic.

The budgeting process for SUBTEL is separate from that of the Undersecretariat of Transport, the other arm of the Ministry. The two Undersecretariats are functionally entirely separate and do not share any administrative or support services.

Table 6.2. Annual budget of Ministry of Transport and Telecommunication and of SUBTEL, 2016-2019

Expressed in thousands of Chilean pesos (M$)

	2016	2017	2018	2019
Ministry of Transport and Telecommunications	1,012,032,112	1,047,649,923	1,088,317,565	1,112,992,297
SUBTEL	15,608,561	28,103,143	17,449,885	50,573,411
% of SUBTEL budget in overall Ministry budget	1.5%	2.7%	1.6%	4.5%

Source: www.dipres.cl and information provided by SUBTEL, 2019.

Headquartered in Santiago de Chile, SUBTEL is represented throughout the country via the Regional Secretariats of the Ministry. In 2016, its headcount was 256, with 45% female staff. A majority of staff is recruited through a process that includes public vacancy announcements and selection panels. The Undersecretariat is structured into six Divisions: 1) Regulatory policy and studies, 2) Inspections, 3) Concessions, 4) Management of the Telecommunications Development Fund, 5) Legal affairs, and 6) Administration and finance.

SUBTEL is governed by Chile's whole-of-government transparency and integrity laws that include Law No. 18.595 on general public administration (*Ley orgánica constitucional de bases generales de la administración del estado*), Law No. 20,285 on access to public information (*Ley sobre Acceso a la Información Pública*) and Law No. 20,730 on lobbying (*Ley que Regula el Lobby y las gestiones que representen intereses particulares ante las autoridades y funcionarios*). Internally, SUBTEL applies a detailed code of ethics (Code) that lays out the five values of the institution as: professionalism, transparency, efficiency, engagement, and honesty. The Code includes the creation of an ethics committee that can answer queries from staff on conflict of interest or harassment. Moreover, the Code foresees mechanisms for complaints - while these cannot be anonymous, SUBTEL ensures the confidentiality of the complainant. In case of breach of the Code, sanctions can be administered in the form of a warning, fine, suspension or removal from office.

Finally, while it is not required to do so by law, SUBTEL prepares a yearly report (*balance de gestión integral*) that includes a review of the Undersecretariat's main activities and achievements over the year, financial information, reporting on staffing and human resources indicators as well as reporting on performance indicators submitted to DIPRES. The latter are comprised of eleven indicators, summarised in Table 6.3 according to their relevant strategic output. The reports include a foreword that is signed by the Minister of Transport and Telecommunications and are published on SUBTEL's website. The latest available report refers to 2018 (https://www.subtel.gob.cl/quienes-somos/balances-de-gestion-integral/).

Benchmarking SUBTEL's governance to other sectors in Chile

The 2018 OECD Indicators on the Governance of Sector Regulators analysed the governance of 37 telecommunications regulators (34 member countries and 3 non-member countries) (Casullo, Durand and Cavassini, 2019[9]). These include data on Chile and enable a comparison of the institutional arrangements of Chile's e-communications sector with those of other sectors of the economy.

The indicators provide a snapshot of how governance arrangements vary along three key dimensions: independence, accountability and scope of action. The ***independence*** component maps the degree to which a regulator operates independently and without undue influence from both the political power and the regulated sectors. The ***accountability*** component covers the accountability of the regulator vis-à-vis various stakeholders, including the government, parliament, the regulated industry and the public. Finally, the ***scope of action*** component sheds light on the range of activities that the regulator performs, such as tariff-setting, issuing standards, enforcement activities and sanctioning powers. The sectors covered by the Indicators across OECD economies are air, e-communications, energy, rail and water. The scores are on a scale from zero to six from the most to least effective governance arrangements (0= most effective; 6= least effective).

Figure 6.1 compares the average indicator scores for the network sectors included in the indicators: e-communications (SUBTEL), energy (Comisión Nacional de Energía), rail (Ministry of Transport and Telecommunications), air (Dirección General de Aeronáutica Civil) and water (Superintendencia de Servicios Sanitarios). The indicators show a diversity of governance arrangements with respect to the independence, accountability and scope of action components. SUBTEL's ***independence score*** shows that its governance arrangements in this component are further from good practice than those of regulators in the energy, air transport and water sectors. Its ***accountability score*** shows arrangements further from good practice than arrangements in the air transport and water sectors. Its ***scope of action score*** suggests SUBTEL is empowered to perform a broader range of activities than regulators in all of the sectors except for the water sector. This comparison suggests that while SUBTEL is entrusted with more responsibilities than its fellow sector regulators, its governance arrangements are further from good practice when compared to some of its peer regulators.

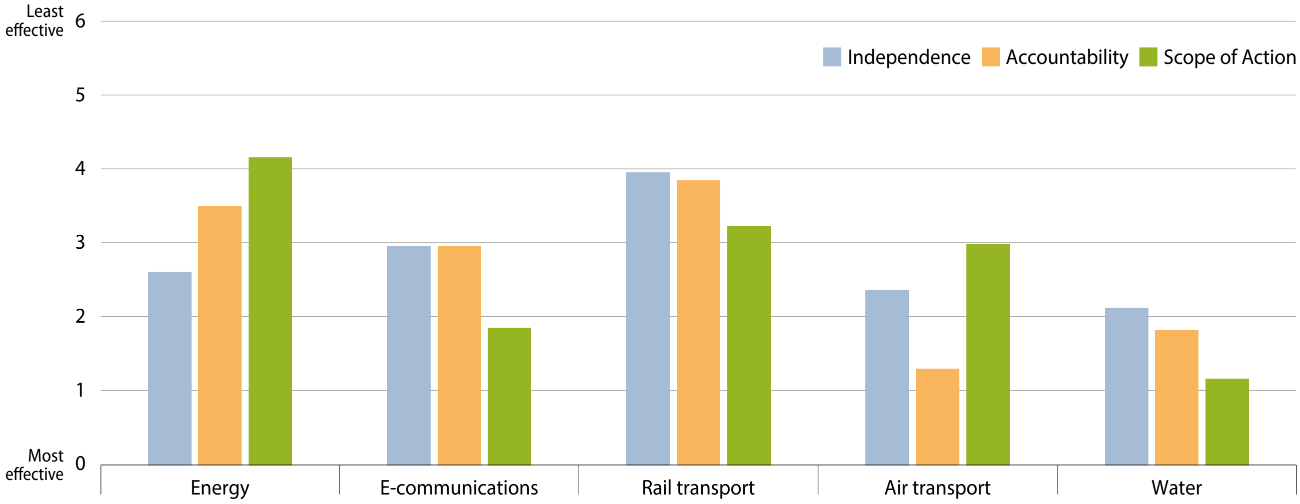
Table 6.3. SUBTEL's 2016 Performance Indicators

Strategic output	Indicator	Formula
Claim resolution and inspections of the telecommunication sector (inspections on services and infrastructure)	Average time to resolve claims filed by users and regulated entities	Number of working days for processing claims in the year t/ total number of resolved claims in the year t
	Average time to resolve repeated claims filed by users against regulated entities	(Number of working days for processing repeated claims in the year t/total number of resolved repeated claims in the year t)
	Percentage of telecommunication users with knowledge of at least one of their rights and obligations	(Number of respondents with knowledge of at least one of their rights and obligations relating telecommunication services in the year t/total number of people surveyed in the year t)*100
Concessions of telecommunication public services, telecommunication and broadcasting intermediaries, permits of limited telecommunication services and amateur radio licences	Average processing time of telecommunication concessions and modification of sound broadcasting	Number of processing time of concessions granted in year t/ number of concessions granted in year t
	Percentage of processing time of limited services permitting (in working days)	Permitting processing time (working days) of telecommunication limited services granted on year t/ number of limited services permits granted during year t.
Legal norms, technical norms, tariff decrees and statistical reports to improve the competitiveness of the telecommunication sector and protect users' rights	Percentage of the population with access to free digital television	(Population with access to free digital television in the year t/total population in the year t)*100
	Percentage of inspected infrastructure sites for addressing emergencies	Number of inspected critical infrastructure sites in the year t/total number of critical infrastructure sites defined by SUBTEL to t-1)*100
	Percentage of penetration of access of fixed and mobile internet	(Fixed internet access + mobile internet access/total of the population)*100
	Price index of a 'basic' internet plan, 15 megabit (USD)	(Annual price of a 'basic' internet plan, 15 megabit/Base annual price of a 'basic' internet plan, 15 megabit)*100
Subsidies of the Telecommunications Development Fund	Percentage of compliance with the milestones of the Austral Fiber Optic project	(Number of executed milestones of the Austral Fiber Optic project in the year t/total number of the Austral Fiber Optic project)*100
	Percentage of the population with free Wi-Fi access (Zonas Wi-Fi ChileGob programme)	(Population with free Wi-Fiaccess in the year t/targeted population of the Zonas Wi-Fi ChileGob programme)*100

Source: (SUBTEL, 2017[8])

Figure 6.1. Compared to some other Chilean regulators, SUBTEL reports fewer good practice governance arrangements for independence and accountability and a broader scope of action

Governance of Sector Regulators' Indicator scores between Chilean regulators



Note: The indicators range from 0 (most effective governance arrangements) to 6 (least effective governance arrangements)

Source: *OECD 2018 Database on the Governance of Sector Regulators.*

Benchmarking SUBTEL's governance to the OECD Indicators on the Governance of Regulators

Analysis of the indicators for the 37 e-communications regulators that participated in the OECD Indicators on the Governance of Sector Regulators shows that, overall, e-communications regulators tend to perform better than other sector regulators in the independence and accountability components. In particular, the e-communications sector ranked as having the second most effective governance arrangements for the independence component and the single most effective arrangements for the accountability component. Across countries, the e-communications sector was also ranked as having the most effective governance arrangements in the scope of action component, indicating that the breadth of actions regulators have is generally broader than in other sectors, as is the case for Chile.

Figures 6.2 to 6.4 show an international comparison of the indicator scores for the participant countries of the Indicators on the Governance of Sector Regulators. As can be seen, SUBTEL's governance arrangements in the independence and accountability components are further from good practice than the majority of participating e-communications regulators. Additionally, SUBTEL's scope of action score suggests that the range of activities SUBTEL is empowered to perform is narrower than that of most other e-communications regulators included in the survey. SUBTEL's independence, accountability and scope of action scores show a gap between SUBTEL's arrangements and those of its peers in OECD countries, which are closer to good practice. The figures map the performance of SUBTEL as per the three aggregate indicators; more detailed data from the OECD Indicators on the Governance of Sector Regulators is used to highlight specific areas or challenges with regard to the governance of SUBTEL in Section 6.2.

Principles and examples of good practice in the governance of telecommunication regulators (Italy, Mexico and United Kingdom)

The governance structures of regulatory authorities vary considerably across countries and sectors and in general, there is no one-size-fits-all that can be put forward as fit for purpose for all country contexts (OECD, 2019[3]). However, good practices for the governance of regulators can be identified (Box 6.1) and important lessons can be drawn from international experiences.

Good practices can contribute to safeguard important features such as independence and accountability (OECD, 2016[10]). For example, arrangements related to a regulator's relationship with the executive (e.g. guidance, separation of competences), staffing (including nomination, appointment and exit of agency heads) and budgeting (including source and autonomy for allocating resources).

BOX 6.1. SEVEN BEST PRACTICE PRINCIPLES FOR THE GOVERNANCE OF REGULATORS

1. Role clarity. An effective regulator must have clear objectives, with clear and linked functions and the mechanisms to co-ordinate with other relevant bodies to achieve desired regulatory outcomes.
2. Preventing undue influence and maintaining trust. Regulatory decisions and functions must be conducted with the upmost integrity to ensure that there is confidence in the regulatory regime. There need to be safeguards to protect regulators from undue influence.
3. Decision making and governing body structure. Regulators require governance and decision making mechanisms that ensure their effective functioning, preserve their regulatory integrity and deliver the regulatory objectives of their mandate.
4. Accountability and transparency. Business and citizens expect the delivery of regulatory outcomes from government and regulatory agencies, and the proper use of public authority and resources to achieve them. Regulators are generally accountable to three groups of stakeholders: i) ministers and the legislature; ii) regulated entities; and iii) the public.
5. Engagement. Good regulators have established mechanisms for engagement with stakeholders as part of achieving their objectives. The knowledge of regulated sectors and the businesses and citizens affected by regulatory schemes assists to regulate effectively.
6. Funding. The amount and source of funding for a regulator will determine its organisation and operations. It should not influence the regulatory decisions and the regulator should be enabled to be impartial and efficient to carry out its work.
7. Performance assessment. It is important that regulators are aware of the impacts of their regulatory actions and decisions. This helps drive improvements and enhance systems and processes internally. It also demonstrates the effectiveness of the regulator to whom it is accountable and helps build confidence in the regulatory system.

Source: OECD (2014), The Governance of Regulators, Best Practice Principles for Regulatory Policy, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264209015-en

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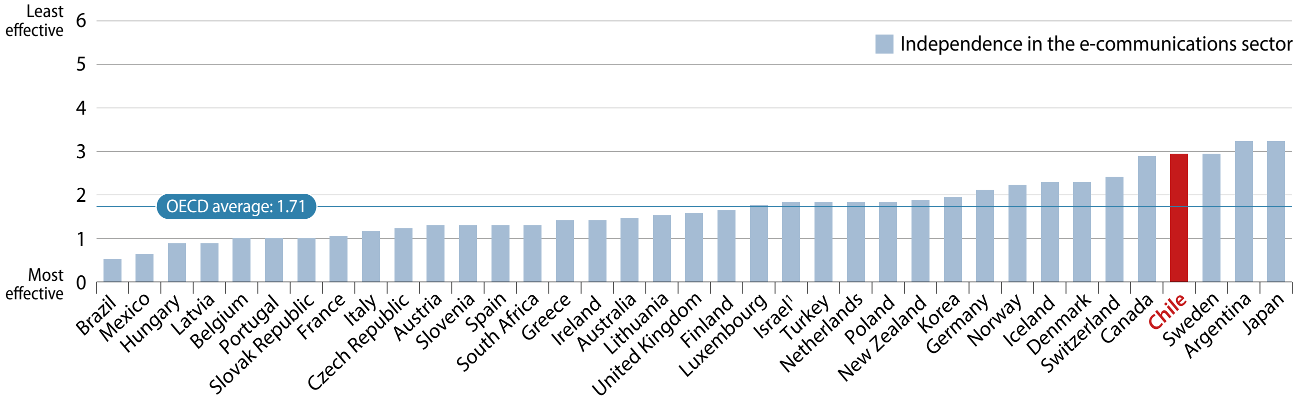
Figure 6.2. SUBTEL reports fewer good practice independence arrangements than the OECD average

Governance of Sector Regulators' Indicators by country, e-communications sector – Independence

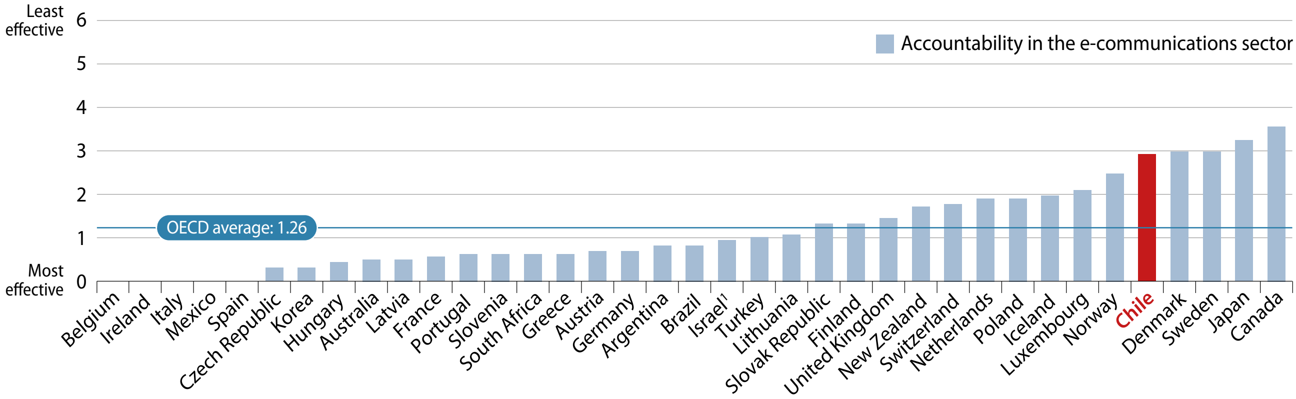


Note: The indicators range from 0 (most effective governance arrangements) to 6 (least effective governance arrangements).

Source: *OECD 2018 Database on the Governance of Sector Regulators.*

Figure 6.3. SUBTEL reports fewer good practice accountability practices are than the OECD average

Governance of Sector Regulators' Indicators by country, e-communications sector – Accountability

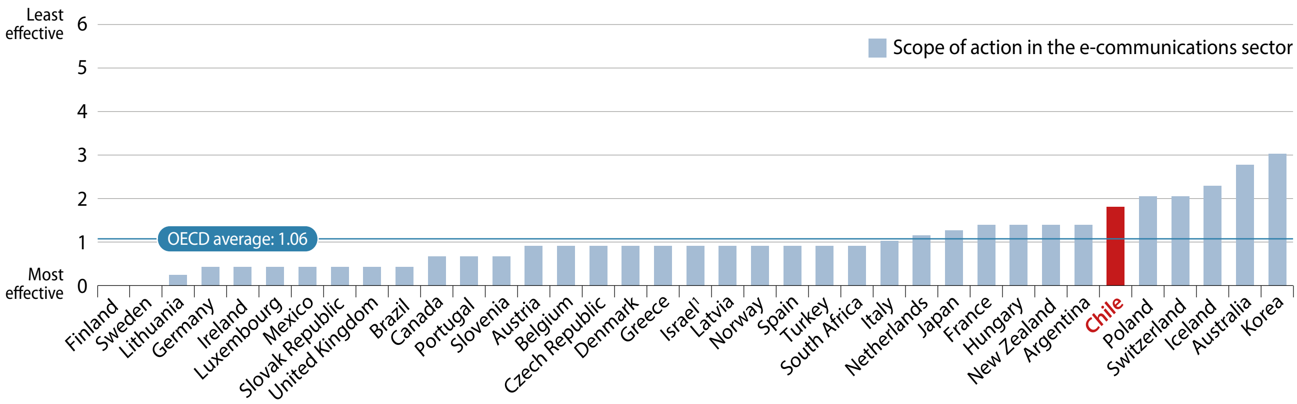


Note: The indicators range from 0 (most effective governance arrangements) to 6 (least effective governance arrangements).

Source: *OECD 2018 Database on the Governance of Sector Regulators.*

Figure 6.4. SUBTEL's scope of activities is relatively narrow

Governance of Sector Regulators' Indicators by country, e-communications sector – Scope of action



Notes: The indicators vary from zero to six from the most to the least effective governance structure. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The OECD average does not include data from the United States and non-OECD members (Brazil, Argentina and South Africa). The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Source: *OECD 2018 Database on the Governance of Sector Regulators.*

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In general, the 2012 OECD Recommendation of the Council on Regulatory Policy and Governance, states that independent regulatory agencies should be considered where:

1. there is a need for the regulator to be seen as independent from politicians, government and regulated entities, to maintain public confidence in the objectivity and impartiality of decisions and effective operation for trust in the market; or

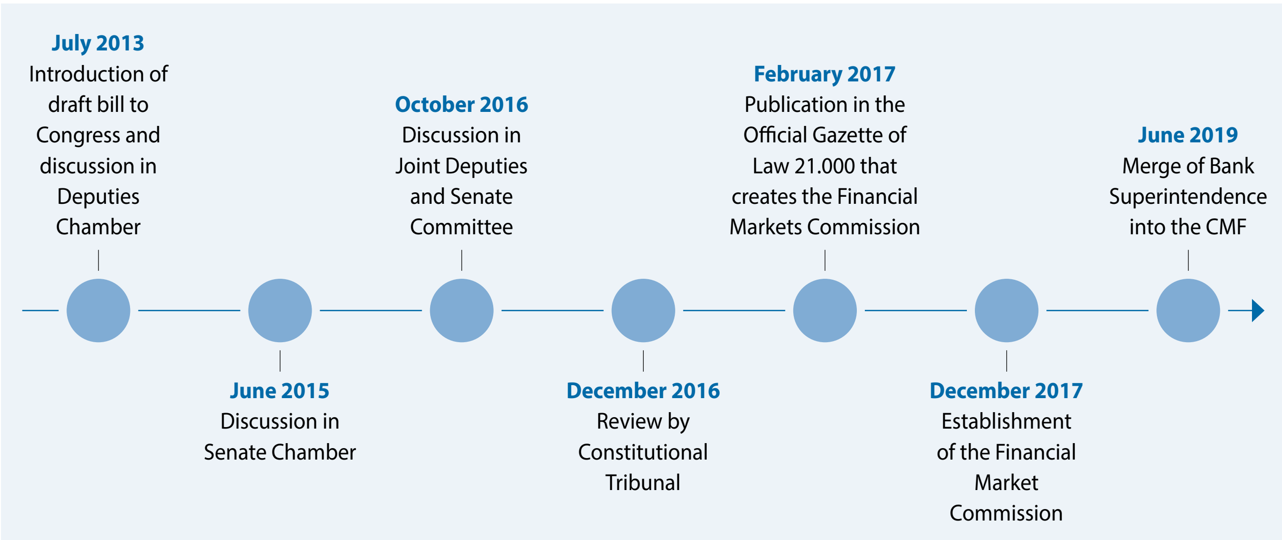
2. both government and non-government entities are regulated under the same framework and competitive neutrality is therefore required; or

3. the decisions of the regulator can have significant impact on particular interests and there is a need to protect its impartiality.

When, in line with these principles, the need for an independent regulatory agency is identified, the agency then needs to be set up in gradual and distinct steps over time. For order of comparison, Figure 6.5 describes the timeline for the creation of Chile's Financial Market Commission (*Comisión para el Mercado financiero*, CFM). (4.5 years from the start of the legislative process to the creation of the agency).

The telecommunications regulators of Italy, Mexico and the United Kingdom exhibit certain good governance arrangements related to independence, accountability and their regulatory practices; Table 6.4 provides an overview of the governance arrangements in selected areas of these regulators.

Figure 6.5. Timeline of legislative process and creation of Chile's Financial Market Commission, 2013-17



Source: (Congreso Nacional de Chile, 2019)

Table 6.4 Overview of governance arrangement in selected countries

Country	Italy	Mexico	United Kingdom
Authority	Authority for Communication Guarantees *(Autorità per le Garanzie nelle Communicazioni, AGCOM)*	Federal Telecommunications Institute *(Instituto Federal de Telecomunicaciones, IFT)*	The Office of Communications, OFCOM
Creation	AGCOM is the Italian communications and media regulatory authority. It was established in 1997 by law 249/97 in order to support the Italian liberalisation of the telecommunication market. AGCOM replaced the former Radio and Publishing Guarantor (*'Garante per la Radiodiffusione e l'Editoria'*) that was responsible for overseeing television and radio broadcasting. The Guarantor was appointed by the President of the Republic and nominated by the Presidents of the two Houses of the Italian Parliament. It had neither regulatory functions nor budget autonomy.	In 2013, Mexico implemented a wide-reaching structural reform that included the aim of modernising its telecommunication and broadcasting sectors, challenging a highly concentrated *status quo*. In June 2013, Mexico's government published a Decree to modify several articles of the Mexican Constitution, including the creation of the IFT as an autonomous constitutional body. In September 2014, the IFT governing statute entered into force. Its creation followed the 2012 OECD recommendations (OECD, 2012[12]) to eliminate the 'double window' by clearly separating competences between the Mexican Ministry of Communications and Transport (*Secretaría de Comunicaciones y Transportes, SCT*) and the former regulator, the Federal Telecommunications Commision (*Comisión Federal de Telecomunicaciones, COFETEL)*. Prior to the reform, both SCT and COFETEL were involved in policy and regulatory activities (OECD, 2017[4])	OFCOM was established under the Office of Communications Act 2002 and operates under a number of Acts of Parliament. These include the Communications Act 2003, the Wireless Telegraphy Act 2006, the Broadcasting Acts 1990 and 1996, the Digital Economy Acts 2010 and 2017 and the Postal Services Act 2011. OFCOM was formally launched in December 2003, inheriting competences of five different regulator (the Broadcasting Standards Commission, the Independent Television Commission, the Office of Telecommunications, the Radio Authority and the Radiocommunications Agency). In 2011, regulatory functions for postal services were transferred to OFCOM.
Functions and powers	AGCOM is the regulatory authority that supervises the telecommunication, television, newspaper and postal services sectors. Its main functions are: • Tariff setting; • To exercise functions as a competition authority; • To impose sanctions. • To protect consumers.	The IFT is charged with regulating, promoting and supervising the telecommunication sector. In addition, the IFT is the competition authority for the telecommunication sector. Its main functions are: • To grant concessions and decide on their extension, amendment or termination. • Tariff setting. • To carry out public tenders for the allocation of spectrum frequency bands. • To exercise competition-related powers in telecommunication services and broadcasting. • To impose sanctions motivated on infringements of laws, regulations or concession titles. • To carry out non-binding public consultation. • To issue guidelines on infrastructure deployment and to develop database of the existing infrastructure. • To define quality service indicators and to publish results obtained while monitoring compliance. *(continued...)*	OFCOM's main legal duties are to ensure that: • the UK has a wide range of electronic communications services; • optimal use is made of the radio spectrum; • a wide range of high quality television and radio programmes are provided by a range of different organisations, appealing to a range of tastes and interests; • people are protected from harmful or offensive material, unfair treatment and invasion of privacy on television and radio; • the universal service obligation on postal services is secured in the UK. OFCOM can enforce consumer law on behalf of consumers but does not have the power to resolve individual consumer complaints about telecoms or postal services, unlike in TV and radio. In addition, OFCOM has competition law powers.

Country	Italy	Mexico	United Kingdom
Functions and powers *(continued)*		• To publish statistical information and metrics referring to the telecommunication and broadcasting sectors on a quarterly basis. • To resolve any disputes relating to content retransmission.	
Strategic planning	AGCOM defines its strategic objectives and annual work programmes independently.	The IFT defines its strategic objectives and annual work plans independently.	Section 2A of the Communications Act 2003 provides the Secretary of State the power to designate a statement of strategic priorities of Her Majesty's Government relating to telecommunication, the management of the radio spectrum and postal services. OFCOM must comply with the statement when carrying out its functions. OFCOM elaborates its work programme independently.
Resources framework	**Budget:** AGCOM is funded entirely by industry fees. The maximum fee is fixed by law. On a yearly basis the regulator proposes a fee which is approved by the Ministry of Economy and the Prime Minister Cabinet (OECD, 2016[10]). The regulator allocates its expenditures independently, within general financial management rules. **Human resources:** The majority of positions are advertised publicly.	**Budget:** The IFT is funded through Mexico's national budget. Following OECD recommendations (OECD, 2012[12]), its funding is autonomous from the Ministry of Communications and Transport budget. The regulator allocates its expenditures independently, within general financial management rules. **Human resources:** The majority of positions are advertised publicly.	**Budget:** The government sets a cap for a period. Within this cap, OFCOM sets an annual budget and the Board approves it. For those costs relating to a specific project that the government has asked the regulator to perform, this is funded through GIA from the Department for Culture, Media and Sport. The Digital Economy Act 2017 allowed OFCOM to keep some spectrum receipts to directly fund the entity. The regulator allocates its expenditures independently, within general financial management rules. **Human resources:** The majority of positions are advertised publicly.
Decision making/ governing body	The Italian Senate and the Chamber of Deputies each elect half of AGCOM's Board members, respectively. The elected members are appointed by a decree of the President of the Republic. The Prime Minister nominates a Chairman, in agreement with the Minister for Communications. The nominee is subject to the binding opinion of parliamentary committees of the Senate and the Chamber of Deputies, which can hold hearings of the nominee. Following a favourable opinion by two thirds of the members of each relevant parliamentary committee, the Chairman is formally appointed by a decree of the President. In 2011, following a spending review, the number of Board members was reduced from nine to five. Board members' mandates last seven years and are not renewable. There are strict incompatibility rules, including the prohibition to perform any type of professional or advisory activity, to be administrator or employed in public or private entities, to hold any type of office, including elected roles or roles at political parties, or interests, also indirect, in sector undertakings. The 'cooling off' period after the termination of the mandate is two years.	The Board comprises seven commissioners who are appointed for a non-renewable nine-year term. The Commissioner President is the head of the regulator. Those aspiring to be appointed as Commissioners need to attest the fulfilment of requirements set in law before an Evaluation Committee composed by Mexico's Central Bank (Banxico), the National Institute for the Evaluation of the Education (INEE) and the National Statistics and Geography Institute (INEGIH). The Evaluation Committee sends to the Executive, a list of candidates that obtained the highest passing grades. The Executive selects one candidate. This decision is sent to the Senate for ratification. The Constitution establishes that Commisioners can be removed because of serious misconduct.	OFCOM has a Board with a Chairman and both executive and non-executive members. The Executive runs the organisation and answers to the Board, while the work of both Board and Executive is informed by the contribution of a number of advisory bodies. There are up to 10 members. The board members are selected by open competition under the Cabinet Office's Governance Code on Public Appointments. The Commissioner for Public Appointments regulates the appointments process. An Independent Panel Member makes the interviews and the Secretary of State makes the final appointment. The Secretary of State for the Department for Culture, Media and Sport ('DCMS') is responsible for appointing the Non-Executive Members to the Board and for approving the appointment of the Chief Executive. Board members can be dismissed through government decisions only in limited circumstances set out in legislation.

Country	Italy	Mexico	United Kingdom
Account-ability and trans-parency	AGCOM is required by law to submit an annual report to Parliament reporting on its activities. AGCOM's Head can be called on to report to the competent parliamentary committees on any matter under AGCOM's competence. AGCOM, like all EU sector Regulators, is also accountable to the EU Institutions, as it is bound to several sectoral rules at EU level. Although not a legal obligation for AGCOM, the authority publishes its strategic objectives within its periodic performance plan and then reports on their fulfilment in a dedicated section of its annual report to the Parliament. In line with legislative requirements, the regulator must publish draft decisions and collect feedback from stakeholders. In addition, the regulator publishes its strategic objectives even with no legislative requirement to do so.	The Commissioner President is required by Law to submit the IFT's annual work plan and quarterly activity reports to the Senate and the Executive. In addition, the agency head can be called upon the Parliament and Executive. Moreover, the IFT has an autonomous internal comptroller appointed by the Chamber of Deputies. Regarding transparency, resolutions and agreements issued by the Board are published in the Federation's Official Gazette. All of the Board's sessions and decisions are published unless they refer to confidential information. In addition, the sense of each commissioner's vote is made public.	OFCOM presents its Annual Report & Accounts to Parliament. OFCOM provides comments on stakeholder responses when it publishes its decisions, and publish how these have been taken into account. In addition, OFCOM publishes on its website all annual reports and plans since 2003 and 2004 respectively.
Examples of the use of regulatory manage-ment tools	AGCOM evaluates the impact of existing regulations when considering new regulatory obligations, either asymmetric (e.g. non-discrimination obligation imposed on Significant Market Power/ SMP operators) or symmetric (e.g., mobile number portability obligations applicable to all market players). AGCOM also carries out public consultation for relevant activities.	Public consultation procedures are mandatory when issuing and amending general rules, guidelines or administrative provisions, unless such disclosure may compromise the effects that the IFT intends to resolve or in emergencies. The IFT provides feedback on stakeholders' comments in line with legislative requirement. In addition, prior to the issuance of rules of a general scope, the IFT must carry out regulatory impact analysis (RIA) in line with Mexico's robust national strategy for regulatory improvement. For carrying out RIA, the IFT co-ordinates with the National Regulatory Improvement Commision (*Comisión Nacional de Mejora Regulatoria, CONAMER*), charged with RIA implementation across Mexico's Public Administration.	OFCOM carries out public consultation. For example, it publishes annual plans for consultation and holds public events for stakeholders in many cities in the UK. The responses are summarised in the plans and attached as an annex. In addition, the Communications Act 2003 requires OFCOM to set up and maintain effective arrangements for consultation with consumers. These arrangements include the establishment of the Communications Consumer Panel, an independent body with the function of advising both OFCOM and other government entities.

Sources: AGCOM (2019), Official Website, https://www.agcom.it/ (accessed 16 December 2020); OFCOM (2019); Official Website, https://www.ofcom.org.uk/home (accessed 16 December 2020); IFT (2019); Official website, http://www.ift.org.mx/ (accessed 16 December 2020); (OECD, 2019[6]); (OECD, 2017[13]); (OECD, 2012[12]).

6.2 CURRENT CHALLENGES IN THE GOVERNANCE OF SUBTEL

The status of the regulator does not match the status of the market

In Chile, the institutional arrangements for the regulation and supervision of the telecommunication sector were devised and implemented in 1977, when SUBTEL was created and when the market was composed of two state-owned operators. The arrangements have not evolved with the transformation of the market, including its liberalisation and the introduction of mobile telephony, mobile, fixed and fibre internet, and pay TV. There have been attempts to modify the institutional governance of the telecommunication sector, the latest with a draft law submitted to National Congress in 2011 proposing the creation of a sectoral superintendency alongside the Undersecretariat. However, no institutional reform has been approved or implemented since 1977 (see Box 6.2).

Moreover, the telecommunication sector is set apart from other sectors in Chile that are supervised by arms-length authorities (*Superintendencias*) (Figure 6.1). In general, the governance arrangements and degree of independence among Chilean regulatory bodies vary widely across the administration and an international comparison shows that Chile differs from institutional practices in most other OECD countries (Figure 6.2). Among Chilean regulators that participate in the Indicators on the Governance of Sector Regulators, the *Superintendencia de Servicios Sanitarios* and the *Dirección General de Aeronáutica Civil* are the only ones that qualify as independent bodies with adjudicatory, rule-making or enforcement powers (OECD, 2019[6]). However, the recent creation of the Financial Market Commission (*Comisión para el Mercado Financiero, CMF*) as an independent agency with a collegial governing body points that the Chilean public administration is maturing towards the model of independent arms-length regulatory bodies found in other OECD countries. Moreover, the 2018 Indicators on the Governance of Regulators, showed that the large majority (84%) of telecommunications regulators in the 37 countries analysed are independent regulators, while only a minority is ministerial (16%).

While there are no public operators in Chile's telecommunications sector, there is a need to bolster the perception of the regulator as being effective and impartial, in particular in the aftermath of recent court decisions to overturn regulator actions and in the run up to the deployment of 5G to the market. More generally, given the strategic importance of the sector for economic development, there is an acute need to ensure that public bodies are able to deliver on their

BOX 6.2. DRAFT LAW FOR INSTITUTIONAL REFORM

On 5 September 2011, the Executive introduced a draft law (BOLETÍN Nº 8.034-1) to create a Superintendence *(Superintendencia)* for the telecommunications sector. It was approved by the Chamber of Deputies in 2013 and moved up for Senate discussion. However, this draft law has not undergone legislative debate since 2014 (the Executive has not marked the bill law as 'urgent' for discussion).

Under the draft bill, this new entity would be 'functionally decentralised' *(funcionalmente descentralizada)* and would have budget autonomy from the sectoral Ministry.

The draft law proposes a separation of competences between SUBTEL and the Superintendence. SUBTEL would remain in charge of the sector policy and the Superintendence would be charged with:

- Enforcement and inspections.
- Imposing sanctions.
- Elaborating technical opinions on concession contracts, as well as permitting and licensing.
- Supervising the correct use of the radio electric spectrum.
- Conducting tariff-setting procedures.
- Collecting relevant data for the telecommunications sector.

Although the creation of a Superintendence could be an improvement to the current model, the draft law focuses on the creation of an enforcement and inspections entity *('organismo estrictamente fiscalizador')* in the terms of Law Decree Nº 3,551, rather than a fully independent regulator (Muñoz, 2019[16]) In addition, the draft law aims to improve sanctioning procedures by introducing a system of administrative appeals. This would require the Superintendency to continue to co-ordinate with a wide range of public bodies and would carry over the fragmentation of regulatory functions for the telecommunications sector.

In addition, leadership would remain unipersonal (the *'Superintendente'*) rather than entrusted to a collegial structure (board of directors). The 'Superintendente' would be nominated and appointed through the National Civil Service proceedings but can be removed at the discretion of the President of the Republic.

Source: (CTT, 2013[17]) (Muñoz, 2019[16]) mandates and to overcome challenges linked to Chile's geographic isolation, high market concentration and regional inequalities.

The concentration of policy, regulation and enforcement functions in one authority creates inherent trade-offs and risks

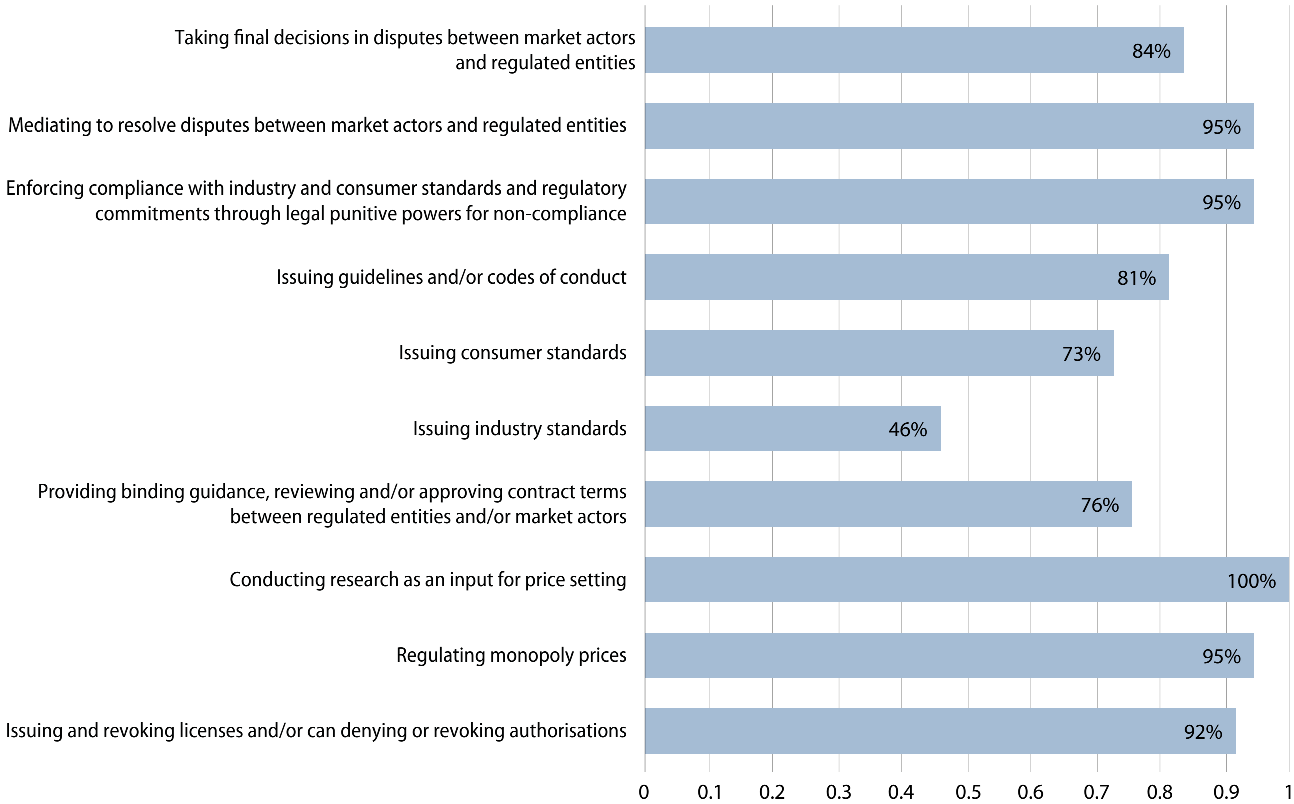
SUBTEL is currently charged with policy design and promoting the development of the telecommunications sector, as well as regulatory and enforcement functions. The Undersecretariat sets its strategic priorities in line with those of the administration and inherent trade-offs exist between its objectives of promoting the development of the sector and supervising its operators. This trade-off is also reflected in resource attribution for policy development between the Telecommunications Development Fund on the one hand, and regulatory enforcement (inspections and sanctioning) on the other, with the latter perceived as lacking adequate resources to be carried out effectively.

As discussed in section 3.1., SUBTEL's regulatory and enforcement functions are broad. It reports performing all of the functions included in the Indicators on the Governance of Sector Regulators (shown in Figure 6.6) except taking final decisions in disputes between market actors and regulated entities and issuing guidelines and/or codes of conduct. Figure 6.6 shows that most other e-communications regulators report performing the same functions (whether individually or with other bodies). SUBTEL is unusual with respect to the issuance of binding industry standards: SUBTEL reports that it does issue these standards while 54% of e-communications regulators do not.

The fact that SUBTEL does not issue guidelines and/or codes of conduct is unusual in a sector where 81% of regulators do. Similarly, SUBTEL is in the minority when it comes to taking final decisions in disputes between market actors and regulated entities (84% of e-communications regulators *do* take final decisions in these disputes).

Figure 6.6. Most e-communications regulators issue guidelines and take final decisions in disputes with market actors

Functions of e-communications regulators as a percent of all answers

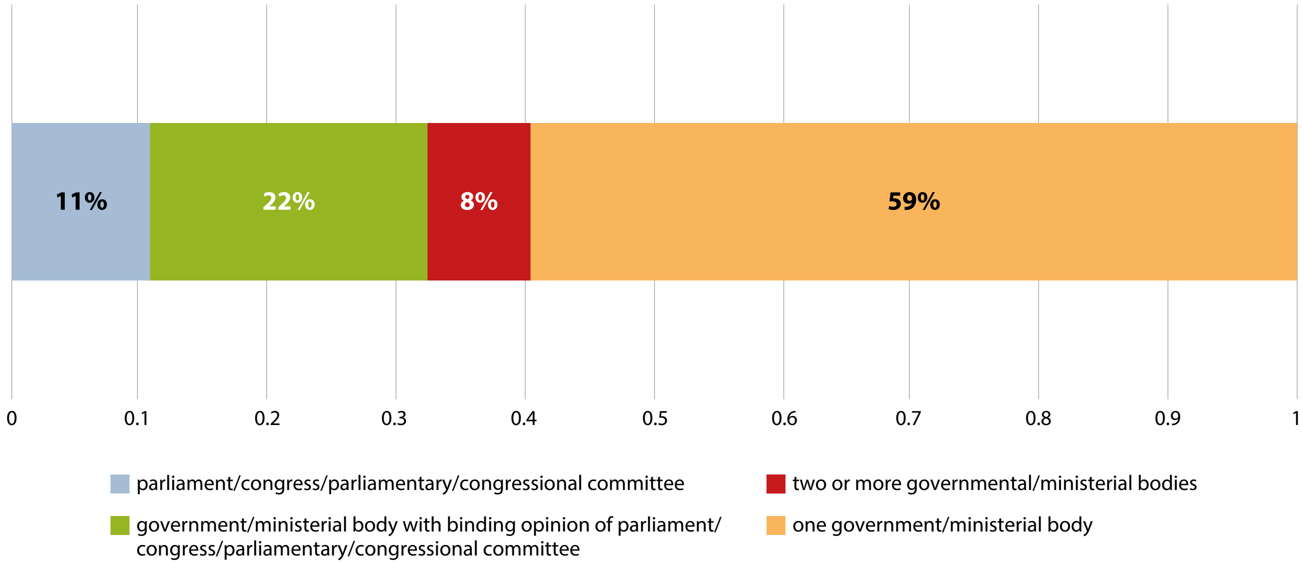


Note: This chart displays the responses for 37 e-communications regulators.

Source: OECD 2018 Database on the Governance of Sector Regulators.

Figure 6.7. A single government body appoints the head of most e-communications regulators

Q: Which body has the legal authority to appoint the agency heads or board members of e-communications regulators? – Percent of all answers



Note: This question was answered as follows in the e-communications regulators surveyed:
– parliament/congress/parliamentary/congressional committee: AUS, ITA, LVA, SVK
– government/ministerial body with binding opinion of parliament/congress/parliamentary/congressional committee: FRA, GRC, HUN, MEX, POL, ESP, BRA, ZAF
– two or more governmental/ministerial bodies: CZE, PRT, LTU
– one government/ministerial body: AUT, BEL, CAN, CHL, DNK, FIN, DEU, ISL, IRL, ISR, JPN, KOR, LUX, NLD, NZL, NOR, SVN, SWE, CHE, TUR, GBR, ARG

Source: OECD 2018 Database on the Governance of Sector Regulators.

The appointment of SUBTEL's leadership and the decision-making process need strengthening

In many OECD countries, regulatory authorities in general are not led by an individual but by a collegial governing board or board of directors (see Table 6.4 for examples from Italy, Mexico and the United Kingdom). The process for selecting and appointing the leadership of the regulatory authority is not only the responsibility of the executive (President or Minister) but the legislative may also be involved. Moreover, OECD Best Practice Principles on the Governance of Regulators propose that mandates of board members are staggered and span over the political cycle. In order to minimise political interference, members of authorities' governing boards have to comply with strict and clear guidelines and policies of conflict of interest (OECD, 2016[18]).

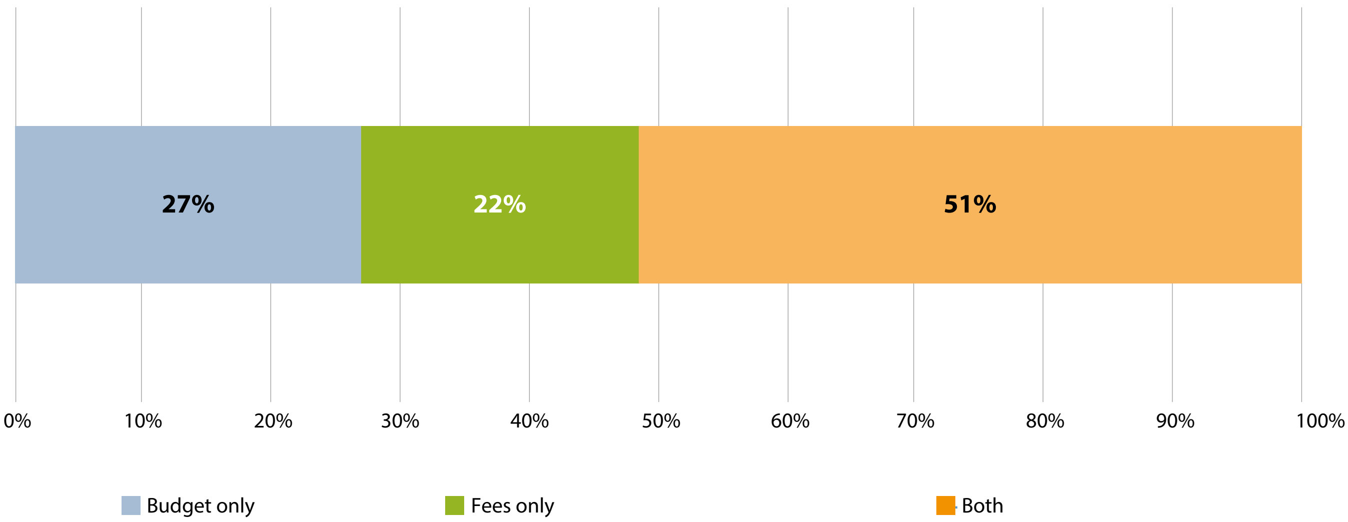
As a ministerial regulator, SUBTEL is led by the undersecretary whose appointment is part of any government's political appointments. As such, a single governmental/ministerial body holds the legal authority to appoint SUBTEL's head. SUBTEL is within the majority here, as 59% of e-communications regulators report the same appointment procedure (Figure 6.7). However, SUBTEL's unipersonal leadership model increases its association to political cycles. The perceived independence, stability and predictability of its regulatory and enforcement regime can be undermined by the political nature of the Undersecretariat as a ministerial body subject to political cycles.

The resourcing framework of SUBTEL seems insufficient for a stable, independent and technical regulator

SUBTEL was created as a new arm of the Ministry of Transport in 1977. It currently only receives under 5% of the total budget of the Ministry, giving it the appearance of the "weaker sibling" of the Ministry of Transport and Telecommunications. Its budget is entirely funded by the government, departing from practices in other OECD countries, where regulatory and enforcement functions are often funded on a cost-recovery basis from fees and levies paid by the industry. The cost recovery model ensures greater stability and visibility in terms of the resourcing of the regulatory authority and provides a certain degree of independence from political interference in the regulator's funding (OECD, 2016[19]).

Figure 6.8. Many e-communications regulators are funded by a combination of government revenues and industry fees

Percent of e-communications regulators funded through budget only, fees only or a combination



Note: This information was derived from responses to two questions. If a respondent answered "not applicable" to the question "If the regulator is financed in total or in part through fees paid by the regulated sector, who sets the level of the fees?," we assumed the regulator was funded through budget only. If a respondent answered "not applicable" to the question: "If the regulator is financed in total or in part through the national budget, who is responsible for proposing and discussing the regulator's budget?",, we assumed the regulator was funded through fees only. If a regulator selected an answer other than "not applicable" for both questions, we assumed the regulator received both budget appropriations and fees.

The e-communications regulators from the countries below fall into the three categories:
Budget only: CHL, CZE, DNK, FRA, DEU, ISR, MEX, POL, SVK, LTU
Fees only: BEL, IRL, ITA, LUX, NZL, PRT, SVN, CHE
Both: AUS, AUT, CAN, EST, FIN, GRC, HUN, ISL, JPN, KOR, LVA, NLD, NOR, ESP, SWE, TUR, GBR, BRA, ZAF, ARG

Source: OECD 2018 Database on the Governance of Sector Regulators.

While the Undersecretariat is perceived to count with technically competent staff, the requirements in terms of specialisation and on-going training for a technical and economic regulator differ from those of a policy institution. Currently, SUBTEL relies often on external consultants for the formulation of technical opinions on regulatory activities, one of its core functions. The rapid transformation of the regulated sectors and increasing data generated by operators highlight the need for technically competent staff and in certain cases, justified departure from government compensation schemes that may not be competitive with private sector salaries.

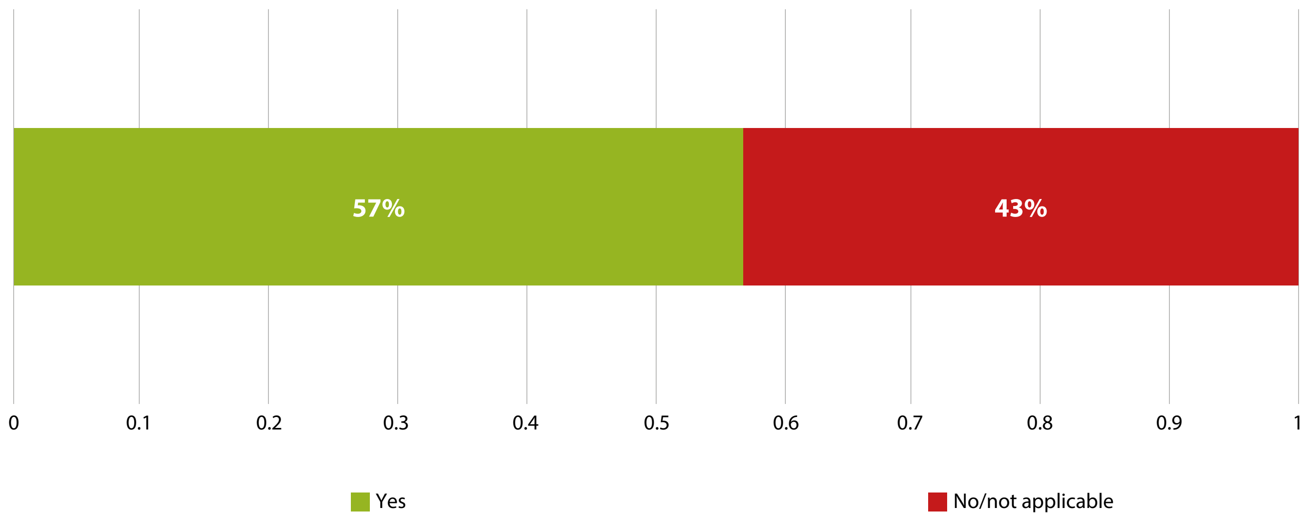
The accountability of regulatory decisions and actions could be increased

SUBTEL currently reports on its performance using strategic objectives and indicators. For these, it sets yearly targets, and publishes its self-assessment in an Annual report (*Balance de Gestión Integral*) on its website. Building on this good practice and institutional culture, the regulator could further develop its strategic planning and reporting system to align reporting with overall strategic objectives, clarifying the narrative of its results, and create opportunities for structured engagement with the legislative branch, regulated entities and consumers.

To maintain accountability to the legislature, OECD guidance states that independent regulators should present a report on their performance to the legislature or legislative oversight committees (OECD, 2014[20]). SUBTEL is not required to do this by law and does not present a report on its activities to Congressional committees. SUBTEL joins a slim minority who do not report in this way to legislative committees, while 57% of e-communications regulators do present a report on their activities (Figure 6.9).

Figure 6.9. Most e-communications regulators present an activity report to parliament

Percent of e-communications regulators presenting a report on their activities to parliamentary/congressional committees



Note: This question was answered as follows in the e-communications regulators surveyed:
– No/not applicable: DNK, SWE, LUX, NLD, CAN, CHL, FIN, ISL, JPN, NOR, POL, CHE, GBR, LVA, SVK, ZAF
– Yes: BRA, NZL, PRT, TUR, LTU, ISR, SVN, FRA, ITA, KOR, AUT, BEL, CZE, DEU, GRC, ESP, IRL, ARG, AUS, HUN, MEX

Source: OECD 2018 Database on the Governance of Sector Regulators.

Moreover, while regulatory reform is a relatively new policy area in Chile, the government has made recent improvements in gradually introducing regulatory quality and policy initiatives, such as those led by the Ministry of Economy (*Agenda de productividad*). The creation of stronger, more specialised independent regulators in Chile would constitute an opportunity for highly specialised authorities to drive forward the regulatory quality agenda. Indeed, in other Latin American countries such as Brazil or Peru, independent regulators have been on the frontlines implementing regulatory management tools (such as Regulatory Impact Assessment or ex-post review) and their experiences in doing so have fed into the development of whole of government regulatory policy. Furthermore, the use of these tools by a strengthened regulator of the telecommunication sector would increase transparency and credibility of decisions linked to the provision of essential services.

Consolidating regulatory functions for the sector would lower co-ordination costs

As stated in Table 6.1, SUBTEL has areas of joint competences or interaction with other public entities. SUBTEL operates within a complex governance system that requires interactions with several public entities, but there are no structured co-ordination mechanisms. SUBTEL regularly interacts with several institutions such as the Ministry of Economy, Development and Tourism (*Ministerio de Economía, Fomento y Turismo*, MEFT) on tariff regulation; the National Service of the Consumer (*Servicio Nacional del Consumidor*, SERNAC) on consumer protection; the National Economic Office (*Fiscalía Nacional Económica*, FNE) on competition matters, the Council for Television (*Consejo Nacional de Televisión*, CNTV), and others. Interaction with other entities is informal and often depends on short-term priorities. However, there are efforts to establish *ad-hoc* working groups (e.g. with SERNAC on inspection activities).

In some cases, these interactions give rise to overlapping functions and conflicts of competencies, which contradict the legal principle of *non bis in idem* and further motivate the need for a single independent authority for telecommunication.

6.3 IMPLEMENTATION ACTION PLAN

Creating an Independent Telecommunication Regulator

POLICY ACTION 14

Set up an independent arms-length economic and technical regulator for the telecommunication sector.

Currently, the governance of Chile's regulatory bodies is irregular across sectors and the public administration. The delivery of the country's policy objectives and the reforms advocated in this report warrant the creation of a dedicated economic and technical regulator with independence from the executive, in line with OECD policy recommendations and practice across OECD member countries. Such a reform of the regulatory governance of the telecommunication sector can provide an opportunity to address the lack of uniformity across the administration and can continue the road towards international best practices started by the creation of Chile's Financial Market Commission (*Comisión para el Mercado financiero*, CFM). The model of Superintendency proposed in the 2011 draft law is not considered fit for purpose, as the Superintendency model of other sectors remains far removed from international best practice and functions resemble those of an inspectorate rather than those of a fully mandated economic and technical regulator.

The creation of such a Telecommunication Regulator (TR) would require the adoption of a law by Congress and its implementation. Two main options are available: 1) the preparation of a new draft law, pre-legislative process, discussion by the legislature and implementation; or 2) a thorough amendment of the 2011 proposal for the creation of a telecommunication regulator.

Objective

- Approval and implementation of law creating an independent arms-length economic and technical Telecommunication Regulator).

Actions

- Prepare draft law, based on work carried out for the 2011 draft and international best practice and defining requirements for a transition phase OR fast track Law Decree 1.762 tabling thorough amendments aligning the agency to international best practice, with particular focus on:
  - functions of TR: separate policy and enforcement functions for the sector and as far as possible, consolidate functions currently distributed among a number of public bodies
  - leadership: move away from unipersonal leadership model tied to political cycles, building in checks and balances and transparency in nominations and appointments and delinking mandates from political cycles
  - resources: introduce concept for (at least part of) funding to be recovered from regulated entities
  - accountability: require TR to report on its results and publish content linked to its regulatory decisions (regulatory impact assessments, stakeholder consultation comments and feedback, outcomes of inspection activities, etc.)
  - co-ordination: ensure efficient and transparent communication and co-ordination mechanisms with other public bodies with responsibilities in the sector
- Lobby for and secure support from the Secretariat of the Presidency to fast track and prioritise discussion of the law in Congress
- Conduct stakeholder consultation on the draft law / amendments
- Carry out analysis of resources necessary for the new regulatory authority to carry out its mandate, benchmarking with similar institutions internationally

Timeframe

- Evaluate which legislative option is best fit for needs of the sector – this decision will define the timeframe and pre-legislative/legislative process

Institutions/Stakeholders involved

- Ministry of Economy, Development and Tourism; Ministry of Justice, Ministry of Transport and Telecommunications, and the General Secretariat of the Presidency
- National authorities for competition, consumer protection, television and the competition court, and other national bodies intervening in the telecommunication sector
- Regulated entities and operators of the telecommunication sector
- Use regional/international networks such as Regulatel and the OECD Network of Economic Regulators as sounding board, for peer experiences and benchmarking

Policy instrument

- New law OR Law Decree 1.762 for the creation of an independent telecommunication regulator
- Guidelines and norms implementing the new law

Milestones, indicators and evaluation

- Completion of draft legislation/amendments to draft legislation
- Approval of draft legislation by both Chambers of Congress
- Completion of secondary legislation
- Creation of the Agency, recruitment of the Board and transfer of staff from SUBTEL
- Time to fast track amended law through legislative process
- Time to prepare related secondary legislation

POLICY ACTION 15

Define and implement a phased approach for the creation of an independent telecommunication regulator.

In parallel to the legislative process, a phased approach for the creation of TR will be necessary to bridge the duration of the legislative process.

Objective

- Ensure gradual transition to an independent TR.

Actions and timeframe

Phase 0: Preparation (TBC depending on chosen legislative approach)

- (Legislative process)
- Update analysis undertaken in 2010-11 regarding separation of functions and resources from SUBTEL to TR based on sector needs. Based on this, map out necessary financial and human resource needs for TR and as far as possible, start advertising positions;
- Build uptake of regulatory management tools such as regulatory impact assessment and stakeholder engagement, including early stage consultations and transparent feedback, in SUBTEL regulatory activities;
- Define an inspections and enforcement strategy that is compliance-focused and takes into consideration risk and focuses on outcomes, and map necessary resource requirements for its implementation;
- Nominate or begin identifying nominees for members of the TR Board, so as to proceed with appointment process of the Board rapidly – transition requirements regarding pre-employment restrictions should apply and the number of board members should be limited to three to five members;

Phase 1: Transition (6 months)

- Creation of Telecommunication Regulator (TR);
- Transfer of functions from SUBTEL and other public bodies to TR;
- Finalise appointment of members of the Board;
- Ensure predictable and transparent co-ordination and information sharing mechanism in place for sector at this crucial stage;
- Begin design of internal processes for predictable and transparent decision making and functioning of TR;
- Define strategic framework including objectives and targets that measure both sector and internal TR performance.

Phase 2: Stabilisation (2 years)

- Implement organisational strategy and monitor the achievement of targets within the strategic framework, and communicate on these in a transparent manner using feedback to reorient or adjust strategic focus;
- At two years from the creation of the agency, implement a scan of institutional functioning and performance for adjustments to internal organisation and management structure and resource allocations;
- Share learning from creation of the independent regulator and its impact on sector performance with Chilean public administration (and in international fora), in the interest of harmonising governance arrangements across sectors in line with international best practice.

Institutions

- SUBTEL
- Telecommunication Regulator (TR)
- Ministry of Economy, Development and Tourism
- Ministry of Finance

Policy instrument

- 2020 and subsequent budgets
- Amendments to laws transferring functions / powers to TR
- SUBTEL internal guidelines on the use of good regulatory practice
- TR internal guidelines and strategic framework

Milestones and indicators

- Creation of TR
- Appointment of TR board members
- Full staff of TR recruited
- Scan of institutional functioning at two years of creation

Evaluation

- Timeliness of regulatory activities by TR (e.g. permits)
- Clarity in understanding of TR role vs other sector actors (Survey of perception of TR by stakeholders)
- Clear institutional mandate and identity (Staff survey)

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Telecommunication is a rapidly growing sector worldwide and a strategic factor of economic development at all levels – from individual firms to regions and countries. The COVID-19 crisis has highlighted the importance of a well-performing telecommunication sector to facilitate teleworking, home schooling and social communication. In Chile, the telecommunication sector has experienced rapid and impressive advances in recent years. Despite significant improvements over time, the digital economy has not yet reached the full potential in Chile. As many other countries, Chile is still facing numerous challenges related to deploying the communication infrastructure; sharing information regarding preferable zones for infrastructure deployment; spectrum allocation; and the governance of the sector.

At the request of the Government of Chile, this OECD Assessment aims at facilitating institutional coordination towards the successful implementation of a number of policy actions to enhance productivity, competitiveness and welfare. It focuses on four areas: 1) ensuring low barrier to entry to the telecommunication market; 2) information management for infrastructure deployment; 3) spectrum management; and, 4) the creation of an independent telecommunication regulator. To help address the cross-sectoral nature of the challenges related to telecommunications, the Assessment was prepared by an OECD multidisciplinary team with experts from the Economics Department, the Directorate for Science, Technology and Innovation, and the Public Governance Directorate. The OECD team worked closely with a number of Chilean institutions, including the Ministry of Economy, the Ministry of Transportation and Telecommunications, and the Subsecretariat of Telecommunications (SUBTEL).

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THE ROAD TO 5G NETWORKS

EXPERIENCE TO DATE AND FUTURE DEVELOPMENTS

OECD DIGITAL ECONOMY PAPERS

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BETTER POLICIES FOR BETTER LIVES

Foreword

This report on "The Road to 5G Networks" was prepared by the Working Party on Communication Infrastructure and Services Policy (WPCISP). It provides an overview of 5G developments, an initial discussion of the implications for communication infrastructure and considers some future regulatory issues. The report focuses on countries' experiences concerning "5G National Strategies" as well as current technological trials. This paper was approved and declassified by written procedure by the Committee on Digital Economy Policy on 3 May 2019 and was prepared for publication by the OECD Secretariat. This report was drafted by Alexia Gonzalez Fanfalone with contributions by Sam Paltridge from the OECD Secretariat and WPCISP delegates regarding their country experiences. It was prepared under the supervision of Sam Paltridge and Verena Weber.

This publication is a contribution to the OECD Going Digital project, which aims to provide policymakers with the tools they need to help their economies and societies prosper in an increasingly digital and data-driven world. For more information, visit www.oecd.org/going-digital. #GoingDigital

Note to Delegations:

This document is also available on O.N.E. under the reference code:

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Executive Summary

The fifth generation of wireless networks, 5G, represents an evolutionary process of previous generations of wireless networks (i.e. 2G, 3G, and 4G). This next generation of wireless technology is intended to provide download speeds of 20 gigabits per second (Gbps), 10 Gbps upload speeds, and latency of one millisecond (ms). This represents download speeds 200 faster (upload speeds 100 faster) compared to current Long Term Evolution (LTE) networks (i.e. 4G), as well as one-tenth the latency of 4G. 5G is being conceived for three use case scenarios: enhanced mobile broadband (eMBB), massive machine type communications (mMTC), and ultra-reliable and low latency communications (ULLC).[1]

The next generation of wireless networks holds potential to stimulate innovation and meet the increasing demands of the digital economy. Industry stakeholders have expressed the view that 5G is not only the next mobile technology, but rather a new approach for converged communication systems that make more efficient use of available resources in their networks, including hardware, software, and spectrum to enable new and better services and applications for businesses and consumers.

5G represents an advance in mobile technology and, as mobile networks can be thought of as providing extensions of fixed networks, it will add to broadband capabilities across all parts of digital economies and societies. For those that see broadband networks as a General Purpose Technology (technologies that benefit and have long-lasting transformative effect on a large segment of the economy), the new capabilities it brings can be used to foster growth and productivity gains across a range of different scenarios and economic sectors. In this sense, 5G may potentially help:

- Support the introduction of new applications and services at higher speeds with lower latency.
- Improve firm efficiency and innovation through increased download speeds of broadband services and the use of more effective cloud solutions that rely on low latency.
- Enable greater use of IoT services and applications (including mission critical services) that may rely on low latency and ultra-reliable broadband, and thus:
    - improve health outcomes through IoT devices that will allow tailored services (e.g. remote surgery) in a timely fashion, and
    - improve industrial productivity through, for example, remote robotics or haptic technology.
- Promote new forms of competition in mobile and fixed broadband markets.

The extent of 5G benefits will ultimately depend on the speed at which 5G will be rolled- out, and how quickly it is taken-up (by both businesses and consumers). In addition, the benefits will be contingent on the evolution of business models, the development of the standards, and the adaptability of the regulatory and institutional frameworks to these developments. Finally, the potential welfare gains of 5G will be a function of the integration of different technologies, and the degree of interoperability of devices and applications.

This report examines what the future of "5G" could mean for communication markets in terms of investment, good practices in spectrum management, competition, coverage and meeting the increasing requirements of the digital transformation. The focus of the report is the description of some country case studies, approaching the issue from a two-fold perspective: 5G national strategies, and technological trials. Finally, a range of questions are considered around the development of 5G network infrastructure in areas such as investment.

The report explores how 5G may represent a paradigm shift, as it is the first standard conceived with the IoT world in mind, where different IoT applications have different capacity requirements. At the same time, industry verticals, as well as enhanced mobile broadband applications, are likely to drive 5G development in its initial stages. Accordingly, given the diversity of use-case scenarios, the network architecture of 5G will have to be flexible to meet different demands. One way to introduce this flexibility is through *network slicing* (Ericsson, 2017[1]). Network slicing is a form of network virtualisation allowing several logical service networks, referred as slices, to be provided over the same underlying physical infrastructure. This would allow different "slices" to deliver different network characteristics. Although this is already available for current technologies, it is likely to be a key feature of the next generation of wireless networks, as core 5G networks make network slicing more effective.

The report points out that many stakeholders have noted that 5G is the first generation of wireless networks where use cases are driving the technological developments, with new trials and partnerships organised to develop usage scenarios and to foster business models for 5G. Indeed, new partnerships are arising, not only among industry verticals and horizontal players, but also among countries. In Europe, a clear example are the 5G corridors (i.e. highways) that involve the collaboration of many European countries in order to prepare for connected vehicles, and in the future with fully automated vehicles that may potentially use 5G.

The report explores two major technological developments that are becoming mature for 5G: beamforming and the use of Massive Multiple-Input Multiple Output (MIMO) arrays. MIMO is a wireless system that uses two or more transmitters and receivers to send and receive data simultaneously. Massive MIMO makes use of base stations (i.e. transmitters and receivers) arrayed with dozens or hundreds of individual antennas. It moves in a somewhat different direction from the current practice of using large cell towers (i.e. macro cells), and instead, Massive MIMO uses a very large number of service device antennas that are operated coherently and adaptively. Beamforming is a traffic-signalling system for cellular base stations that identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process (IEEE, 2017[2]). Beamforming can help massive MIMO arrays to make more efficient use spectrum (IEEE, 2017[2]). In addition, thanks to the new technologies, higher frequency bands, such as millimetre wave (mmWave) bands, can also be used for mobile wireless services. These developments for 5G imply that instead of there being just hundreds of thousands of macro-cells wireless towers, there will be a major increase of cellular sites, or "small cells", worldwide.

While the industry standardisation process for 5G is still ongoing, one evident trend is that 5G networks will require smaller cell sites, complementing traditional large cell towers. That is, although 5G is likely to be deployed in low and mid-frequency bands for coverage reasons, it will also be deployed using mmWave bands for capacity reasons that will require small cells. Small cells will complement the overall network coverage with capacity. As a result, this will require bringing smaller cells closer to connected devices through a process called "network densification". Such cells will need to be connected to backhaul, underlining the need for increased investment in next generation network deployment and access to backhaul connectivity. Therefore, new policy approaches aiming at improving investment conditions to support 5G will be required.

Spectrum is an essential input for wireless communications, and therefore, it is of critical importance for 5G. The spectrum requirements for 5G can be segmented in three main frequency ranges: low frequency bands (<1 GHz), mid-frequency bands (1-6 GHz), and high bands (>24 GHz). A globally harmonised spectrum framework is crucial for 5G as it will enable economies of scale and facilitate cross border coordination.

New regulatory issues arise with 5G, and one main concern for stakeholders relates to power density regulation (or electromagnetic limits in a given location). Other regulatory issues include the implications of "network densification" and "network slicing." Infrastructure sharing agreements among operators are likely to become common in order to mitigate the costs of deployment. The nature of these infrastructure sharing agreements may change as well, as they may possibly relate to deeper forms of network and spectrum sharing (i.e. in the active layer of networks compared to only passive infrastructure sharing agreements). This may cause new competition and regulatory challenges to arise, and communication regulators may have to adapt to this development.

While the technology and business cases are still rapidly evolving, some of the traditional telecommunication regulatory issues will likely become even more crucial and relevant for the successful deployment of this new generation of wireless technologies. As mobile networks become a further extension of fixed networks, due to network densification and improved performance/capacity, these key regulatory issues will include: streamlining rights of way (to deploy massive numbers of small cells and backhaul connecting the cells), efficient spectrum management, deployment and access to backhaul and backbone facilities, and new forms of infrastructure sharing.

The Road to 5G Networks: Experience to date and future developments

1. Introduction

The fifth generation of wireless networks 5G, also commonly referred to as IMT- 2020, represents an evolutionary process of previous generations of wireless networks (i.e. 2G, 3G, and 4G). That is, 5G is the next stage of development from previous and existing radio access technologies. The first generation was intended to offer analogue voice (and has already been phased out), while the second generation represented a jump from analogue to digital with the main usage scenario being voice and simple data transmission, such as SMS. At present there are still 2G networks in some countries, retained to service legacy machine-to-machine connections in addition to the extensive voice coverage, though they have been phased out in others (Telegeography, 2017[3]).[2]

The third generation of wireless networks or 3G, (formally known as the IMT-2000), offered faster data transfers intended for multi-media use, and for the first time, users were introduced to mobile broadband. Innovations in terminal devices followed (e.g. after the introduction of the first iPhone in 2007), which increased the demand for higher download speeds.

After 2010, the fourth generation of broadband wireless networks emerged, 4G (i.e. IMT-Advanced),[3] offering more data transmission capacity, which translated into faster mobile broadband. This was intended mostly to be an improvement to support video streaming, which had been growing rapidly in terms of data per user.

The fifth generation of wireless networks, or 5G, is intended to meet the IMT-2020 specifications. That is, 5G is being developed with three main generic use case scenarios: enhanced mobile broadband (eMBB); massive machine type communications (mMTC); and critical communications/applications (Ultra-reliable and low latency communications, URLLC).[4]

The technological goals for the development of the next generation of wireless networks, 5G, include higher speeds, lower latency, and secure networks that can be integrated with 4G as part of existing MNO networks and other alternative network technologies (3GLTEinfo, 2015[4]).[5] This new generation of broadband wireless networks may represent a paradigm shift, as it is the first standard conceived taking into account IoT, where many billions of IoT devices are expected to be connected, and where different IoT applications have different capacity requirements. In addition, trials in certain countries, such as in the United States, have exhibited the potential of using 5G for Fixed Wireless Access (FWA) in urban settings. In this sense, 5G can be “evolutionary” from previous generations, or become “revolutionary” by providing new options for fixed access in urban areas and for those IoT services that require low latency.[6]

The standardisation process of each generation of wireless networks is a continuous undertaking where a family of standards are agreed by the industry so that they comply with certain specifications, enabling global connectivity and economies of scale. A major player in the standardisation process is the 3rd Generation Partnership Project (3GPP), which regroups seven telecommunication standard development organisations (i.e. ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC). The first phase of the industry-led standard setting process was concluded in June 2018, where the first 5G standard called "5G New Radio" in its "standalone version" was agreed. This first phase of the standard is intended for a scenario of "enhanced mobile broadband" (i.e. 3GPP Release 15), and in its standalone version it means that it does not rely on the core network of existing 4G networks. The second phase is expected to be concluded by the end of 2019, which will be designed to enhance the 5G Ecosystem for massive M2M and critical IoT applications (i.e. Release 16).

While the completion of the second phase of this international industry standard has yet to be agreed for "5G" (i.e. Release 16 should be finalised by the end of 2019), a number of operators have announced trials of the next generation of mobile wireless networks based on Release 15. Among many examples, these include the deployment of advanced wireless capabilities for the Winter Olympics, which took place in February 2018 in PyeongChang, Korea. Meanwhile, field trials are also underway in Japan with a commercial launch aimed for the 2020 Summer Olympics. In Italy, several operators are trialling 5G in several cities including Bari and Matera. In the United Kingdom the government launched the "UK Government's 5G Testbeds and Trials Programme" in 2017 that is set to run until 2021. In the United States, several operators have engaged in 5G trials in urban settings, and tested FWA solutions. Finally, recent developments include the first 5G commercial offers. For example, on 5 April 2019, Korea started to offer commercial 5G services by the three leading operators (KT, SK Telecom and LGU+) using as a terminal device the Samsung Galaxy S10 5G smartphone, with prices ranging from KRW 55 000 (USD 49.97) to KRW 80 000 (USD 72.7) per month (Nikkei Asian Review, 2019[5]).[7] These are just a few examples of country experiences, while a more comprehensive list is found in Section 5 of the report.

To achieve the goals that stakeholders have for the next generation of wireless networks it seems prudent to ask some of the same questions that have arisen with every new generation of mobile wireless technologies. Such questions include deployment costs, competition and coverage issues, and perhaps others that may be novel such as the regulatory solutions required to meet the added degree of complexity with the increasing interaction of players in adjacent markets (i.e. vertical industries). Many believe that "5G" will have smaller cells and require improved and upgraded backhaul networks, including in areas such as along highways and roads. At the same time, as with previous wireless generations, efficient spectrum management becomes key for successful deployment. Finally, it seems clear that fixed and wireless networks are in many ways converging, as this next generation of wireless requires fixed networks to be deployed closer to the user.

This report examines what the future of "5G" could mean for communication markets, good practices in spectrum management, competition, coverage and meeting the increasing requirements of the digital economy. A focus of the report is the description of selected country case studies, approaching the issue from a two-fold perspective: 5G national strategies, and technological trials. Finally, a range of questions are considered around the development of 5G network infrastructure in areas such as investment.

2. The promise of 5G

2.1. The technological promise of 5G

As with every generation of wireless broadband technology, the standardisation process is a critical evolutionary step. Along with spectrum harmonisation, industry standardisation is one of the key enablers, facilitating global connectivity and economies of scale of manufacturing and opening the door for downstream innovations.

The International Telecommunication Union, a United Nations Body, in its Radiocommunication Sector (ITU-R), is in charge of ensuring efficient use of spectrum worldwide by extending international cooperation among all member countries. In particular, ITU-R allocates the bands of the radio-frequency spectrum, and coordinates efforts to eliminate harmful interference of radio stations among different countries. The formal international process to define the IMT-2020 (5G) requirements is led by ITU-R Working Party 5D (Box 1). The improvement of the next generation of wireless networks, *vis-à-vis* 4G (i.e. Long Term Evolution (LTE) networks), includes:

- higher speeds up to 20 Gbps in downlink (i.e. 200 times faster than 4G)
- lower latency (i.e. 10 times lower than 4G), and
- higher density of devices connected per square kilometre (i.e. over a million devices connected per square kilometre) (ITU, 2017[6]).

The 5G standard will have to address a wide range of applications with distinct network requirements, including commercial and industrial IoT. The 5G standard holds the promise of addressing the adaptability networks will require for each of these applications. For instance, Machine-to-Machine (M2M) applications with potentially millions of devices, such as sensors, may require a long battery life, and may not be sensitive to latency issues, whereas fully automated vehicles and remote surgery applications could require ultra-reliability of the network and are both sensitive to throughput and latency issues (Ericsson, 2017[1]).[8]

One of the main challenges to be addressed concerning IoT is to ensure a reliable connection that is interoperable with other devices and networks. In this respect, the 5G standard holds the promise of augmenting IoT capabilities by enabling a higher density of connected devices, longer battery life, lower latency, and ultra-reliable connections (5G Americas, 2018[7]).

While 5G promises a network solution to cope with the growth and diversity of connected devices, the challenge of security risks persists. In this respect, the Release 15 of the standard includes some enhanced digital security features. For example, the encryption of IMSI numbers may render obsolete the fake mobile base stations (i.e. known as IMSI catchers or stingrays), and some stakeholders have mentioned that network virtualisation may reduce the size of the network's target surface mitigating the effects of attacks or network failures. In addition, governments are already working together to establish a common approach to enhance digital security for 5G. For example, on 26 March 2019, the European Commission (EC) recommended a set of operational steps and measures to ensure a high level of cybersecurity of 5G networks across their member States (European Commission, 2019[8]).

Box 1. ITU usage Scenarios of IMT-2020

In 2015 the ITU set forth the "Vision" of the desired capabilities of IMT-2020 (i.e. "5G"), which is set to be more flexible, reliable and secure than previous IMT, with the three main intended usage case scenarios: enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine type communications (mMTC) (ITU, 2015[9]).

On 22 February 2017, the ITU Working Party 5D defined the minimum requirements related to the technical performance of IMT-2020 radio interface, which would represent new capabilities of systems beyond IMT-2000 (i.e. "3G") and IMT-Advanced (i.e. "4G"), (Table 1).

The ITU vision is that 5G networks will be able to provide 20 Gbps of peak theoretical downlink speed and 10 Gbps of peak theoretical upload speed, (i.e. theoretical rates related to the inherent capability of the technology, not what actual users will experience). In addition, some 95% of users should experience at least 100 Mbps.

Table 1. Minimum technological features of IMT-2020

IMT-2020 Feature	Minimum Requirements	Usage scenario to be evaluated	Comparison to 4G (LTE)
Peak data transmission rate	Downlink peak data rate: 20 Gbps Uplink peak data rate: 10 Gbps	eMBB	200 times faster 100 times faster
Spectral efficiency	Downlink peak spectral efficiency: 30 bit/s/Hz Uplink peak spectral efficiency: 15 bit/s/Hz	eMBB	
Latency	4 ms for eMBB1 ms for URLLC	eMBB and URLLC	For URLLC, it is 1/10 the latency of LTE
Connection density	1 000 000 devices per square km	mMTC	100 times the devices

Source: ITU (2017), "ITU-R Working Party 5D, Minimal Requirements Related to Technical Performance for IMT-2020 Radio Interfaces", Feb 22, 2017.

Source: ITU (2017), "ITU-R Working Party 5D, Minimal Requirements Related to Technical Performance for IMT-2020 Radio Interfaces" (ITU, 2017[6]);
ITU (2015), "IMT Vision: Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond" (ITU, 2015[9]);
ETSI (2017), "5G: Study on Scenarios and Requirements for Next Generation Access Technologies (3GPP TR 38.913 version 14.2.0 Release 14" (ETSI, 2017[10]).

2.1.1. Is 5G evolutionary or revolutionary?

5G is both evolutionary as well as revolutionary. It is evolutionary in the sense that, in its initial stages of deployment destined for the usage in enhanced mobile broadband, it will coexist with prevalent 4G networks. Furthermore, many of the technological innovations for 5G, such as Massive MIMO and network slicing, are also backward compatible. The revolutionary aspects of 5G are likely to “kick-in” when the second phase of the standardisation process is agreed upon in 2019. This second phase will be dedicated for usage in massive machine type communications and critical IoT applications that will allow the deeper digital transformation of vertical industries, such as healthcare, Industry 4.0 and the automotive industry, to name a few examples.

Aside from the standards, the realisation of 5G will require major new infrastructure deployment, both in fixed and wireless networks. This includes evolutionary changes such as upgrading existing infrastructure as well as a step change in cell densification requiring not only heavy investment in an abundant number of new cell sites, but also significant new investments in fibre backhaul facilities. The migration towards mainly software- defined radio and core network functionalities will change the way networks are operated and managed. Therefore, regulatory frameworks should be conducive to competition and innovation, as well as continuing to foster incentives to invest in networks.

Finally, it is critical to note that providing telecommunication services relies on the complementary capabilities of different types of network facilities, whether they be fixed backhaul networks, terrestrial microwave networks, or satellite networks (e.g. both geostationary and non-geostationary) (OECD, 2017[11]).[9] In fact, the joint initiative between the European Commission and the European ICT industry called the “Infrastructure 5G Private Public Partnership” (5G-PPP), highlights that, “*the concept of 5G combines various access technologies, such as cellular, wireless, satellite and wireline, for delivering reliable performance for critical communications and improve area coverage*” (5G-PPP, 2017[12]).

Trials around the world are exploring the potential demand of 5G services and the new IoT opportunities that require partnerships with industry verticals. These new business model opportunities are being balanced with the investments (capital expenditures) required by connectivity providers. Some trials described in this report focus on testing new business models by exploring the willingness to pay of users for novel capabilities. For example, in areas such as the automotive sector, there appears to be future demand for low latency and high-speed communication services in the current generation of Intelligent Transport Services (ITS) as the industry potentially transitions to fully automated vehicles.

It is likely that the demand across the entire digital economy will be the main source of industry revenue that drives investment in 5G and the infrastructure needed to support its development. For this to occur, a key element will be the openness of 5G to innovation. Just as the Internet was successful because of its ability to be an open platform for the innovation required to bring new services to market that stimulate demand, then so too will this be the case for 5G.

2.2. The potential benefits: the economic promise of 5G

This new generation of wireless networks, 5G, may hold the potential to stimulate innovation and meet the increasing demands of the digital economy. Industry stakeholders have expressed the view that 5G is not only the next mobile technology; it is also a new approach for converged communication systems that make more efficient use of available resources to enable new and improved services and applications. Innovative technologies (e.g. massive MIMO, beamforming or edge computing), will be deployed to support an effective utilisation of the available network resources instead of a 'one-size-fits-all' system as of today. In this context, the network slicing principle (i.e. a form of network virtualisation allowing several logical service networks, referred as slices, to be provided over the same underlying physical infrastructure), is a particularly innovative approach and inherent to the 5G concept.

5G represents an advance in mobile technology and, as mobile technology can be thought of as providing extensions of fixed networks, it will add to broadband capabilities across all parts of digital economies and societies. For those that see broadband networks as a General Purpose Technology (GPT), the new features it brings can be used to foster growth and productivity gains across a range of different scenarios. In this sense, 5G may potentially help:

- Foster the introduction of new applications and services, at higher speeds with lower latency.
- Improve firm efficiency and innovation through increased download speeds of broadband services and the use of more effective cloud solutions that rely on low latency.
- Enable greater use of IoT services and applications (including mission critical services) that may rely on low latency and ultra-reliable broadband, and thus:
    - improve health outcomes through IoT devices that will allow tailored services (e.g. remote surgery) in a timely fashion, and
    - improve industrial productivity through, for example, remote robotics and haptic technology.
- Promote new forms of competition in the wireless and fixed broadband markets.

The extent of 5G benefits will ultimately depend on the speed in which 5G is rolled-out, how quickly it is taken-up, and how well the regulatory and institutional frameworks adapt to these developments.

Some initial studies have endeavoured to estimate different scenarios of the economic contribution that could be made by 5G networks. According to a study commissioned by Qualcomm, "The 5G Economy", 5G's full economic benefit around the world should be realised by 2035 in a broad range of sectors such as transport, health, education, industrial IoT. However, the study underlines that two thirds of the potential benefits would rely on the second phase of the standardisation process of 5G (i.e. Release 16) that focuses on massive and disperse IoT services and mission critical IoT applications (i.e. massive machine type communications, and ultra-reliable and low-latency communications, respectively) (Campbell et al., 2017[13]).

Meanwhile, a recent report by the Australian Bureau of Communications and Arts research looked into the effect of 5G and productivity, as it will enable a broad range of applications such as robotics and the IoT (Box 2). The report estimated the benefits as well as the costs of deployment, and concluded that 5G could improve productivity across the Australian economy and increase GDP per capita by up to AUD 2 000 (USD 1 492.5) by 2030 (Australian Government, 2018[14]).

Box 2. Economic benefits of 5G: the case of Australia

"*Consumers and businesses consider mobile connectivity essential. 5G, the next generation of mobile wireless network technology, which is expected to commence rollout in Australia from 2019, will improve consumer experiences and business utility through faster data transmission and more reliable connectivity.*

5G also represents a step change from previous generations of mobile technology by enabling lower latency—the time it takes for signals to travel through the network. This gives it a wider range of applications by providing the responsive digital technology required to support innovations such as robotics and the Internet of Things (IoT).

Digital transformation of this scale has long held the promise of improving economic outcomes, and 5G is the next development in continuing the critical enabling capacity of communications services across the economy. However, as with previous technologies, some investment choices are likely to be made when the broader economic and commercial benefits are still uncertain.

5G is likely to improve [multifactor productivity] MFP growth across the economy. This could add an additional AUS 1 300 to AUS 2 000 in gross domestic product per person after the first decade of the rollout. This estimate of the economic benefit is likely to be conservative in that it does not fully take into account the consumer and non-market benefits that are not captured in economic statistics. These include cost and time savings for households arising from 'smarter cities' and the indirect effects from improvements in health services on participation and productivity—both enabled by better mobile telecommunications.

The sharing economy (which harnesses household assets for market production) is also likely to increasingly blur the line between productive and household sectors in terms of the drivers of output, innovation and productivity growth. As with any transformative digital technology, there may also be distributional effects within and between industries, and across society, as resources are reallocated.

A critical determinant of the economic impact of 5G will be the extent to which it is more than an incremental advance on previous mobile technology, or even a more radical shift to a 'general purpose technology' (GPT)—one typically associated with industrial revolutions. There are reasons to suggest that mobile wireless technology may itself be closer to the definition of a GPT, with 5G representing a substantial improvement in what that mobile technology can offer."

Source: Impacts of 5G on productivity and economic growth: April 2018 Working paper, (Australian Government, 2018[14]).

2.2.1. The impact of 5G in vertical industries

5G will have a large impact in many vertical industries. Current trials are concentrating on energy, transport and mobility, health care, agriculture, industry, public safety, environment, tourism and culture. However, this list is not exhaustive and the impact could be extended to other areas. Some selected examples of applications and innovations that may be possible in the next generation of wireless networks are briefly discussed below.

The future of the health and the manufacturing industry: Haptic technology for remote surgery and industrial robotics

Haptic technology enables the manipulation of distant objects. This is accomplished through, for example, a person interacting with a "sensory" remote control device and a machine at a different location. It requires very little latency to work effectively. That being the case, 5G may, enable for the first time this technology to be widely used in a wireless environment. Medical applications that require ultra-reliability in communication networks (besides the low latency requirement) could be one area to take advantage of this technology. In Sweden, Ericsson has an ongoing collaboration with ABB on robotics and remote control engineering with applications on e-health and remote diagnosis (Ericsson, 2018[15]). A further example comes from the United States, where Verizon mentions 5G as a way to develop remote surgery applications (Verizon, 2018[16]).

Healthcare has been positioned as one beneficiary of 5G, with a 2017 Ericsson report predicting a USD 76 billion revenue opportunity by 2026 for operators addressing healthcare transformation with 5G (Ericsson, 2017[17]). In the United Kingdom a number of health applications are being explored through the 5G Testbeds and Trials Programme, including the Liverpool 5G Testbed which is exploring how 5G connectivity can transform patient monitoring, support independent living in the home and the facilitate communication between hospitals and the community (UK5G, 2018[18]).

Automated and connected vehicles

While 'connected cars' have been commonplace for several years, in reality this has largely been about Infotainment and some basic elements of Safety related Intelligent Transport Services. Increasing the levels of vehicle autonomy are likely to make new demands on communication infrastructures. While infotainment will likely continue to be a key consumer service, fully automated vehicles, sometimes called driverless or autonomous vehicles, will generate very large amounts of data that may be transmitted in real time, or when vehicles are stationary (e.g. when garaged or parked).[10] The connectivity requirements for these communication demands may have substantial implications for network infrastructure.

There is a difference in concepts between Autonomous driving, connected driving and automated driving with varying requirements for connectivity. *Autonomous driving* is based on the use of sensors and radar in the vehicle itself (i.e. a vehicle works "autonomously"). Autonomous driving may not rely on the availability of any network. However, with information received through networks, autonomous driving may become more efficient. *Connected driving* refers to vehicles that use connectivity and supports autonomous driving. The major part of connected driving uses ITS (i.e. short-range technology) which establishes vehicle-to-vehicle communication, and connectivity of the vehicle with road infrastructure. In the case of vehicles connected to mobile networks, it is only for special "added value" features of the car such as telematics and "infotainment" (i.e. security relevant driving features do not depend on mobile connectivity in this case). *Automated driving* describes the fact that the driver is getting less and less involved in the driving process (i.e. Level 1 to Level 5 of Automation). For example, Level 5 automation refers to a "fully automated vehicle".[11]

The diverse types of communication purposes of automated vehicles may rely on different technologies. There are three main types of communications for vehicles: vehicle-to-infrastructure (V2I), Vehicle-to-Vehicle (V2V), and vehicle-to-network (V2N) communication. The connectivity behind these communications can be advanced wireless connectivity (i.e. 5G) as well as short-range technology. For example, Vehicle-to-vehicle communication is not necessarily reliant on advanced wireless technologies, as it could also be based on dedicated short range communication technology (DSRC) and Intelligent Transport Systems (ITS) (BEREC, 2018[19]).

It is expected that V2N communication will build upon 5G; while for the cases of V2V and V2I, 5G will perhaps be complementary. For example, the "*CAR 2 CAR Communication Consortium*", involving members such as Volkswagen, Renault and others , are considering to use ITS-G5 in order to promote safety related applications (Car-2-Car Communication Consortium, 2018[20]). Nevertheless, there is an active debate in the European Union over the technology choices, and it is possible that there will be a combination of technologies running in the early stages of deployment of the automated vehicles' landscape.

In addition, 5G may have a more prominent role in the near future. Since 2016, several technology companies (i.e. Ericsson, Huawei, Nokia, and Qualcomm) have started to develop a peer-to-peer wireless technology coined C-V2X ("cellular-vehicle-to-everything") with the potential to warn vehicles about obstacles that cameras and radars might not catch (MIT Technology Review, 2018[21]). The second phase of standardisation process by 3GPP scheduled for 2019 (Release 16) is working on enabling a 5G-New Radio based C- V2X (Qualcomm, 2018[22]).

Intel has expressed the view that for fully automated vehicles to become a reality, data flows in and out of such cars need to be accomplished at faster rates than today's LTE mobile networks. Thus, Intel has pointed out that 5G networks may become the "oxygen" for fully automated vehicles (VB, 2017[23]).

BMW highlights that one of the main challenges for automated driving is that in order to process all the data gathered by sensors, wireless networks need to be further advanced, including with 5G. They say that for Level 5 automated vehicles (i.e. fully automated vehicles), with at least 33 sensors ranging from scanners to LiDARs, 5G networks will need to be in place by 2020 (BMW Blog, 2017[24]). They note that fully automated driving requires downloading very detailed maps in real time, and BMW believes this would require ubiquitous 5G connectivity. Furthermore, connectivity is likely to be important for security reasons, placing further demands on networks. By way of example, BMW says their vehicles need to be connected to a back-end so that, in the event of a security attack or vulnerability being detected, an encryption update can be automatically provided on more than 10 million vehicles within 24 hours (CarAdvice Australia, 2017[25]).

There have been several trials testing 5G technologies on connected vehicles. For example, in February 2017, SK Telecom achieved 3.6 Gbps data transfer speeds when successfully testing their 5G network with a BMW connected car running at 170 km/h using the 28 GHz spectrum band (ZDNet, 2017[26]). In May 2017, Ericsson, in one of Verizon's 5G trial networks, made use of beamforming technology (i.e. a traffic-signalling system that identifies the most efficient data-delivery route for cellular base stations) in moving vehicles during the Indianapolis-500 race week. This trial attained download speeds of 6 Gbps (ZDNet, 2017[27]). More recently, in February 2018, SK Telecom in Korea and Telefónica in Spain tested 5G-V2X communication technologies in their fully automated driving trials. SK telecom plans to bring vehicles with 5G-V2X technology to major Korean highways by 2019 (VentureBeat, 2018[28]).

In the future, automated vehicles making use of 5G networks may require the establishment of new partnerships among countries. In light of this, in April 2018, a number of European countries signed agreements to establish cross-border 5G corridors for connected and automated driving. This builds on an existing agreements (signed in 2017) between 27 EC member States to conduct cross-border 5G trials (Mobile World Live, 2018[29]).[12]

An example of a 5G corridor is the one signed May 2018 by Greece, Bulgaria and Serbia for the creation of an experimental cross-border *Balkan Corridor* that will provide testing of connected and automated cars to Western Europe using 5G technology. Likewise, in September 2018, Lithuania, Latvia and Estonia signed an agreement for the "Via Baltica- North" initiative to develop an experimental 5G cross-border corridor. New trials are expected to be conducted in 2019 to test Level 3 (out of 5) of automation of vehicles. 5G- PPP has launched a call for proposal to fund up to EUR 50 million (USD 58.8 million)[13] for experimental projects in three 5G European cross-border corridors: the Brenner path between Bologna and Munich (Italy-Austria-Germany), Metz- Merzig- Luxembourg (France-Germany-Luxembourg), and Porto-Vigo and Evora-Merida (Portugal-Spain) (European Commission, 2018[30]).

New partnerships, as the 5G corridors described above, are likely to become important with the deployment of 5G and the prevalence of fully automated vehicles. For example, the International Telecommunications Users Group (INTUG) has highlighted that frictionless cross-border 5G ecosystems are crucial for IoT devices that are mostly agnostic of national borders.

Virtual Reality (VR), Augmented Reality (AR) and Mixed/Merged Reality (MR)

Virtual Reality (VR), Augmented Reality (AR) and Mixed/Merged Reality (MR) technologies are set to benefit from the consistent throughput, higher capacity and low latency provided by 5G. VR experiences immerse users in a fully-computer generated world. AR experiences overlay digital information onto the real world of the user, whereas MR experiences are those in which the real and virtual worlds are intertwined, allowing for an interaction with and manipulation of the physical and virtual environment. A recent Intel report estimates that 5G will unlock the potential of AR and VR, creating more than USD 140 billion in cumulative revenues between 2021 and 2028 (Intel, 2018[31]).

There have been several trials demonstrating the potential of 5G for AR, VR and MR. For example, in the United Kingdom the Smart Tourism project is delivering enhanced visual experiences for tourists using AR and VR in major attractions in Bath and Bristol. As part of this project, the BBC and Aardman Studios are collaborating to provide an experience at the Roman Baths in Bath. They will use a position-orientated mobile device rendering the user's viewpoint as a 'Magic Window' in real time, allowing them to witness key moments from the history of the Baths such as its discovery in pre-Roman times and Victorian-era excavations (BBC, 2018[32]).

Mining

The next generation of wireless networks, 5G, could enhance the applications that increase safety and productivity in mining. The use of IoT and 5G in mining may provide new business opportunities, and provide innovations that may transform the mining sector. For example, embedded sensors in ventilation systems and rock bolts, "smart" management of stock, and preventive maintenance, are all examples of where IoT can be applied in areas that may increase safety and productivity in mines. Perhaps one application with a more transformative impact in mining is the remote operation of machinery. Many companies are already switching to LTE, as opposed to using Wi-Fi, in mining activities because of wide coverage and data throughput (Mobile Europe, 2017[33]). It is expected that 5G will further enhance the capabilities of IoT in mining.

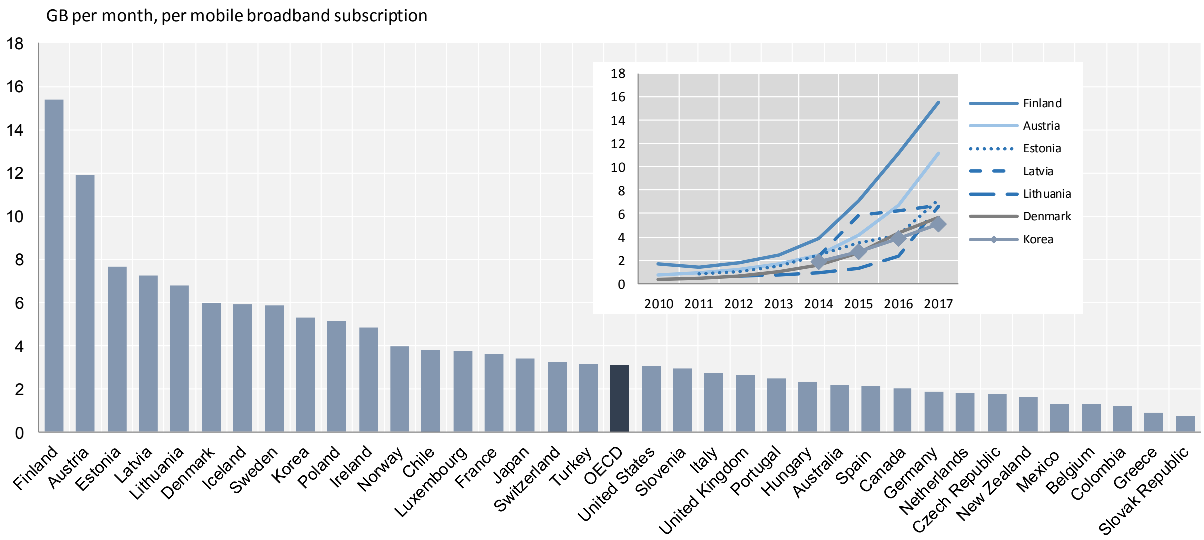
Some trials in mining have been underway. For instance, a cross-industry consortium (composed by Telia, Boliden, Ericsson, Volvo, ABB, RISE SICS and LTU) joined forces for the Industrial Mobile Communication in Mining (PIMM) project, with the aim of testing how mobile connectivity can make mines safer. In August 2017, this consortium tested 5G technology for safety communications in the Kankberg underground mine in Boliden, Sweden (RR Media Group, 2017[34]). Among other things, the trial showed how wireless-cellular connectivity within mining environments could help in the use of remote control machinery (Mobile Europe, 2017[35]).

2.2.2. The benefits of 5G and new forms of competition in mobile and fixed markets

More and more throughout the OECD, mobile networks, at their core, become an extension of fixed networks. This trend is even more acute in 5G as it is becoming increasingly critical to deploy fibre further into fixed networks to support increases in speed and capacity to connect small cell deployment ("network densification"). The expansion of fixed networks with sufficient capacity to support all types of access technologies becomes crucial as fixed networks can be used to more effectively take on the 'heavy lifting' of the increasing demands on wireless networks, especially where radio spectrum is scarce.[14] As data-usage per mobile broadband subscription continues to grow in the OECD, alternative access paths that allow the offloading of data reduces the amount needing to be transferred across cellular bands, thus freeing spectral capacity to improve mobile access (Figure 1).

Figure 1. Mobile data usage per mobile broadband subscription, 2017

RHS: Evolution of top OECD countries in mobile data usage per mobile broadband subscription, 2010-17



Note: The graph includes updated data for Mobile broadband subscriptions (2016 and 2017) and Mobile data volume/usage (2017) as well as the changes in the methodology (multiplier 1024 is used to convert TB into GB; the total amount of GB is divided by the yearly average number of Mobile broadband subscriptions).
Source: OECD, Broadband Portal, www.oecd.org/sti/broadband/oecdbroadbandportal.htm

Therefore, with the network densification brought about with 5G, and the exponential increase of data traffic, the core infrastructure of both fixed and mobile networks will continue to be complementary. For example, in 2016 about 60% of data used on mobile

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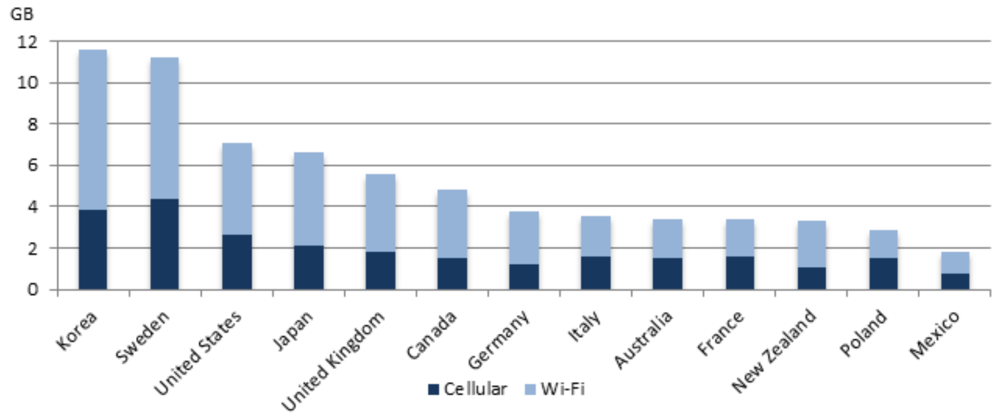
devices in OECD countries off-loaded traffic onto fixed networks through Wi-Fi or femtocells (OECD, 2018[36]; CISCO, 2017[37]).[15] For countries like Korea or Sweden, in 2016 this Wi-Fi off-loaded traffic represented 67% and 61% of the total data traffic per mobile broadband user per month, respectively (Figure 2).

Figure 2. Total data per mobile broadband user (smartphone) per month (GB), 2016

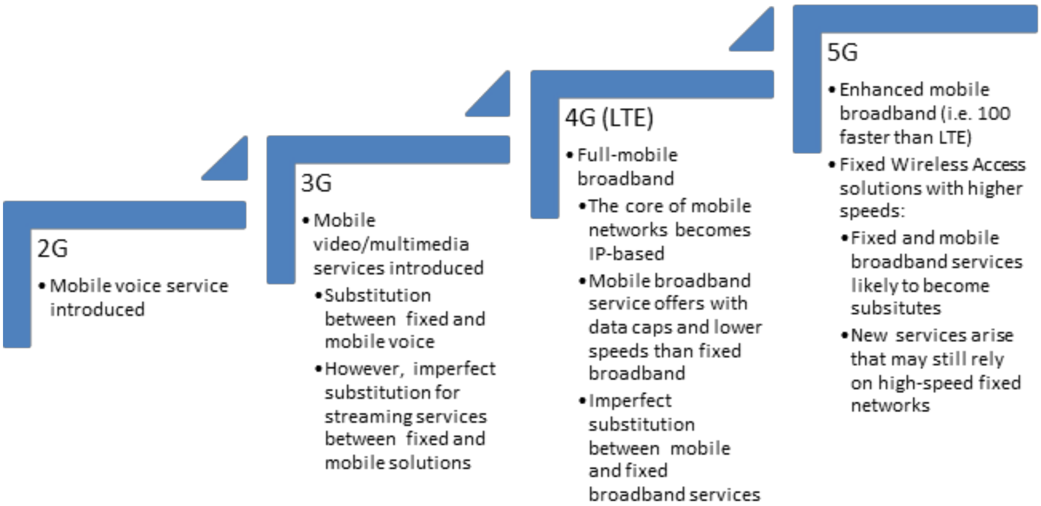
Mobile Traffic disaggregated by the Wi-Fi Offloaded traffic and Cellular network traffic



Note: Offload Wi-Fi traffic calculated using CISCO VNI data of percentage of Smartphone offloaded traffic.
Source: OECD (2018) "Digitalisation Review of Sweden" using CISCO VNI and OECD Broadband Portal.

In the past, communication networks across the OECD were typically stand-alone endeavours, with separate firms and business models operating on independent fixed, wireless and broadcasting networks. With convergence of fixed and wireless networks, both fixed and mobile networks will continue to play a complementary role in digital transformation, and, as noted in a recent report by the European Commission, the convergence of the two technology families is likely to be essential for 5G (European Commission, 2017[38]).[16] However, specific services provided over these networks have gradually become substitutes in an evolving manner with new technological advances. The nature of competition between fixed and wireless services has evolved with each generation of wireless networks (Figure 3).

Figure 3. The evolution of competition* between services (fixed and mobile) across wireless network generations



Note: *Note*: *Illustrative diagram (i.e. does not exhaustively portray all cases or scenarios).

The second generation of wireless technologies (2G) essentially aimed at offering voice and text services. While the technology had the capability to provide some substitution for fixed services, operators tended to charge a premium for the additional functionality of mobility. Over time, and pressured by competition, this pricing model gave way to one that encouraged users to shift from fixed telephony to mobile voice services. Fixed network operators responded by offering new capabilities over broadband networks, and mobile operators then strove to introduce some of these capabilities in their services over 3G networks (e.g. video streaming). This process continued with 4G networks, which became the first mobile networks to be specifically designed for the Internet Protocol (IP). The IP capability encouraged the growth of smartphones, which in turn increased potential for the substitution of some services.

With the next generation of wireless technologies (5G), complementarity of fixed and mobile networks will continue, while some degree of substitution of new emerging services will remain. Fixed networks continue to evolve apace with 1 Gbps speeds being increasingly common in OECD countries, and 10 Gbps being launched in a handful of countries in 2018. These capabilities will enable new services in areas such as Augmented Reality (AR) and Virtual Reality (VR). At the same time, as occurred with 4G, the countries that are most advanced in next generation fixed networks will likely be those that are best placed to support the development of 5G given its reliance on fixed networks for backbone and backhaul support.

The next generation of wireless network enabling fixed wireless solutions: will it boost competition?

Some of the potential advantages that 5G will have over 4G, has led industry experts to believe that 5G fixed wireless networks could, in the future, be able to compete across all services with wireline broadband services (Datacomm Research Company, 2017[39])

The way 5G will affect competition between fixed and mobile communication service providers will perhaps vary from country to country. For instance, in the United States, Charter, a cable company, is conducting 5G trials (Fierce Wireless, 2017[40]), and Verizon, both a fixed and a wireless company, is investing in 37 million miles (60 million km) of fibre in the next three years (ArsTechnica, 2017[41]). Verizon engaged in this strategy, in part, to strengthen a proposed 5G fixed-wireless challenge to other fixed providers, including outside its traditional fixed-line service area (Seeking Alpha, 2017[42]). In the United Kingdom, for example, the government set out measures in the Future Telecoms Infrastructure Review to boost competition and to drive fibre rollout as they consider it a priority for 5G (UK Department for Digital, Culture, 2018[43]). Such measures include allowing "unrestricted access" to Openreach ducts and poles (i.e. BT's wholesale infrastructure company) for both residential and business broadband use, including for essential mobile infrastructure (UK Department for Digital, Culture, 2018[43]).

Recent developments in Fixed Wireless Access (FWA) in the United States offer a glimpse of what competition between fixed and wireless providers may look like in terms of subscriber broadband with new solutions provided by 5G. Many industry players believe that 5G FWA solutions will provide consumers with a viable option to fixed broadband in urban areas. Verizon launched in October 2018 its "*5G Home Internet*", a FWA solution using its proprietary technology called "5G Technology Forum" (TF) standard, and not the global standard 5G-New Radio (NR). Verizon has said it will upgrade to 5G-NR when equipment is available to comply with the industry standard at no cost to subscribers. It launched the service in four cities in the United States (i.e. Houston, Indianapolis, Los Angeles, and Sacramento), at a price of USD 70 per month (USD 50 per month for existing mobile customers), and recently announced Panama City, Florida as its fifth 5G city (Verizon, 2018[44]). The company says that its "5G home Internet" service provides download speeds of 300 Mbps to nearly 1 Gbps with very low latency and has no data caps (Ars Technica, 2018[45]). This may offer increased choice for consumers located in areas of the United States that otherwise only have a single fixed broadband provider.[17]

On the other hand, some remain sceptical of the short-term potential for 5G to compete with fixed broadband services. One report undertaken for the United States NTCA, a trade association of rural broadband providers, says that fixed and mobile technologies are still essentially complementary rather than substitutes (Thompson and Vandestadt, 2017[46]). The main reason given was that a study commissioned by them found that performance is still significantly hampered by interference issues inherent to mmWave spectrum (Arris and CableLabs, 2017[47]). That being said, some industry stakeholders have also noted that fixed line rural providers receive subsidies that may not be available if FWA technologies develops apace.

Advances in MIMO, beamforming, edge computing and so forth may render 5G more appealing and mitigate the concerns inherent to the use of mmWave spectrum (Fierce Wireless, 2017[48]).[18] Nevertheless, the most likely scenario is that a mix of fixed and wireless technologies, including satellite, will be involved in improving broadband services in rural areas.

3. The Enablers of 5G

3.1. Spectrum for 5G

Spectrum is the primary essential input for wireless communications, and therefore, its timely availability is of critical importance for 5G, and the various networks it will depend upon. While the technological advances behind 5G, such as small cell deployment, will enhance spectral efficiency and thus allow spectrum to be used more intensely, demands on this scarce resource are expected to continue to increase. That is, network densification and technological improvements in spectrum efficiency are likely to be insufficient to satisfy the predicted data demand without additional spectrum resources.

The ITU-R, in particular the Working Party 5D, in line with the "Vision" of the technical requirements for IMT-2020 (i.e. the ITU-R name for 5G New Radio, see Box 1), undertook a study to determine spectrum demand for the new IMT-2020 (ITU, 2015[9]). The ITU-R study highlighted that spectrum in the frequency range between 24.25-86 GHz would be needed to satisfy the expected data rates of the enhanced mobile broadband (eMBB) usage scenario. This created the basis for the discussion at the World Radiocommunication Conference in 2019 (WRC- 19) to decide on globally harmonised spectrum resources for 5G in bands above 24 GHz. Having been first discussed at the World Radiocommunication Conference in 2012 (WRC-12), the rest of the accompanying spectrum for 5G is expected to be finalised in November 2019 in the ITU's WRC-19.[19]

The spectrum requirements for 5G can be segmented in three main frequency ranges: low frequency bands (<1 GHz), mid-frequency bands (1-6 GHz), and high bands (>24 GHz). In the low bands, the 600 and 700 MHz bands have been frequently identified as suitable candidates that would help with the transition from 4G to 5G.

In the mid-range bands, the 3.4-3.8 GHz band has been prioritised for 5G in many countries, while other countries are looking at extending that range to include 3.9-4.2 GHz. Spectrum from 3.4-3.6 GHz bands is already globally allocated for mobile and has been identified for IMT. For example, in the European Union (EU), the Radio Spectrum Policy Group identified 3.4 – 3.8 GHz frequency band as the primary band for 5G bringing the necessary capacity for new 5G services.[20] In the Americas, several regulators have identified different blocks within the range of 3.3-3.8 GHz bands that could be used to deploy 5G. The latter could be due to significant mid-range spectrum shortages in certain blocks across countries in the region. In Asia, the People's Republic of China (hereafter "China") has already made available the 3.3-3.6 GHz bands for IMT. Japan has made available the 3.4-3.6 GHz bands, Korea the 3.4-3.7 GHz bands, and India the 3.3-3.6 GHz bands (Huawei, 2018[49]).

In the third category, also known as millimetre wave (mmWave) spectrum, from the WRC- 19 agenda item, as well as decisions in Europe, Latin America and the United States, it is likely that spectrum above 24 GHz will become key for 5G networks. For example, the pioneer 5G band identified by the Radio Spectrum Policy Group in Europe is 24.25- 27.5 GHz (26 GHz), and work on this has been completed in CEPT. In many parts of the Americas and Asia, the 28 GHz band, followed by portions of the 37-43.5 GHz band, have been identified for 5G.

Spectrum management is likely to become a more complex task for regulators, and the efficient methods for countries to manage it will likely vary depending on the regional and international context of spectrum use. For this reason, globally agreed harmonised bands for mobile wireless broadband services are crucial. As countries work harder to allocate spectrum for IMT use, "virgin spectrum" will be harder to find. The future may lead to more sophisticated spectrum sharing and the "co-existence" among services in the same band.

Spectrum managers globally either have already made bands available in the three ranges mentioned above, or are currently working to do so. For instance, the 700 MHz band, which has been coined as prime spectrum for wireless communication due to its coverage characteristics, has been released in some parts of the world already. In the 3.4- 3.8 GHz frequency range, work is ongoing to enable access of large blocks of spectrum. In addition, to ensure optimal use of spectrum (i.e. efficient spectrum management), the re-planning of frequency bands is currently being undertaken to ensure effective co-ordination and/or co-existence between different types of spectrum users.

Different approaches to spectrum management are being used in the OECD to free-up spectrum for 5G and maximise spectrum efficiency. To benefit from the capabilities the 5G's new radio technology is delivering, large contiguous blocks of spectrum per operator may be needed. An important task for policy makers to make the 3.4-3.8 GHz band suitable for '5G New Radio' is to ensure the relocation of existing service applications (e.g. the fixed-service (microwave) or fixed satellite services) into the upper or lower edge of the band. Current studies in ITU-R intend to provide solutions for the coordination of these services using dynamic real-world interference scenarios.

Although licensed spectrum remains a priority for the efficient delivery of 5G services, access to spectrum on an unlicensed basis is also likely to be necessary. In addition, the increase of other spectrum access paradigms, such as shared spectrum, will likely play an important role as well. Both licensed and unlicensed spectrum have advantages depending on its usage. For 5G, licensed spectrum has the important advantage of providing predictable usage conditions, allowing operators to better endeavour to guarantee quality parameters to their customers.[21]

Most of the envisaged 5G applications will rely heavily on quality parameters such as guaranteed latency, data rate or capacity. The same applies to other services, which rely on stable and known conditions of the mobile network. Unlicensed spectrum, often known as "license-exempt" spectrum, is also likely to play an important role in complementing licensed spectrum to satisfy future data and capacity demand, especially at fixed locations.[22]

Finally, shared spectrum, which is the usage of a region's radio frequencies by several players, may play an increasingly important role to help ease the spectrum demand. Spectrum can be shared by different users, at different times, codes or geographical locations (OECD, 2014[50]). Therefore, different paradigms of spectrum sharing may emerge depending on the country or region.

Spectrum harmonisation

As mentioned previously, the international process to define the 5G requirements to fulfil the IMT-2020 is led by the ITU-R through the Working Party 5D. The industry- led standardisation body, 3GPP, undertakes the technology specifications that will be deployed in network and consumer equipment. Collectively, the ITU and the 3GPP will drive spectrum harmonisation activities. The ITU will focus on the spectrum requirements and harmonised frequency ranges among countries, and 3GPP will concentrate on equipment and device specifications among industry players according to the spectrum that will be used for 5G. Therefore, a globally harmonised spectrum framework is highly important for 5G as it will enable economies of scale and facilitate cross border coordination.

The studies in ITU-R, and their regional working groups such as the European Conference of Postal and Telecommunications Administrations (CEPT), the Inter-American Telecommunication Commission (CITEL) or the Asia-Pacific Telecommunity (APT), provide the technically harmonised solutions for the co-ordination of all wireless services, including 5G. The regional bodies are currently preparing for the World Radiocommunication Conference (WRC-19).

Within Europe, the CEPT has completed the technical work for all three bands (CEPT, 2018[51]). Within the European Union, the Radio Spectrum Policy Group (RSPG), in addition to the 700 MHz and the 3.4–3.8 GHz band, identified the 26 GHz band for the initial deployment of 5G (European Commission, 2016[52]). Most European countries are expected to select this band to launch 5G services by 2020 (EC Radio Spectrum Committee, 2016[53]). The European Union Radio Spectrum Committee (RSC) has reached a binding harmonisation agreement regarding the 700 MHz band. Similarly, building on the work of CEPT, the RSC is working on harmonisation decisions for 3.4-3.8 GHz and 26 GHz and these are due to be completed in the near future. Given that CEPT has moved steadily forward in the harmonisation process and that the first phase of the industry-led standardisation was concluded in June 2018 (i.e. Standalone 5G-NR), Europe may see more 5G trials in the second half of 2018. The majority of previous trials in Europe focused on the non-standalone 5G standard and on interoperability.

The Asia-Pacific Telecommunity (APT) has approved a recommendation to use the 700 MHz band for 5G, which translates into 26 countries identifying this band for 5G services, including Australia, Japan, Korea and New Zealand (Australian Government, 2017[54]). Korea used the 28 GHz band for the Winter Olympic games of February 2018, and Japan has stated its intentions to use this band in the 2020 Summer Olympics.

In Australia, the Australian Communications and Media Authority (ACMA) revealed in September 2017 that it plans to speed up the process to release and license spectrum for 5G services, namely in the 26 GHz band, currently reserved for fixed communications and radio astronomy. The ACMA consulted publically on planning options for the 26 GHz band in September-October 2018 (ACMA, 2018[55]).

Brazil is updating its regulation to release the 3.4-3.6 GHz band for 5G, together with 2.3-2.4 GHz band that may also be used for 5G. The last sub-6 GHz band to be released in the short term is the 1.5 GHz band that may also be used for 5G. Brazil intends to release the 26 GHz (24.25 – 27.5 GHz) band in 2019-20, as the pioneer band in mmWave.

Mexico is the first country in Latin America to free-up the 600 MHz band for 5G services, which is currently allocated to mobile services. This process finalised in October 2018. In the Americas, this band has also been identified for IMT by Bahamas, Barbados, Belize, Canada, the United States, and Colombia. In mid-2017, the Mexican communication regulator, the Instituto Federal de Telecomunicaciones (IFT), had a public consultation process regarding the 24.25 GHz and 86 GHz bands for the potential identification as IMT spectrum that could be used for 5G services. Mexico is also observing what the FCC (United States) is doing regarding the 28 GHz band, and what Europe is doing with regards the 3.4-3.6 GHz band. The IFT has auctioned the 2.5 GHz band. The winners, AT&T and Telefónica, will be able to offer mobile telephony and Internet services with greater speed and quality, as well as move towards the deployment of 5G services. The IFT has also identified other IMT bands that may be auctioned in the upcoming five years that could eventually be used for 5G. Namely, these are the 600 MHz, 2.3 GHz, 1.4 GHz and 3.3 GHz bands. Finally, Altán Redes, the winning bidder for a national wholesale network (Red Compartida) has mentioned to the IFT that the 700 MHz band they were granted has been prepared to offer 5G services in the future.

The United Kingdom is also working to make suitable spectrum available in the high (24.25 GHz–27.5 GHz, and other bands above 30 GHz), medium (3.4–3.8 GHz) and low frequency (700 MHz) bands (Ofcom, 2018[56]).

In the United States, the Federal Communications Commission (FCC) has announced that it will increase the availability of spectrum above 24 GHz for 5G (FCC, 2019[57]) .The FCC proposes to free up another 2.75 gigahertz of 5G spectrum in the 26 and 42 GHz bands (FCC, 2018[58]). In addition, the FCC also has taken steps to facilitate 5G buildout in the 2.5 GHz, 3.5 GHz, and 3.7-4.2 GHz bands (FCC, 2019[57]). Furthermore, the United States is clearing the 600 MHz band through an incentive auction for the potential early deployment of 5G. While some MNOs in the United States may use 600 MHz spectrum for 5G, there is no requirement it be used for this rather than, say, LTE-Advanced. 5G is expected to be deployed in the United States over multiple low-, mid- and high-frequency spectrum bands.

Spectrum assignments for 5G have begun in 2018, and they are expected to continue in 2019 in many OECD countries (Table 2). For instance, in Europe spectrum assignments have begun in Austria, Finland, France, and the United Kingdom. Other planned (or recently concluded) auctions include that of Canada, Chile, Germany, Italy, and the United States.

The European Electronic Communications Code, adopted on December 2018, fixes an ambitious calendar for spectrum assignment, whereby the year 2020, 5G frequency bands have to be assigned. In light of this, Europe has recently seen several auctions take place. Recent 5G auctions include the one conducted in Italy on October 2018, and Switzerland on February 2019. In Germany, the 5G auction begun in March 2019 with four players bidding. The German auction concluded on 12 June 2019 with a total of 420 MHz auctioned, raising EUR 6.55 billion (USD 7.4 billion).[23] In addition, the auction resulted in the entry of a fourth player in the German mobile market, 1&1 Drillisch (BNetzA, 2019[59]).

In the United States, the FCC held its first 5G spectrum auctions in 2018 in the 24 GHz and 28 GHz bands. In 2019, the FCC will auction the upper 37 GHz, 39 GHz, and 47 GHz bands. With these auctions, the FCC will release almost 5 gigahertz of 5G spectrum into the market, more than all other flexible use bands combined.

Policy makers around the world have a difficult task at hand when designing spectrum auctions as they are attempting to strike the right balance between expanding coverage, assigning the spectrum to the operator that will make the most efficient use of it (expressed by their willingness to pay), and promoting investment. For example, coverage obligations should ensure that access is as widespread as possible, but unrealistic targets can also add unrecoverable operating expenditures for operators. In addition, fostering investment certainty through longer licenses may help to deploy 5G.

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Table 2. Spectrum bands being made available for 5G in OECD countries

	Spectrum Frequency Bands		
	High	**Middle**	**Low**
Australia	26 GHz	3.4-3.6 GHz	700 MHz
Austria		1.5 GHz, 3.4-3.6 GHz, & 3.6-3.8 GHz	700 MHz
Canada	26, 28, and 37-40 GHz	3.5 GHz	600 MHz
Chile		3.5 GHz	700 MHz
Denmark(i)		1.8 GHz, 2.1 GHz, 2.3 GHz, 2.6 GHz	700 MHz, 800 MHz, 900 MHz
European Union	26 GHz (24.25-27.5 GHz)	3.4-3.8 GHz	700 MHz
Finland	26.5 and 27 GHz	3.4 GHz and 3.8 GHz	
France(ii)		2.6 & 3.6 GHz*	
Germany(i) & (ii)	24.25-27.5 GHz	2.1 & 3.4-3.8 GHz*	700 MHz (703-733 MHz/758-788 MHz)
Ireland	26 GHz	3.6 GHz (awarded)	
Japan(iii)	28 GHz (27.5-29.5 GHz)	3.6-4.2 GHZ & 4.4- -4.9 GHz	
Korea	28 GHz (26.5-28.9 GHz)	3.42-3.7 GHz	700 MHz
Mexico	[Above 24 GHz](iv)	2.5 GHz	600 MHz (700 MHz)(v)
Netherlands		1.4, 2.1 & 3.6* GHz	700 MHz
New Zealand			700 MHz
Spain	26 GHz	1.5 GHz, 3.6-3.8 GHz	700 MHz
Sweden		3.4-3.8 GHz	
Switzerland		1.4 GHz, 3.5-3.8 GHz	700 MHz
United States	24, 28, 37, 39, 47 GHz; 26, 42 GHz(iv)	2.5, 3.5, 3.7-4.2 GHz*	600, 800, 900 MHz
United Kingdom	EU bands + 26 GHz, and 57-71 GHz	3.4-3.8 GHz	700 MHz

Notes: (i) All issued licenses for spectrum use in Denmark are technology neutral, and all licenses can therefore be used for 5G. In Germany, licenses for Mobile/Fixed Communications Networks (MFCN) are technology neutral, and as such, all bands licensed to public mobile network operators can be used for 5G based on the commercial considerations by the operator. The bands mentioned are those where first deployment of 5G is likely. (ii) Spectrum at 700 MHz has been already awarded and can be used for 5G. (iii) All "5G" frequency bands in Japan have been allocated in April 2019 (end of fiscal year 2018). (iv) The regulator plans to make available the bands, subject to public input. (v) Used by the National Wireless Wholesale Network in Mexico (i.e. Red Compartida).
Source: Please refer to Table A.1 in Annex A for the complete list of sources.

3.2. Technological advances and network performance improvements

Numerous industry stakeholders and analysts consider the step from 4G to 5G networks a profound technological change that will reshape the broadband market. In particular, 5G networks will make use of mmWave spectrum (i.e. high frequency bands expected to play a key role in 5G networks), which have the potential of improving the capabilities of today's broadband networks (5G Americas, 2018[7]). The main technological advances that can lead to network performance improvements are:

- an increase in the amounts of spectrum available for 5G as it will now also utilise high frequency bands
- the use of new technologies such as massive multiple-input-multiple-output (MIMO) and beamforming, and
- the use of smaller cells to increase capacity by reducing the number of users sharing the same spectrum (Datacomm Research Company, 2017[39]).

One major technological development that is becoming mature for 5G is Massive Multiple-Input Multiple Output (MIMO) antennas that allow for precision beamforming. Massive MIMO is the use of dozens or hundreds of individual antennas in a single array. It moves in a somewhat different direction from the current practice of using large cell towers (i.e. macro cells), and instead, Massive MIMO uses a very large number of service device antennas that are operated coherently and adaptively.

These small antennas (i.e. micro cells) deployed massively help focusing the transmission and reception of the signal into smaller regions of space (i.e. precision beamforming technique to focus signals on each user). The latter improves data rate transmission (i.e. throughput measured in Mbps) and energy efficiency, as well as reducing interference. However, one main challenge of the use of narrow beams (precision beamforming) is establishing and maintaining the communication link between the base station and the mobile device. Since signals in mid-band and high-band 5G frequencies may experience propagation issues (e.g. reduced penetration through walls), network densification becomes key to address this limitation. Some industry stakeholders have suggested that a large-scale deployment of massive MIMO may require the review of current regulations on power density levels, and the improvement of spectrum management.

Notwithstanding, much of the research into massive MIMO that was developed for 5G is widely available for 4G. That is, Massive MIMO has already been incorporated into wireless broadband standards including LTE and Wi-Fi. For instance, in October 2017, Verizon jointly with Ericsson ran a trial for massive MIMO in the AWS (1.7-2.1 GHz) bands in Irvine, California (Ericsson, 2017[60]). Operators may choose to deploy this type of technology in sites experiencing congestion such as in densely populated urban areas; however, some experts suggest that massive MIMO may be more practical in the mmWave bands because antennas can be small (as opposed to lower frequency bands that require larger antennas).

The amount of MIMO transmitters are likely to depend on the spectrum used as well as the number of antenna elements. For instance, the mobile operator Three Austria has upgraded its 4G networks to use massive MIMO, in what they call “pre-5G”, and instead of using eight antennas in 4G transmitters, they are placing 64 antenna elements in “pre-5G” transmitters. As such, the operator highlights that this allows up to eight broadband users in parallel to surf online at the maximum available speed, increasing network capacity significantly. Compared to road traffic, 4G today would be equivalent to a two-lane highway, where “Pre-5G”automatically converts it into an eight-lane highway. The operator expects that a full 5G network will have 128 or more antennas per transmitter, thus increasing even further the capacity (Three Austria, 2019[61]).

Another important technological development is beamforming. As defined by IEEE, “beamforming is a traffic-signalling system for cellular base stations that identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process” (IEEE, 2017[2]). That is, the main benefit of beamforming is to concentrate the capacity to a specific user rather than having a singlewide range beam that covers an entire area (i.e. it allows for various “mini-beams” to different users). Therefore, beamforming can help massive MIMO to make a more efficient use of spectrum by mitigating one of its main challenges, which is the reduction of interference while transmitting more information from many more antennas at once (IEEE, 2017[2]). In addition, beamforming may primarily help address some issues inherent to the use of mmWave spectrum. By focusing a signal in a “concentrated beam” that points only in the direction of the user, rather than broadcasting in many directions at once, beamforming may help contour issues related to high frequency cellular signals which are easily blocked by objects and tend to weaken over long distances (IEEE, 2017[2]).

Technological improvements and spectral efficiency

One of the advantages of 5G is said to be improved spectral efficiency (i.e. the net data rate that can be supported per unit of spectrum) compared to 4G. Spectral efficiency is usually expressed as the net data rate in bits per second (bps) over the channel bandwidth expressed in hertz (Hz), and depends on several parameters. One of the main drivers for spectrum efficiency gains in 5G is the possibility of spatial frequency reuse. For example, the new 5G New Radio standard agreed on June 2018 by the Industry involves an improvement of spectral efficiency through the introduction of massive MIMO and beamforming. These two technologies allow the steering of the mobile beam to dedicated customers and thus to reuse the same spectrum to serve another customer in the same cell but at a different location. Some industry stakeholders expect a three-fold increase in spectral efficiency (Rysavy Research/ 5G Americas, 2017[62]).

In addition, some industry stakeholders state that much of the performance gains in 5G will come from wider radio channels. Radio channels of 200 MHz and 400 MHz, and even wider in the future, will enable "multi-Gbps" peak throughput (Rysavy Research/ 5G Americas, 2017[62]). In other words, as 5G can use channels wider than 100 MHz, which are available in the millimetre wave spectrum, rather than 40 MHz wide channels in spectrum available currently for 4G, it may allow 5G to increase performance compared to current LTE technologies.

Finally, in addition to new bands below the 6 GHz range, 5G will be able to use spectrum available in bands above 24 GHz (e.g. ITU-R is studying possibilities in bands in the range 24.25-86 GHz for WRC-19) for mobile services. This opens the opportunity of using additional spectrum for communication services.

3.3. Network Slicing: a key feature of 5G bringing new possibilities

Network slicing is a form of network virtualisation allowing several logical service networks (called slices) to be provided over the same underlying physical network infrastructure. The users of the different "slices" can then experience different characteristics. Resources such as computing, storage, access equipment, and so forth, can be either dedicated exclusively to one logical network, or sliced, or shared among different "slices" (Ericsson, 2017[1]). Due to the variety of demands placed by different types of usage expected in the future, —in terms of latency, reliability and download speeds (e.g. enhanced mobile broadband, massive M2M, or critical applications) —, services can be provided with different performance features over the same physical network. This "virtualisation" is a key characteristic proposed for 5G networks.

The main benefits of network slicing is that it allows operators to provide specific services with high levels of security, tailored to specific needs (e.g. industrial users may have different needs than emergency networks), and in an isolated manner. This would allow users of the slice to reach new business segments without a significant cost increase. Several parameters may vary between different slices of the network such as latency, throughput, the degree of mobility, the level of security, business model (operator vs customer managed), and geographical distribution. In this sense, operators may be able to charge differently based on service characteristics of the slice. A Service Level Agreement (SLA), for example, could be set up where the operator agrees to deliver a service at a given quality within a slice. In addition, network slicing could be used for Radio Access Network (RAN) sharing between operators.

Two technical developments that in combination make "network slicing" possible are Software Defined Networks (SDN), and Network Function Virtualisation (NFV). Both of these developments have been trialled for 4G, and are readily available features in the 5G standard from the start (Cave, 2018[63]). The full potential of network slicing, however, will probably occur when the core network is replaced or upgraded in the transition from 4G networks to 5G. NFV decouples the network functions, such as network address translation (NAT), firewalling, intrusion detection, domain name service (DNS), and caching, to name a few, from proprietary hardware appliances so they can run in software (SDX Central, 2018[64]). On the other hand, SDN transfers network functions, such as switching, from the hardware to the software layer and is complementary to NFV for network management. For example, a software-defined-network for the transport network could make it possible to configure a virtual private network (VPN). Both these developments have been standardised by ETSI, and are the basis to allow a network resource to be controlled in a decentralised manner by third parties that manage this "virtual slice" of the network that meets a given set of requirements (i.e. network slicing).

Apart from virtualisation, other software advances that are currently being developed to enhance 5G capabilities relate to edge computing. Edge computing, as an evolution of cloud solutions, makes it possible to shift computing resources to the "edge" of the network to reduce latency and increase bandwidth efficiency (ETSI, 2018[65]). Multi- access Edge Computing (MEC), previously referred to as Mobile Edge Computing in 2017, is the computing architecture created by the European Telecommunications Standards Institute's (ETSI) group, with the primary aim of improving content delivery to users. Technically, it provides an "*IT service environment and cloud-computing capabilities at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to mobile subscribers*" (Hu et al., 2015[66]). In the future, MEC may become important for certain applications such as Augmented Reality (BEREC, 2018[19]).

5G will accommodate a large variety of scenarios in terms of usage; therefore, the network architecture will have to be flexible to meet this demand. One way to introduce this flexibility is through network slicing in order to improve efficiency. According to Ericsson, a major player in many 5G trials underway, the main advantages they foresee of network slicing is that it provides the potential to optimise the functional deployment and configuration of the network, as well as allowing independent operations and lifecycle management of each slice (Ericsson, 2017[1]). As mentioned previously, the full potential benefits of network slicing will be realised once the 5G core network will have been upgraded.

Box 3. Network slicing and potential regulatory implications

A question that has arisen in some countries is whether 5G network "slicing" will be consistent with their 'net neutrality' regulation. Some say the practical implications for current open Internet rules are speculative at this stage in relation to 5G. This is because how different 5G elements evolve, such as network slicing, not only depend on the eventual technological capabilities, but also market demand, degree of competition, commercial strategies, and so forth. Nonetheless, some believe that current regulatory approaches may

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create uncertainty for market players and impede investment in 5G. Others say that this feature will have little or no effect and the rules are technologically neutral.

Depending on how the slices are determined, they may or may not have implications to network neutrality rules. For example, if establishing different features and prioritising speeds is made among slices (e.g. one for environmental sensors and another for autonomous vehicles) and that in other respects they are non-discriminatory, this would not seem to conflict with some approaches to net neutrality.

Telecommunication operators have always tiered pricing for attributes such as capacity or data usage in ways that are aimed at different usage patterns and while the technology may have changed the principle may be little different. In Europe, for example, BEREC recognises that network slicing in 5G networks may be used to deliver "specialised services" (BEREC, 2016[67]).[24] Furthermore, in a Consultation report by BEREC they reiterated that, "*regulation is technology-neutral and applies to 5G just as it does to any other network technology. Therefore, if an ISP wishes to use network-slicing in a 5G environment, it could offer a specialised service"* (BEREC, 2016[68]).[25]

Nonetheless, some European operators have concerns that current network neutrality regulation could hamper network developments as network slicing is an integral part of 5G (FT, 2016[69]). However, others say that these fears by the operators may be overstated, as in their view net neutrality rules and 5G deployment are not contrary to each other. They note that operators across all regulatory environments, including those with stronger net neutrality positions, are moving ahead with trials and plans for deployment.

Meanwhile, some say that slicing may work in favour of network neutrality as it holds the potential to be engineered to put the decision about the slices in the hands of the users. In such a case, there would be no discrimination by the ISP and the user chooses the level of service (Telecom TV, 2016[70]). Nonetheless, irrespective of 5G directions, promoting an open Internet and the need to preserve robust and competitive Internet access services will remain a regulatory priority.[26]

However, a recent independent study "*5G and Net Neutrality: a functional analysis to feed the policy discussion*", commissioned by industry and public stakeholders in the Netherlands, found that the technological neutrality regulation in Europe allows for the development of 5G (i.e. there is no a priori ban on any 5G technology element). In addition, the report highlights that "*the assessment of the alignment of 5G with net neutrality rules depends not only on the 5G technologies, but also on the specific combination of services, applications and network architecture. It is not possible to come to an overall assessment with a single outcome on the alignment of 5G technology with net neutrality rules*". Therefore, some of the concerns expressed by operators in 2016 may be outdated (TNO, 2018[71]).

Sources: BEREC (2016), "BEREC Report on the outcome of the public consultation on draft BEREC Guidelines on the Implementation by National Regulators of European Net Neutrality rules"; "The Financial Times (2016), "European telecoms groups unveil 5G manifesto"; TNO (2018), "5G and Net Neutrality: A TNO Study"

However, some stakeholders have expressed the opinion that given that network slicing appears to be an inherent feature of how the 5G standard is being developed, it may have implications for current regulatory frameworks in relation to network neutrality rules (Box 3).[27] Contrary to that, some European regulatory authorities are of the opinion that network slicing, as well as other features of 5G, may be implemented under European

Union net neutrality rules, either as a specialised service or a reasonable traffic management measure. However, if 5G technologies are applied in private networks (e.g. on industrial production sites if the network is construed as a separate logical network from the public Internet), the European Union net neutrality rules are not applicable.

3.4. Developments of 5G New Radio: the emergence of a standards ecosystem

The standardisation process of each generation of wireless networks is a continuous undertaking where a family of standards are agreed by the industry so that they comply with certain specifications. A major player in the standardisation process is 3GPP, which focuses on the standards for network equipment, chips and devices. Networks, radio systems and terminal devices, all need to "speak the same language", in order to have a functional standard.

Important milestones in the standard setting process were achieved in 2018 for 5G. In December 2017, the 3GPP plenary agreed on the first implementable 5G New Radio (NR) non-standalone standard (3GPP, 2017[72]). Non-Standalone 5G- NR means that much of the network will rely on presently deployed 4G technology, but that devices can start using the 5G NR non-standalone standard. In other words, an important feature of the 3GPP 5G NR non-standalone standard resides in the ability for LTE and 5G NR to co-exist and share the same low frequency bands without having to fully free those bands from LTE use. This standard completion is an essential milestone to enable cost-effective, interoperable and full-scale deployment of 5G (3GPP, 2017[72]). It took the industry a step further in achieving a full standalone standard (i.e. 5G NR-SA) when it was determined in June 2018 by 3GPP.

With these two 3GPP milestones, i.e. "non-standalone 5G" (NSA-5G) in December 2017 and the "standalone 5G" (SA-5G) standard in June 2018, the industry has completed what is called the first phase of the 5G standardisation process that complies with IMT-2020 requirements (both part of Release 15 of 3GPP). The difference with these two is that the former requires current 4G network equipment to be deployed on, and the latter be deployed as an entire new network. This first phase of the standard, which is now completed, is intended for use in "enhanced mobile broadband" (i.e. 3GPP Release 15). The second phase, which is expected to be concluded in June 2019, will be designed to enhance the 5G ecosystem for massive M2M and Critical IoT applications, and hence this second phase is expected to achieve full compliance with IMT-2020 requirements.

The trials up to date have been using this "pre-commercial" 5G standard, i.e. NSA-5G. Commercial launches from 2019-21 are expected to be based on Release 15 with enhanced mobile broadband applications as the foundation of future 5G innovations. This does not mean the standard setting process is completed. In fact, the industry is now working on Release 16, where new 5G technologies will expand the ecosystem. Commercial launches from 2021-22 are expected to be based on Release 16, which will focus on IoT usage scenarios (i.e. massive machine type communications and ultra-reliable low-latency communications). More specifically, Release 16 of the standard, expected to be finalised in June 2019, is focusing on a variety of topics, such as Vehicle-to-everything (V2X) applications, 5G satellite access, Local Area Network support in 5G, wireless and wireline convergence for 5G, network slicing and the IoT, among others (3GPP, 2018[73]).[28]

Many industry stakeholders expect the first wave of 5G commercial networks to begin by the end of 2019 or early 2020. Qualcomm, a leading manufacturer of mobile chips and radio technology, insists that 5G will be available in mobile devices in 2019 (CNET, 2017[74]). With this in mind, Qualcomm announced in October 2017 its chip for 5G smartphones that allows the transmission of information between 5G networks and devices (CNET, 2017[74]). In January 2018, ZTE announced it was ready to launch a 5G ready device in 2019 (Mobile World Live, 2018[75]). Apple is set to launch the first 5G iPhones in 2020 using Intel modems (FastCompany, 2018[76]).

Given all these ecosystem (technological) developments, in conjunction with the regulatory developments, many observers note that more 5G trials will be undertaken in 2019, noting that most trials up to now have focused on the non-standalone standard and on interoperability.

3.5. Access to backhaul and investment in NGA networks: key enabler of 5G

With the spectrum access and the industry standardisation process for 5G are progressing well, another evident trend is that 5G networks will require smaller cell sites, complementing traditional large cell towers. This is required to bring greater connectivity to the networks and lower latency in the form of small cells closer to connected devices through a process called 'network densification'. Such cells will need to be connected to backhaul, underlining the need for increased investment in next generation network deployment. New policy approaches aiming at improving investment conditions for 5G should therefore also provide for a predictive and encouraging framework for private investments in fibre and other backhaul solutions.

Taking fibre backhaul closer to the end-user, whether the business location or residential dwelling, is important for increasing speed across all technologies, not only 5G, including final connections using co-axial cable or copper. A growth in fibre backhaul availability should help support projected capacity demands, in particular, demands raised by 5G networks. Although the ideal indicator for the latter would be a measure fibre-backhaul coverage or availability, in the absence of this measure at the OECD level, fibre subscriptions (FTTH) could be used as proxy for fibre availability (Figure 4).[29] However, a caveat should be noted. While fibre subscriptions may be illustrative of general trends in fibre deployment, it is not an ideal measure of fibre backhaul coverage as subscriptions are a function of customer choice given different available technology types.

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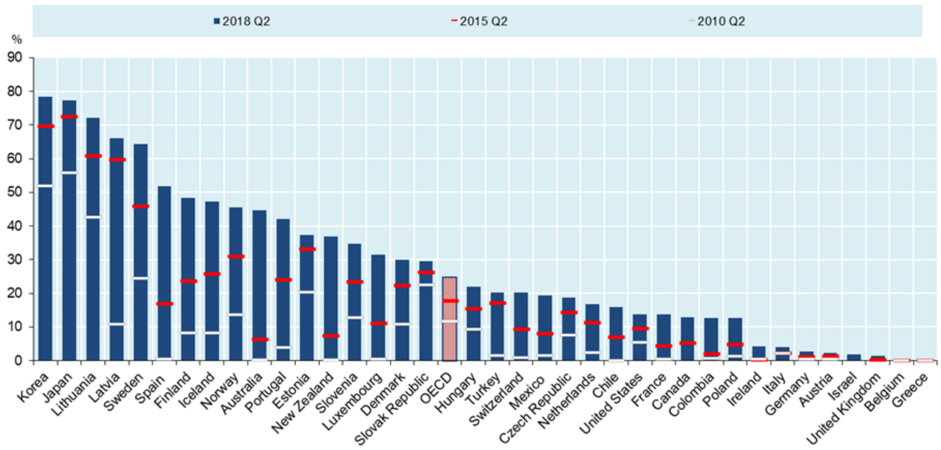
Figure 4. Percentage of fibre connections in total fixed broadband, June 2018



Note: Definitions: Fibre subscriptions data includes FTTH, FTTP and FTTB and excludes FTTC. Some countries may have fibre but have not reported figures so they are not included in the chart. Switzerland and United States: Data are estimates. Germany: Fibre includes fibre lines provided by cable operators.
Source: OECD, Broadband Portal, www.oecd.org/sti/broadband/oecdbroadbandportal.htm

While various types of xDSL remain the prevalent access technology in telecommunication networks across the OECD, with 38% of fixed broadband subscriptions, it is slowly being replaced by fibre, which now accounts for 24.8% of fixed broadband subscriptions (up from 12% eight years ago) after a 15% increase in the twelve months to June 2018 (Figure 4).[30] However, the share of fibre masks significant cross-country differences. Japan and Korea are the only OECD countries where fibre subscriptions account for more than 75% of total broadband subscriptions; they are also two of the few OECD countries with operators that offered in 2018 or are planning to offer in 2019 10 Gbps download speeds for residential services. In contrast, Ireland, Italy, Germany, Austria, Israel, the United Kingdom, Belgium and Greece recorded percentages of less than 10% in June 2018 (Figure 4).

4. The 5G challenge: implications to infrastructure

4.1. Implications of network "densification"

4.1.1. Smaller Cells and More Fibre Backhaul

The process of adding capacity to wireless networks can be accomplished by making more spectrum available, making use of it more efficiently or adding to the number of cellular sites. The latter has become known as "network densification". These small cells will be mostly connected to fibre backhaul. Under certain conditions, microwave may also be used to connect small cells but this will likely be to a macro tower connected to fibre (PC World, 2016[77]).

Network densification for 5G may be different when using low and mid frequency bands versus mmWave band spectrum. In the high range spectrum, the increase of cell sites is inherent to the propagation properties, while in low-mid frequency bands the increase may be due to the use of Massive MIMO in 4G core networks. This development for 5G implies a rapid increase of cellular sites worldwide. For instance, in the city of Boston (United States), Verizon has stated that it will require 8 000 to 10 000 small cells for its 5G deployment using the mmWave band to match current 4G coverage (CNBC, 2017[78]). Another informative example of the scale of base stations needed for the next generation of wireless networks is the announcement by China Telecom in March 2018, when the company highlighted the need to deploy more than 2 million 5G-enabled base stations across China in order to provide its current (and projected) customer base 5G services (Light Reading, 2018[79]).

An increase in network densification raises the question of having sufficient backhaul capable of meeting the requirements of 5G. One study by Deloitte has suggested, in the United States, that "wireline broadband access supports as much as 90 percent of all Internet traffic even though the majority of the traffic ultimately terminates on a wireless device". As such, they argue that the success of network densification will ultimately depend on fibre deployment. They concluded that an estimated USD 130 to USD 150 billion of fibre investment is needed in order to meet future broadband needs in the United States (Deloitte US, 2017[80]).

By way of example, Verizon has stated that it is committed to redesigning its network "from the cloud through high-speed fibre infrastructure to edge computing to 5G" (Seeking Alpha, 2017[42]). To do so, in addition to running 5G trials in 11 cities, through a partnership with Corning signed on April 2017, they are investing a total of USD 1.05 billion to deploy 12.4 million miles of fibre per year over three years investing (Seeking Alpha, 2017[42]). Furthermore, the company has purchased 37.2 million miles (60 million Km) of fibre to be installed between 2018 and 2020, to boost the capacity and lower the latency of its wireless network (ArsTechnica, 2017[41]). The expansion in fibre is viewed as an integral part of the company's 5G-deployment strategy.[31] This raises the issue of the capital expenditure requirements that may arise with 5G.

4.1.2. Implications for rights of way and infrastructure sharing: are "lampposts" the new towers?

Most projections for 5G, whether for fixed wireless or mobile use, involve a relatively limited distance between a user and a fixed line backhaul point of connection (PC World, 2016[77]). Although traditional macro tower sites currently used will continue to exist for coverage purposes, technological developments in massive MIMO could mean that transmitters may be observed as close as lampposts (Figure 5). One reason why transmitters would need to be closer to the user is linked to the fact that, in some instances, 5G will use mmWave spectrum, and thus 5G cells will have shorter range compared to previous generations of mobile services.[32] In order to ensure low latency to support a future with, for example, fully automated vehicles or any other data demanding service, more close proximity transmission sites will be required.

Figure 5. New transmission sites for 5G

5G site in lamppost

Note: Small-cell transmitter on a streetlight in Providence, Rhode Island.
Source: The Providence Journal (Glenn Osmundson, 2017[81]).

This required "network densification" may magnify the traditional challenges operators or tower companies have always had in securing rights of way (i.e. permissions to install towers or masts).[33] In addition, the importance of access to ducts, -which are not only used by fixed operators but also by mobile operators to install fibre cables connecting cellular base stations-, will continue to increase with 5G. Some countries in the OECD are looking to streamline such procedures. For example, in April 2017, the FCC initiated a rulemaking that seeks to streamline deployment rules for mobile broadband providers and reduce regulatory barriers to deployment. It has since adopted several orders to streamline both fibre and small cell deployment, as discussed below. As a further example, in January 2018, the Radio Spectrum Policy Group (RSPG) of the European Union identified that need as well in their "RSPG Second Opinion on 5G networks" (RSPG, 2018[82]). In fact, the new European Electronic Communications Code in its article 57 seeks to reduce regulatory burdens for small cell deployment within the European Union (European Commission, 2018[83]).

In the largest cities of many OECD countries, there is an increasing number of fixed and wireless operators deploying fibre deeper into the networks and securing rights of way very close to users (e.g. lampposts). In the United Kingdom, for example, Arqiva, a mobile telecommunication and broadcasting tower provider, secured in 2017 the access to around 15 000 lampposts across London (Arqiva, 2017[84]). In addition, this company, in July 2017 launched in central London the first field trial of 5G Fixed Wireless Access (FWA) technology in the United Kingdom (and Europe) in partnership with Samsung.[34]

With the capital expenditures needed to deploy 5G due to network densification new infrastructure sharing arrangements may arise. For instance, in Korea mobile operators and ISPs (i.e. SK Telecom, KT, LGU+ and SK Broadband) announced in April 2018 that they would share the costs of 5G infrastructure deployment by engaging in infrastructure sharing agreements. Through the initiative they expect to save around KRW 1 trillion (USD 933 million) over the next decade (Telecompaper, 2018[85]).[35]

"Network densification" will have important technical, regulatory and policy implications for all levels of government (where municipalities will play a key role), industry and the public. By way of example, some questions could be how many operators can technically share a lamppost? Other street infrastructure -such as rooftops, water towers-, can be used to support deployments, which in turn may lead to co- investment strategies. What are the implications for competition, infrastructure sharing, spectrum management, and so forth? Will local governments wish to extract rents from micro cells in the same manner as they have for macro cells? What levels of investment will be required to make sure that backhaul reaches all the micro sites? Finally, how does the public feel about having multiple micro cells transmitting in their street or outside their residence? Other than reducing the costs of small cell deployment, other public interests at a municipal level may exist, such as landscape protection, which should also be considered.

Rights of Way

5G will make new demands on all stakeholders in areas such as rights of way, particularly in terms of the location and backhaul to support smaller cells. As the deployment of 5G requires many additional sites, operators may require access not only to public facilities such as ducts and poles but also to lampposts and buildings to be able to rollout 5G networks. Harmonised procedures to get all necessary permissions will be needed for service to be developed apace.

An example of recent regulatory action to streamline rights of way is the recent FCC Order, "*Accelerating Wireless and Wireline Broadband Deployment by Removing Barriers to Infrastructure Investment,*" adopted on the 26 September 2018 (FCC, 2018[86]). The decision clarifies the FCC's views regarding the amount that municipalities may reasonably charge for small cell deployment given the practicalities of 5G deployment and the importance of 5G to the United States. In particular, the FCC declared that, pursuant to Section 253 of the Communications Act, fees should be a "reasonable approximation of the municipalities' costs". In offering guidelines for determining this, the FCC cited the rules of twenty states that limit upfront pole fees to USD 500 for use of an existing pole, USD 1 000 for installation of a new pole, and recurring fees of USD 270.

Small cell deployment by mobile operators can be an expensive pursuit. For instance, it is estimated that Boston's current contract with Verizon charges the company USD 2 500 per small cell site, and another communication provider pays Boston USD 500 per pole, plus 5% of its gross revenues (Boston Globe, 2018[87]). Although the FCC has stated that many local authorities are on board with its low-cost proposals, some municipalities are appealing the decision, as they view it as an "infringement to local authority" (Ars Technica, 2018[88]). The FCC says the order could reduce deployment costs by USD 2 billion, and while this is in some ways a relatively small amount compared to the estimated USD 275 billion it will take to deploy 5G across the country, it is still substantial (FCC, 2018[86]). In addition, this estimate may underestimate savings related to expedited deployment given the time it has historically taken to obtain rights of way permits. By defining presumptively reasonable periods for local authorities to grant or deny different permit applications, the FCC's order stands to substantially increase the pace of deployment, potentially decreasing the time it takes to obtain the requisite permissions from years to weeks (FCC, 2018[86]).

Another example for facilitation of small cell deployment can be found in the new European Electronic Communications Code (EECC). Article 57 of the EECC aims to minimise authorisation requirements and costs of small cell deployment. According to a specific EECC provision, competent authorities shall not subject the deployment of small-area wireless access points, i.e., small cells, to any individual town planning permit, to other individual prior permits, or to any fees or charges going beyond the demonstrated administrative charges. In addition, countries in Europe are requested to ensure that operators have the right to access any physical infrastructure controlled by national, regional or local authorities that is technically suitable to host small-area wireless access points, such as street furniture such as light poles, street signs, traffic lights, billboards, bus and tramway stops and metro stations (European Commission, 2018[83]).

The United Kingdom reformed its Electronic Communications Code (ECC) in 2017 as part of the Digital Economy Act 2017. These reforms, which came into force in December 2017, were intended to reduce the cost and make it easier for operators to deploy communication infrastructure. The amendments included changes to the basis on which access to land is valued when an agreement is imposed by a tribunal and is expected to lead to reductions in the amounts that communication operators pay site providers over time. In addition, the United Kingdom Government's 5G Strategy announced that it would create a 'Local Connectivity Group', to bring together representatives from industry, local areas, the communications regulatory authority Ofcom and Government to agree how each can support the deployment of digital infrastructure at the local level. The Group is developing best practice guidance highlighting practical ways to overcome barriers to digital infrastructure deployment. This will include guidance and recommendations for the deployment of small cells for 5G.

Infrastructure Sharing

Infrastructure-sharing provisions may help reduce costs for network and service providers while enabling the development of new and innovative services for end users (OECD, 2017[89]). The principal benefits of network sharing are significant cost savings for operators and increased geographical coverage for users. For example, a recent report by BEREC highlighted that wireless infrastructure sharing, depending on the type (i.e. passive, active excluding spectrum or active including spectrum), can save operators from 16-45% in capital expenditure and 16-35% in operating expenses (BEREC, 2018[90]). Cost savings are usually sufficient to encourage industry agreements to engage in network sharing. The main drawbacks of sharing are a reduction in the operator's incentives to invest in its own network and concerns by competition authorities that too much common information among operators might lead to collusion (OECD, 2014[91]). At present, almost all OECD countries encourage infrastructure sharing, provided that the advantages outweigh the drawbacks (i.e. that sharing is not detrimental to competition).

As 5G networks are deployed, many expect that infrastructure sharing will become increasingly important to accommodate transmission sites (namely, cell towers or other sites where electronic communications equipment can be placed), which are expected to increase one hundred fold to achieve the lower latency standards of 5G while using a shorter wave spectrum. In fact, BEREC has stated that as a result of cell densification, most countries in Europe believe that infrastructure sharing agreements will become increasingly important in the future, and most National Regulatory Authorities are considering how 5G will impact these agreements (BEREC, 2018[90]).

Some countries have considered the question of infrastructure sharing implications on 5G deployment with more detail and have already taken a stance. Such is the case of Austria, where the responsible regulatory body, Telekom-Control-Kommission (TKK), published a position paper on infrastructure sharing in mobile networks. While TKK's measures aim to encourage investment in 5G networks, they also plan to prohibit active infrastructure sharing in the largest cities for the deployment of sub 6-GHz spectrum during ongoing/upcoming spectrum awards – with the exception of some indoor and non-replicable infrastructure (Telekom-Control-Kommission, 2018[92]).

Due to the increase in investment requirements brought about by 5G, infrastructure-sharing agreements are likely to increase. For example, in countries such as Korea, the Communications Minister asked in January 2018 the three major wireless operators to collaborate on the deployment of 5G technology to meet a previously agreed timeline of first commercial operations in 2019 (Mobile World Live, 2018[93]). Subsequently, in April 2018, the main mobile network operators (MNOs) agreed to build a common 5G infrastructure, and with this agreement they expect to save USD 934 million over a decade by sharing 5G base stations (Telecompaper, 2018[85]).[36]

Some industry stakeholders say that although infrastructure sharing agreements seem a natural outcome, due to the high investments involved, operators should be free to negotiate and agree on commercial terms, such that sharing is neither imposed where it is not viable nor prevented where it would benefit connectivity. Finally, some stakeholders, such as INTUG, have mentioned that other benefits of network sharing for 5G can be the role these agreements may play for the efficiency and interoperability of IoT applications, especially for their coverage within complex in building and shared space environments like transport hubs (e.g. airports, hospitals, entertainment theme parks, shopping malls, university campuses and leisure complexes).

4.1.3. Power density regulations

As micro cells may help provide services with lower latency and to cope with the increased generation of data traffic, their deployment could be critical to address the demands of the digital transformation and the objectives policy makers have for using the technology for public policy goals (e.g. improved outcomes in health, transport and so forth). On the other hand, policy makers are seeking to balance cell site deployment with other policy objectives such as health considerations and/or minimising environmental disruption at a local level.

In some areas, the public has had concerns about the location of macro-cells. In the light of network densification, this may therefore mean these issues again come to the fore. In addition, in respect of 5G, a regulatory issue could arise. It has been suggested that small cells may not be permissible under the current power density regulations in some OECD countries.

Italy, for example, has said that for 5G, one of the main regulatory issues that need to be considered is the current limit placed on power density (i.e. "exposure limits to electromagnetic fields") which are quite low. Furthermore, according to many Italian operators, 70% of the cellular sites are not available to rollout new antennas due to current rules.

At present, several regulators in Europe are looking into how to modify current power density regulations so as to ensure that every European Union country can deploy 5G in a timely manner while giving due consideration to the reasons they were imposed. Harmonisation of power density regulations with the relevant stakeholders would significantly contribute to reduce cost in mobile network rollout.

4.2. The investment challenge

The costs of deploying 5G networks requires substantial upfront investment, and the drivers of such costs will depend on the necessary upgrades to existing Radio Access Networks (RAN) and core networks, as well as the need to roll out more backhaul associated with small cell deployment. As with any mobile network that preceded 5G, deployment costs are affected by population density as well as the spectrum bands used for 5G. The frequency band of spectrum allocated to 5G in each country will directly affect cost, as it impacts the need to deploy cells, e.g. higher frequency bands may require more base stations which leads to higher deployment costs (Australian Government, 2018[14]). In this sense, some ways that policy makers may seek to help reduce deployment costs are: promoting infrastructure sharing agreements, improving rights of way, and efficient spectrum management.

Although network densification required for 5G will raise deployment costs given current market conditions, some technological developments, such as network slicing, have led some operators to believe that 5G may work as "one network that fits all". To the extent that 5G enhances, extends or replaces existing networks (e.g. replacing the need to have separate industrial dedicated networks), some economies of scale, for example through the virtualisation of networks, may improve the profitability of 5G rollout. For instance, in May 2018 a company in the United States has stated that building a "multi-purpose" 5G network may help drive costs down (CNBC, 2018[94]).

Studies conducted to estimate the cost of 5G deployment

Several studies have been undertaken to estimate 5G rollout costs in Europe. For example, a study prepared for the European Commission in 2017 estimated that the cost of 5G deployment in European Union Member States would be approximately USD 59 billion by 2020.[37] Meanwhile, the studied expected a "spill over effect" to the general economy creating benefits of USD 148 billion by 2025 (European Commission, 2017[95]).[38]

Deployment costs for 5G networks, as with any network, also depends on the technology-mix used, the geography of the country, and the population density in each area of the country (i.e. urban, rural or remote areas). For example, in the Netherlands, a 2018 report provided a detailed cost model of 5G deployment scenarios depending on the technology (mobile only, or fixed wireless), geographical area (six different geo-types ranging from urban, suburban, different types of rural areas), and speeds aimed to be achieved with 5G networks (i.e. 30 Mbps, 100 Mbps or 300 Mbps). The study finds that, for the case of the Netherlands, the scenario of a "5G-mobile-only" service reaching 100 Mbps in an urban setting would require an investment per user of USD 66 (EUR 55). The same for service in a rural area would cost from USD 436-8 916 (EUR 362-7 400) depending on how remote the area is (Stratix, 2018[96]).[39]

The United Kingdom Government's Future Telecoms Infrastructure Review (FTIR) considered the likely capital expenditure associated with deploying 5G in the United Kingdom, using the 700 MHz and 3.5 GHz spectrum (subject to the outcome of future auctions). The model considered the 700 MHz spectrum deployed on all existing sites, and the 3.5 GHz spectrum band deployed predominantly to provide additional capacity in areas of high demand (UK Department for Digital, Culture, 2018[43]). The Review's high-level assessment is that this would cost around GBP 4-5 billion (USD 5.3- 6.6 billion). The FTIR also considered a variety of scenarios for small-cell deployment, and found that the level of deployment across areas will be influenced by a variety of factors, such as costs, rights of way, emerging 5G services, and the level of capacity demand. The Review states that there is no consensus on the number of small cells required for 5G nor on the degree of infrastructure sharing. As an indicative example, the FTIR's estimates suggest that the capital costs of deploying 200 000 small cells (which would allow providing outdoor coverage in most urban areas in the United Kingdom), could amount to around GBP 3 billion (USD 4 billion).

There is a wide range of estimates regarding the level of investment that may ultimately be required to deploy 5G. Different cost-models use a variety of assumptions, including different deployment periods, capital expenditures that would have been made in the normal course of maintaining existing networks, and so forth. The latter partially explains the difference in results. That being said, the amounts are, for the most part, substantial. In 2016, for example, a report commissioned by the European Telecommunication Network Operators' Association (ETNO) found that 5G rollout in Europe across urban areas and major transportation corridors would require USD 211 billion for required densification in 5G radio access networks (Bock and Wilms, 2016[97]).[40]

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5. Trials and 5G strategies in different countries and regions

In many countries around the OECD and elsewhere, 5G trials have been conducted in recent years (Table 3). This section of the report covers the experiences in selected countries regarding trials as well as national 5G strategies.

Table 3. 5G Trials in different Countries

Country	Date	MNO (+Network and equipment provider) and Research Institutes	Spectrum Band	Throughput & (Latency)	Notes
Australia	2017	Telstra (Ericsson)	26 GHz	18-22 Gbps	Massive MIMO, Melbourne
	2016	Optus (Huawei)	3.5 GHz		
Austria	Feb-18	T-Mobile (Huawei)	3.7 GHz	3 Gbps (<3 ms)	
Chile	Dec-17	Claro (Nokia)	27 GHz*	9 Gbps	Operator's HQ
China	Jan-19	ZTE			5G Core network tests
	Jan-19	China Unicom (ZTE)			Using ZTE 5G smartphone
	Jun-18	Nokia	3.5 GHz		End-to-end 5G-NR
	Sep-17	Ericsson-Intel	3.5 GHz		Massive MIMO, beamforming
	Jul-17	ZTE	26 GHz	13 Gbps	Wireless, 7 tests
		ZTE	3.5 GHz	19 Gbps (<0.416 ms)	Use of Massive MIMO, beam forming and Intel's "5G mobile trial platform"
Colombia	Jan-18	Claro (Nokia)	28 GHz*	10 Gbps	
Hungary	Oct-17	Telekom (Ericsson)	15 GHz	22 Gbps	First 5G connection in Hungary
	Jul-18	Telekom (Huawei)	3.7 GHz	2-3 Gbps	Real time remote diagnosis; rescue with drone; Gaming in augmented reality
	Sep-18	Vodafone Hungary (Huawei)	3.5 GHz		Hungary's first 5G live video broadcast
	Jan-19	Telekom (Huawei)	3.7 GHz		
	Mar-19	Telekom (Huawei)	3.7 GHz		
	Apr-19	Telekom (Huawei)	3.7 GHz		
	Apr-19	Telekom (Huawei)	3.7 GHz		
Ireland	Feb-18	Vodafone (Ericsson)	3.6 GHz	15 Gbps	
Italy**	Feb-18	Fastweb, Ericsson	3.6-3.8 GHz		Rome
	Dec-17	Vodafone Italia	3.6-3.8 GHz		Milan
	Oct-17	Enel, CDP and Wind Tre	3.6-3.8 GHz		Prato and L'Aquila
	Sep-17	TIM, Fastweb and Huawei	3.6-3.8 GHz		Bari and Matera
Japan	2017	NTT DoCoMo	4.5 GHz, 28 GHz	< 10 Gbps	Up to 30km/h
	2017	NTT Communications	28 GHz	< 2 Gbps	above 90km/h
	2017	KDDI	4.5 GHz, 28 GHz	(> 1 ms)	Up to 60km/h
	2017	Advanced Telecommunications Research Institute International (ATR)	28 GHz	< 10Gbps	

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	2017	Softbank	4.5 GHz, 28 GHz	(> 1 ms)	Up to 90km/h
	2017	National Institute of Communication (NICT)	3.7 GHz, 4.5 GHz, 28 GHz	(> 1 ms)	1 million devices/km^2
Korea	Feb-15	SKT and Samsung	28 GHz	7.5Gbps (<1ms)	Millimetre-wave beamforming
	Feb-16	KT and Ericsson	28 GHz	25.3 Mbps (<1ms)	Massive MIMO, beamforming
	Oct-16	KT and Samsung	28 GHz		End-to-Ent First Call, PyeongChang 5G Special Interest Group (SIG) common specification, Suwon(Samsung Electronics' Digital City Campus)
	Oct-17 to Mar-18	KT, SKT, LGU+, Samsung, Ericsson, Nokia, Huawei	28 GHz, 3.5 GHz	20 Gbps (<1 ms)	5G Tablet terminal, Outdoor in PyeongChang, Seoul, Gangneong
South Africa	Jan-18	MTN and Ericsson	800 MHz*	20 Gbps (<5 ms)	
Spain**	Jan-18	Telefónica (Nokia)			Segovia
	Jan-18	Telefónica (Ericsson)			Talavera de la Reina
Sweden	Aug-17	Telia, Boliden, Ericsson, Volvo, ABB, RISE SICS and LTU Technologies			Kankberg underground mine in Boliden
	Oct-16	Telia (Ericsson)	800 MHz & 15 GHz	15 Gbps (<3 ms)	Outdoor trial in Kista
Switzerland	2018	Swisscom (Ericsson)	3.5 GHz		Trial
	2018	Salt (Nokia)	3.5 GHz		Demo
	2017	Sunrise (Huawei)	3.5 GHz		Demo
United Kingdom	Dec-17	Vodafone (Ericsson)	3.5 GHz	2.8 Gbps (<5 ms)	London
	Nov-17	EE (Huawei)	3.5 GHz		Massive MIMO/ 5G NR
	Oct-18	Vodafone	3.4 GHz		Massive MIMO
	Oct-18	EE (Huawei)	3.4 GHz		Live trial, Canary Wharf, London
United States	2018	Verizon (Nokia)	28 GHz		Wireless, Washington, D.C.
	2017	ATT (Ericsson and Intel)	28 GHz & 39 GHz	1 Gbps*	Wireless
	2017	ATT (Qualcomm/ Ericsson)	28 GHz & 39 GHz	2 Gbps	Fixed Wireless Access
	2016	Sprint (Nokia)	73 GHz	2 Gbps	Santa Clara trial
	2017	Verizon (Samsung/ Ericsson/ Nokia/Cisco)	28 GHz		Fixed Wireless Access in 11 cities

Note: *Temporary License. **Announced trials (to be confirmed whether trials took place).
Source: Please refer to Table A.2 in Annex A for the complete list of sources by country.

5.1. Australia

The Australian government published a 5G strategy in October 2017, covering subjects such as fully automated vehicles, Industry 4.0, and Artificial Intelligence. This document highlights how 5G, unlike previous generation networks, will represent a shift in the telecommunication industry away from a focus on voice, and more towards mobile broadband and industrial applications. The maturing of 5G networks will help the proliferation of IoT, and in particular fully automated vehicles. The document highlights the benefits of fully automated vehicle applications as it could reduce traffic congestion, estimated to cost USD 40.6 billion (AUD 53 billion) by 2031. In addition, fully automated vehicles could also reduce road accidents in Australia that at present are estimated to cost USD 20.7 billion (AUD 27 billion) annually (Australian Government, 2017[54]).[41]

Australia plans to support the deployment of 5G by four key actions: making spectrum available, actively engaging in spectrum harmonisation, streamlining procedures for infrastructure deployment by mobile carriers, and reviewing existing regulatory arrangements to ensure they are adapted to the 5G environment (Australian Government, 2017[54]). The Australian government has also convened a working group to bring together representatives from the public and private sector. The aim for this multi-stakeholder working group is to foster an ongoing dialogue on 5G issues.

Given that the 3.6 GHz band is a pioneer band for early 5G deployments, the Minister for Communications in Australia made decisions to re-allocate this band to mobile broadband use in Australia in March 2017. The Australian Communications and Media Authority (ACMA) held a spectrum auction of 125 MHz in the 3.6 GHz band at the end of 2018. The auction concluded 12 December 2018, with four companies being awarded 5G spectrum, raising a total revenue of AUS 853 million for the 350 lots available, equivalent to AUS 29/MHz/pop (ACMA, 2018[98]). The ACMA has also released its Five-Year Spectrum Outlook (ACMA, 2019[99]), and published options papers for the 26 GHz and 28 GHz bands (ACMA, 2018[55]; ACMA, 2019[100]).

Both Telstra and Optus (the largest and the second largest MNOs in Australia), have welcomed the ACMA's proactive approach to make available mmWave spectrum for 5G (The Age, 2017[101]). The first live 5G trial in Australia was conducted by Telstra and Ericsson in Melbourne, and achieved download speeds of 18 and 22 Gbps making use of beam forming technology and massive MIMO (ZDNet, 2016[102]). Vodafone and Nokia also carried out 5G trials in Australia in late 2016 (Vodafone, 2016[103]).

5.2. Austria

With the aim of paving the way for 5G, Austria's Regulatory Authority for Broadcasting and Telecommunications (Rundfunk und Telekom Regulierungs, RTR) launched a consultation on the award procedure for frequencies in the 3.4 GHz-3.8 GHz band range in July 2017 (Telegeography, 2017[104]). The spectrum auction in the 3.4 to 3.8 GHz band, Austria's first 5G auction, is expected to take place in the first quarter of 2019. It will play an instrumental role for 5G deployment as it would be a band offering both broad coverage and high bandwidth for the next generation of wireless services (RTR, 2019[105]).

In February 2018, T-Mobile Austria, in partnership with Huawei, demonstrated the first 5G live operation of a drone flight in the city of Innsbruck. The trial consisted of two radio cells using the 3.7 GHz frequency bands, and specifications similar to 3GPP's 5G New Radio standard (Release 15). The trial in Austria delivered speeds of 3 Gbps and latency of three milliseconds (Mobile Europe, 2018[106]).

In April 2018, the Austrian Government published its 5G strategy under the theme "Austria's path to becoming a 5G pioneer in Europe". Its objective is to realise a full coverage with 5G. The government commits, inter alia, to innovation-friendly spectrum auctions not explicitly aimed at maximising revenues. Furthermore, the Austrian governments plans to reduce fees for usage of public locations for antennas and other network equipment. According to the strategy, the broadband funding scheme "Breitbandmilliarde" will be adapted to improve the specific requirements of 5G rollout. Furthermore, the government seeks to conclude a "broadband pact" with telecommunication operators.

5.3. Brazil

Anatel, the communication regulator in Brazil, has been discussing technical and spectrum management issues to establish a consensus on spectrum allocation for 5G before the formal definition of a standard by the International Telecommunications Union (ITU) at the November 2019 World Radio Communications (WRC-19) conference. In this sense, Brazil made the 39.5-40 GHz band available for 5G services. Anatel is currently working toward making available more spectrum in the mmWave band for the IMT-2020, based on the sharing and compatibility studies presented at the ITU-R Task Group 5/1. Brazil intends to anticipate the identification of 26 GHz band for IMT, and identify 37-43.5 GHz, or parts thereof, for IMT-2020 in accordance to WRC-19 decisions.

Given the vast amount of rural and remote areas in the country, Brazil is interested in the development of extreme long-range 5G solutions (i.e. cellular base stations with a radius of 50 kilometres or more) for connectivity in low-density areas. The government is sponsoring universities that are developing prototypes in the 300 MHz- 3 GHz bands (i.e. UHF band) with the support of the Ministry of Science, Technology, Innovation and Communications.

5.4. Canada

In Canada, all the major operators are conducting trials, or have completed trials, with the main 5G equipment providers. Trials have taken place in both the 3.5 GHz and 28 GHz bands for both fixed and mobile wireless applications. The government has issued developmental licenses to facilitate these trials.

The Government of Canada has recognised the potential of 5G to stimulate innovation by investing in ENCQOR, which stands for “Evolution of Networked Services through a Corridor in Quebec and Ontario for Research and Innovation.” The ENCQOR project is led by five anchor companies—Ericsson, Ciena Canada, CGI, IBM Canada and Thales Canada—, and engages large and small companies, academia and not-for-profit organisations. Its main goal is to establish a strategic large-scale technology demonstration project. This project will include a pre-commercial digital test bed, i.e. a virtual living lab, to advance the development of 5G networking solutions and next-generation technologies and applications. The project will support the research and development of new 5G technologies by establishing an open digital test bed that allows Canadian companies and researchers in Ontario and Quebec to test innovative ideas and solutions.

The Government of Canada is currently working towards making more spectrum available for flexible use, which would include 5G fixed and mobile networks. On 6 June 2018, it published the Spectrum Outlook 2018-22, a multi-year release plan for spectrum to support next-generation commercial mobile, satellite, licence-exempt, and backhaul services.

Work is also ongoing on specific low-, mid-, and high-frequency spectrum bands for 5G. The Canadian 600 MHz spectrum auction started on 12 March 2019, with bidding rounds finalised by 4 April 2019. Twelve operators participated in the auction that included 112 spectrum licenses in 16 geographical areas. The auction raised CAD 3.5 billion (USD 2.7 billion), and 104 licenses were awarded, including 40 licenses awarded to regional providers (Government of Canada, 2019[107]).[42] The first of two public consultations required to make the 3.5 GHz band available in late 2020 was launched on 6 June 2018. This consultation focusses on revisions to accommodate flexible use for fixed and mobile services and seeks preliminary comments on potential changes to the 3.8 GHz band.

For millimetre wave spectrum, the government launched an initial consultation on releasing this spectrum to support 5G in 2017, and an addendum consultation in 2018 focussed on an additional band. These consultations are laying the groundwork for making the 26, 28, and 37-40 GHz bands available for licenced use, and the 64-71 GHz band available for unlicensed use.

5.5. China

In 2018, the Chinese government authorised carriers to test 5G technology in major cities across the country. Chinese communication operators are in the process of deploying 5G networks in 16 cities to trial the technology. China has also announced plans to commercialise 5G as early as 2020.

The three major operators in China are planning to deploy 5G using the 3.5 GHz band. In September 2017, Ericsson, in partnership with Intel, completed the first 5G multi-vendor and end-to end interoperable trial across the 3.5 GHz spectrum in China (Ericsson, 2017[108]). This trial made use of Massive MIMO, beamforming and Intel's "5G mobile trial platform" (ZDNet, 2016[102]).

To meet the network densification requirements of 5G, China Mobile announced it aims to deploy 10 000 5G base stations across the country by 2020 (RCR Wireless, 2019[109]). Another main operator in the country, China Telecom, underlined in March 2018 that to provide services for its current (and projected) customer-base, the company will need to deploy more than 2 million 5G-enabled base stations across China (Light Reading, 2018[79]).

The 5G trials being carried out in China are part of the research initiative called IMT-2020 (5G) promotion group that was jointly established in 2013 by the Chinese Ministry of Industry and Information Technology, the National Development and Reform Commission, and the Ministry of Science and Technology. The IMT-2020 Promotion Group launched tests starting in 2016. The Mobile Network Operators participating in this group include China Mobile, China Telecom, China Unicom, and the Japanese operator NTT DoCoMo. Equipment providers such as Huawei, ZTE, Ericsson, Nokia, Datang and Samsung are also part of the initiative. Other members of the initiative are Qualcomm, Intel, and Mediatek. The tests of the Chinese IMT-2020 Promotion Group involve three phases: a) key technologies testing, b) the verification of the technology solution, and c) the 5G-system verification. In January 2019, ZTE announced that it had complete the third phase of the IMT-2020 5G core network trial (RCR Wireless, 2019[109]).

5.6. European Union

The "5G for Europe Action Plan" is a multi-stakeholder initiative by the European Commission that aims at boosting efforts for the deployment of 5G infrastructures and services across the "European Digital Single Market" by 2020. The European Commission (EC) proposes to align 5G roadmaps among European Union countries, make spectrum available for 5G ahead of the 2019 World Communication Conference, and promote early deployment as well as 5G-based innovation. On October 2018, the EC's COCOM Working Group on 5G published a "Report on the exchange of Best Practices concerning national broadband strategies and 5G "path-to-deployment" (European Commission, 2018[110]). In addition, the European Commission has a 5G Observatory which monitors market developments and preparatory actions taken by industry stakeholders and Member States (European Commission, 2018[111]).

In addition, the European 5G Infrastructure Public Private Partnership for 5G (5G-PPP), a joint initiative between the EC and the ICT industry in Europe launched in 2013, produced research results feeding into the action plan (European Commission, 2016[112]). The 5G-PPP aims to secure a leading role for Europe in this realm by delivering technologies and standards for the next generations of communication infrastructures, and is currently in its second phase where 21 new projects were launched in June 2017 (5G-PPP, 2018[113]).

Work from the Radio Spectrum Policy Group (RSPG) in the Europe Union has highlighted, among other issues, that the availability of the primary 5G band, i.e. 3.4-3.8 GHz, will be key for the success of 5G in Europe (RSPG, 2018[82]). Furthermore, that authorities should seek to reduce 5G deployment costs by streamlining rights of way (European Commission, 2018[114]).

National efforts to deploy very high capacity networks will continue to be supported by the European Commission through regulatory measures, especially by the new European Electronic Communications Code (EECC), as well as funding initiatives. The new EECC will facilitate the rollout of 5G networks by making rules for co-investment more predictable and by promoting risk sharing. In addition, the EECC provides a specific regulatory regime for wholesale-only operators and ensures the availability of 5G radio spectrum by improved coordination of planned radio spectrum assignments. Financial support for broadband deployment will continue in the post-2020 budget of the European Union. The European Commission's proposal for a second generation of the Connecting Europe Facility (CEF) will focus on supporting deployment of very-high capacity digital networks, including 5G, with a proposed budget of EUR 3 billion (USD 3.53 billion), complementing the European Regional Development Fund (ERDF) during the 2021-27 period, which should continue to be the main instrument for rural broadband deployment.

In addition, the EECC foresees new rules for spectrum management by European Member States, which were motivated by the advent of 5G. In particular, Article 49 of the EECC sets a minimum period of 20 years for wireless broadband spectrum licences in order to promote investment certainty.[43] Furthermore, Article 50 of the EECC prescribes that European Union member countries should take a decision on the renewal of any individual rights of use for harmonised radio spectrum in a timely manner before the expiry of those rights.[44]

5.7. France

Arcep, the communication regulator in France, has placed a high priority on 5G, as announced by the head of the regulator in March 2018 (ARCEP, 2018[115]). In December 2017, the Ministry of Economy and the Secretary of State in charge of the Digital Economy, developed a national 5G strategy that was shared for public consultation (Ministère de l'économie et des finances, 2017[116]).

Meanwhile, Arcep conducted a public consultation during the first quarter of 2017 regarding "new frequency bands for 5G and innovation". As a result, Arcep decided to make available frequencies in the 3.4-3.8 GHz bands for 5G services. In February 2018, Arcep assigned frequencies in the band 3.6-3.8 GHz to Orange and Bouygues Telecom to undertake 5G trials (ARCEP, 2018[117]).

In March 2017, Arcep also released a report to share its understanding of the issues and challenges at hand to foster the deployment of 5G networks (ARCEP, 2017[118]). Key findings were that some 5G base stations would need to be larger to cope with the use of MIMO and, urban deployment of 5G would require using infrastructures such as bus shelters, lampposts, public buildings and billboards. At the same time, the regulator highlighted the likely substantial investment of connecting 5G cells with fibre insofar as it will probably be necessary in the majority of cases to ensure expectations in quality of service. According to Arcep, the industry would have to develop innovative technological approaches that will minimise the costs of deploying 5G in rural areas.

In July 2018, Arcep, jointly with the French Government, published the report "An ambitious roadmap for 5G in France". The document outlines how to speed-up the deployment of 5G and how to foster opportunities of new business models among vertical industries (Box 4).

Box 4. An ambitious roadmap for 5G in France

The French government, working jointly with Arcep, is launching four main large-scale projects as a "Roadmap for 5G" in France. The first project is to free-up and allocate spectrum frequencies for 5G. In addition to the frequency bands that have already been allocated to mobile operators, -which could be used for 5G rollouts (e.g. the 700 MHz and 1800 MHz bands)-, two new frequency bands have been identified at the European level: the 3.5 GHz and the 26 GHz bands. Arcep is working to ensure the availability of these frequencies for trials and commercial launches, and will be holding a public consultation on these topics in October 2018.

The second project is about fostering the development of new scenarios for the use of 5G, which is being heralded as a disruptive technological generation. Particularly, France is encouraging pilot projects that will test the new potential uses of 5G: monitoring traffic, optimising energy efficiency. The purpose is to bring together interested parties (i.e. local authorities, operators, equipment suppliers, vertical industry players, beta-testers, innovative start-ups), and facilitate the creation of consortia for conducting pilot projects. In January 2018, Arcep launched a "5G pilot" window to allow players along the value chain to request frequencies in different cities, to design and test usage cases and business models.

The third project is to support the deployment of 5G infrastructure by the private sector including by streamlining rights of way. The French government and Arcep also plan to provide a guide for best practices to facilitate the deployment of 5G networks (e.g. regarding the terms governing operators' access to street furniture). Arcep will also assess the feasibility and opportunity to share small cell networks.

The fourth project is about ensuring proper dialogue and transparency to inform the public about the consequences of these deployments in terms of exposure to electromagnetic fields. The threshold values for exposure to electromagnetic fields are set by the regulatory framework, and apply regardless of the technology (2G, 3G, 4G or 5G). The 5G networks that will be deployed by operators must therefore comply with these threshold values as fully of existing technologies.

Source: « 5G: An Ambitious Roadmap for France » (ARCEP, 2018[119]).

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5.8. Germany

Germany's communication regulator, BNetzA, has published a draft decision on a procedure to award spectrum for 5G in the 2.1 GHz range (1920-1980 MHz / 2110-21070 MHz) together with unpaired spectrum in the 3.4-3.7 GHz range.[45] Furthermore, up to 100 MHz of spectrum will be made available for 5G applications for vertical industries based on individual licensing in the 3.7-3.8 GHz band. In addition, BNetzA held a public consultation in 2018 on the 26 GHz band for 5G services.

The first auction for 5G frequencies started in March 2019, as Germany expects the first commercial 5G services to be launched end of 2020 (Telegeography, 2018[120]). By 2 April 2019, BNetzA reported that EUR 4.1 billion (USD 4.82 billion) were offered by the four bidders (i.e. 1&1, Deutsche Telekom, Vodafone, and Telefonica) in the 152nd round of the 5G spectrum auction (Telecompaper, 2019[121]). The auction concluded 12 June 2019 with a total of 420 MHz auctioned, raising EUR 6.55 billion (USD 7.4 billion).[46] In addition, the auction resulted in the entry of a fourth player in the German mobile market, 1&1 Drillisch (BNetzA, 2019[59]).

Deutsche Telekom (DT), the largest MNO in Germany, expects to have several 5G commercial trials in Europe during 2018. In 2017, DT in partnership with Huawei had tested a 5G connection in Central Berlin that reached more than 3 Gbps, and latency lower than 3 milliseconds using 3.7 GHz spectrum (RCR Wireless, 2017[122]). DT has also stated that the company is fully on track to launch commercially in 2020 (RCR Wireless, 2018[123]).

As part of the "network densification" needed for 5G, DT announced in the Mobile World Congress (2018) that the company had rolled out in Europe 40 000 kilometres of fibre in 2017, and plans to deploy an additional 65 000 in 2018 to be deployed in Germany (RCR Wireless, 2018[123]).

Concerning new partnerships that are arising for 5G test labs, Nokia and Telefonica Germany in January 2018 announced a Memorandum of Understanding (MoU) for an "early 5G innovation cluster" to test network solutions and technologies in Telefonica's lab in Munich. Telefonica also plans to have trials in 2018 in Berlin to test "*Massive MIMO for high-throughput and multi-access Edge Computing (MEC) for Ultra-Reliable Low latency Communications (URLLC)*" (Telefonica, 2018[124]).

The German Government has stated that their main objective is to unlock the potential of 5G and make Germany a leading market for 5G applications. In July 2017, Germany established a Government 5G Strategy "5G-Strategie für Deutschland" bundling all on-going and future measures (Federal Government of Germany, 2018[125]). The Strategy includes five pillars including making available suitable spectrum for 5G, supporting fibre deployment, promoting cooperation with verticals, fostering research and the creation of 5G cities and regions. Subsequently, 5G targets were included in the coalition treaty of the new Federal Government established in February 2018 (Federal Government of Germany, 2018[125]).

Before the current 5G strategy, the German government launched the "five Steps toward 5G mobile communications" initiative during the 5G conference in Berlin in September 2016. A 5G dialogue forum was initialised as well, supported by the 5G focus group of the Digital Networks and Intelligent Mobility Digital Summit platform. It brings together telecommunications companies and vertical industries from the health, manufacturing, transport, and logistics sectors to integrate themselves into the standardisation and research process for 5G.[47]

Germany is promoting technologies such as automated and connected driving with the aim of enhancing road safety, reducing road congestion, and decreasing air pollution. The Federal Ministry of Transport and Digital Infrastructure supports the development of digital test-beds in the public realm, which provide industry and the research community with an opportunity to gain experience in real-world driving situations of varying degrees of complexity. Digital test-beds are "laboratories with real-life conditions", on motorways, in urban and rural environments, and in a cross-border context. In particular, the test-beds in urban and rural areas are designed to help people experience new technologies in real-life situations.[48] The lessons learned from the test-beds should provide policymakers with answers to a number of fundamental questions to enable them to improve transport policy decisions.

5.9. Hungary

The Hungarian government launched the 5G Coalition in June 2017, composed by 69 members representing a wide range of stakeholders ranging from the information and communication technology (ICT) sector, the public sector, and academia. The coalition's goal is to establish mid- and long-term strategies that will enable Hungary to make the most out of upcoming developments in 5G, as the Hungarian government expects benefits in areas such as e-health, fully automated vehicles and smart cities (Budapest Business Journal, 2017[126]). The Hungarian government plans to publish its 5G Strategy in the first half of 2019 (Ministry of Innovation and Technology of Hungary, 2019[127]).

With the aim of becoming a digital frontrunner in Europe, the test environment in the city of Zalaegerszeg offers a location for Hungary to become one of the regional centers of 5G trials. In June 2017, a cooperation agreement was signed between the government, the city of Zalaegerszeg, Autóipari Próbapálya Zala Kft (Automotive Test Course Ltd.), Magyar Telekom, and T-Systems Hungary. Magyar Telekom has already built base stations for the largest 4G+ network (with download speeds up to 800 Mbps) in this testing ground. In addition, T-Systems Hungary provides the city with access to modern digital technology and cooperates in testing of self-driving cars and smart transport solutions. The test ground is mainly financed by the government, and serves as an example of how private-public co- operation can yield synergies and contribute to a coherent digital strategy.

5.10. Italy

The Italian strategy for 5G

Italy was one of the first European countries to define the procedures for awarding the "pioneer" 5G bands, with the aim of favouring a timely transition to 5G systems. This is in line with the objectives of the *Action plan* of the European Commission, and the most recent indications in the European Union area that aims to make "5G a reality for all citizens and businesses by the end of this decade" (European Commission, 2016[112]).

In light of the promise of 5G, Italy has revised its radio spectrum policy. In 2017, the Ministry of Economic Development identified the 3.7 and 3.8 GHz bands for the implementation of project proposals concerning 5G pre-commercial trials that would be carried out over a four-year period.

The Italian trials involve the adoption of technological solutions of the 5G family both for radio access and for system aspects, including network-slicing features, and they are aimed to analyse the different usage case scenarios defined by the ITU in their IMT-2020 Vision.

Along with the Ministry's action, the communication regulator (AGCom) launched public consultations on possible additional spectrum bands to be used for the development of 5G networks in mmWave spectrum (i.e. the 26 GHz band), which had already been identified at European Union level as a priority band for the development of 5G.

With the goal of facilitating 5G deployment, the 2018 Fiscal Law (Law 205/2017) established the possibility of joint assignment of radio frequencies, both in the 694-790 MHz band and in all the 5G pioneer bands.[49] Italy has decided to make available the 700 MHz frequency band, as well as additional bands (i.e. the 3.6-3.8 GHz band and the 26.5-27.5 GHz). In addition, Italy will auction a portion of the mmWave spectrum.[50] Moreover, in Italy there is the possibility of implementing SDL (*Supplemental Down Link*) applications for PPDR (*Public Protection & Disaster Relief*) and the use of 66-71 GHz band according to the opinion of RSPG (RSPG, 2018[82]). Details on the 5G frequency assignment procedure and coverage obligations that took place in Italy in July 2018 can be found in Box 5.

Box 5. The Italian 5G frequency assignment procedure and coverage obligations

Tendering procedure

In July 2018, the Ministry of Economic Development issued a procedure for the assignment of rights to use frequencies in the bands 694-790 MHz, 3.6-3.8 GHz and 26.5-27.5 GHz. In particular:

- 700 MHz FDD band: six blocks of 5 MHz of coupled spectrum (two of which were reserved for a new entrant)
- 700 MHz SDL band: three blocks of 5 MHz each
- 3.6-3.8 GHz band: four blocks, two of 80 MHz and two blocks of 20 MHz
- 26 GHz band: five blocks, each of 200 MHz

Five companies, -Iliad Italia, Fastweb, Wind 3, Vodafone and Telecom Italia-, submitted their initial tenders on 10 September 2018. The phase of competitive bidding started on 13 September and ended on 2 October 2018, after 14 days and 171 rounds. The total amount of offers reached around EUR 6.55 billion (USD 7.7 billion).[51]

The six blocks for the 700 MHz FDD band have been assigned to the companies Iliad Italia, Vodafone and Telecom Italia (for a total of 10 MHz each), and the five lots in the 26 GHz band were awarded (i.e. one for each company). The four lots on the 3.7 GHz band were assigned to the companies Telecom Italia (80 MHz), Vodafone (80 MHz), Wind 3 (20 MHz) and Iliad Italia (20 MHz). No offer was made for the 700 MHz SDL blocks.

Coverage obligations

To ensure widespread improvements in mobile coverage across Italy, the Ministry of Economic Development, based on the national regulatory authority (AGCom) rules, established coverage obligations for the 700 MHz FDD band and the 3.6-3.8 GHz band.

Concerning the 700 MHz FDD band, the coverage obligations required winning bidders to roll out networks for improved mobile coverage of the population, tourist locations and main national road and rail transport routes (Table 4).

Table 4. Coverage obligations and timeline of the 700 MHz FDD band

Coverage goal	Obligations
National population coverage	• Within 36 months of the nominal availability of frequencies, each winning bidder has to reach 80% of the population. (The new entrant has 12 months more to achieve this goal). • Within 54 months of the nominal availability of frequencies, the winning bidders have to reach collectively 99.4% of the population.
National road and rail transport routes coverage	• Within 42 months of the nominal availability of frequencies, the winning bidders have to cover collectively all the main national road and rail transport routes.
Tourist locations coverage	• Within 66 months from the creation of the Italian tourist locations list, each winning bidder is required to cover at least 90% of tourist locations included in the list. (The new entrant has 12 months more to achieve this goal).

Source: AGCom

Concerning the 3.6-3.8 GHz band, the coverage obligations require 80 MHz winning bidders to deploy improved mobile coverage in a mandatory list of municipalities. Within 90 days from the date of the award, the winning bidders have to submit a list of municipalities to be covered to the Ministry of Economic Development. The winning bidders have 72 months from the date of the award to prove they are ready to provide 5G services in all municipalities of their mandatory list. The mandatory list has to include at least 10% of all Italian municipalities under 5 000 inhabitants. Other Italian municipalities under 5 000 inhabitants are included in a “free” list. Any player, which is not a communication operator, from 120 days from the award, can declare to the Ministry its willingness to offer the service in a municipality of this list based on a leasing contract with the 3.6-3.8 GHz winning bidders.

Finally, concerning the 3.6-3.8 GHz band, the coverage obligations will require 20 MHz winning bidders to reach the coverage of 5% of the population of each Italian region. Concerning the 26 GHz band and 700 MHz SDL, coverage obligations were not defined.

Source: AGCom

In 2018, the Ministry of Economic Development decided to update the national plan of frequency allocation, with the aim to tackle Italy's challenges around spectrum availability. In addition, AGCom is planning to reserve spectrum in the 700 MHz and 26 GHz bands for the fourth mobile operator.[52] Italy is undertaking a number of 5G trials (Box 6).

Box 6. The Italian 5G trials

Public pre-commercial trials

In March 2017, the Ministry of Economic Development launched a call for project proposals to realise public pre-commercial trials of the 5G technology in the 3.6-3.8 GHz band. The guidelines for such proposals insisted that trials should focus on the creation of an ecosystem among all actors including communication operators, business start-ups, academia, public institutions and companies in vertical industries. Both private and public pre-commercial trials have been launched. Furthermore, all trials, both public and private, are financed by the private sector in their entirety.

In August 2017, the ranking of the presented projects was approved and in September 2017, negotiations were concluded. The three geographic areas chosen by the Ministry to carry out the trials are the city of Milano, in North Italy, the cities of Prato and L'Aquila, in Central Italy and the cities of Bari and Matera in South Italy. The choice of these locations was made taking into account:

- the availability of Ultra Broadband networks and infrastructure
- the use of the 3.7 – 3.9 GHz frequency bands
- the balanced geographical distribution of areas (North; Central and South Italy).

The three geographic areas were assigned respectively to the experimentations of Vodafone Italia (Milano); of Wind 3 and Open Fiber (Prato and l'Aquila) and of Telecom Italia; Fastweb and Huawei Technologies Italia (Bari and Matera).

Around 150 5G-use-cases were tested in the described trials in the areas of:

- health (remote diagnostics; e-learning hospitals)
- Industry 4.0 (process digitisation, collaborative robotics, production chain)
- environmental monitoring (smart metres)
- mobility and road safety (assisted driving, logistic, roads surface monitoring)
- tourism and culture (virtual visits, augmented reality)
- agriculture (precision agriculture, production tracking based on blockchain technology)
- public safety (Population Security and Support for Law Enforcement)
- ports and cities (monitoring, logistics, and so forth)
- energy (smart grids and optimisations)
- universities (smart campus)

In L'Aquila, tests were made with a monitoring system for buildings and civil infrastructures, applicable also to the architectural heritage and cultural sites. The aim was to allow real time observation and knowledge of the main essential structural parameters, to notify anomalies and in emergencies.

In Matera, virtual reproductions in 3D, were made of some cultural or archaeological sites (e.g. "Sassi di Matera" or Parco della Murgia"), in order to enable remote "visit". Each project was conceived for a specific territory or area, but the aim was for the technical solutions adopted to be flexible and easily adaptable and replicable on a wider, national or even international context.

The progress made by the first quarter of 2018 points to the potential of 5G network development. Preliminary trials in the cities of Bari, Matera, Prato and l'Aquila achieved the first Italian 5G data connection, with speeds of 2.7 Gbps downlink speed, in the Milan metropolitan area.

Private pre-commercial trials

In 2017, TIM, a leading MNO in Italy, and the City of Turin launched the project "Torino 5G", making Turin the first city in Italy, and amongst the first in the European Union, covered by a new 5G mobile network. In Turin, TIM co-operated on 5G with *Politecnico* and its campus. Moreover, within the TIM Innovation Labs in Turin, TIM realised the "mmWave Lab", focusing on the research of the millimetre waves, testing solutions with frequencies up to 110 GHz.

Collaborating with the Swedish company "Ericsson", TIM, after activating Turin's first 5G-mmWave antenna, has set a new speed record for 5G in Italy, using the 28 GHz band to hit a peak speed of 20 Gbps, which was a record for an urban environment. The spectrum band has been earmarked for 5G due to its large amount of available capacity. In 2018, the project is going to be strengthened with the involvement of new players and Italian start-up and SMEs.

Further private pre-commercial trials are operating in the metropolitan area of Rome and Catania. For the city of Rome, the project "#Roma5g" is taking place by means of an agreement signed between the fixed operator "Fastweb" and the city administration. The experiments are carried out in the 3.4 – 3.5 GHz frequency band. For the area of Catania, the operator is "*Linkem*" in co-operation with Catania General Hospital and other local institutions. The experiments are carried out in the 3.5 GHz frequency band.

All the private pre-commercial trials offer new generation services related to public safety, management of public transport, virtual reality in the context of tourism, introduction of 5G in the manufacturers' productive processes, management of environmental risks, and e-learning applications for paediatric hospitals.

Source: AGCom.

5.11. Japan

Japan aims to launch their first commercial 5G network for the 2020 Tokyo Olympics. In recent years, activities related to research and development (R&D), and international standardisation of technologies and functions supporting 5G (e.g. radio access network technologies), have been accelerated with this goal in mind. On 10 April 2019, the Ministry of Internal Affairs and Communications (MIC) allocated spectrum bands for 5G services to three major mobile operators and the e-commerce firm Rakuten. NTT DoCoMo, KDDI, Softbank and Rakuten were allocated spectrum blocks in the 3.7 GHz frequency band, while NTT DoCoMo was also allocated spectrum in the 4.5 and 28 GHz bands (MIC, 2019[128]).

Huawei and NTT DoCoMo have been working on 5G trials since December 2014. For instance, in December 2017, Huawei and NTT DoCoMo achieved "5G"like download speeds of 4.52 Gbps using the 28 GHz mmWave in a trial that took place in downtown Tokyo. Huawei used its 5G base station, which supports Massive MIMO and beamforming technologies (IEEE Communications Society, 2017[129]). In November 2017, both players conducted a trial which had reached speeds of three Gbps using the 39 GHz mmWave (RCR Wireless, 2017[130]).

In November 2016, using the 4.5 GHz band, a field trail by NTT DoCoMo and Huawei in the Yokohama Minato Mirai 21 District reached speeds of 11.29 Gbps and latency ten times lower than 4G. NTT DoCoMo has also partnered with Nokia on 5G and conducted a trial in 2015 with download speeds of 2 Gbps using the 70 GHz mmWave spectrum (ZDNet, 2016[131]).

From 2017 onwards, the Ministry of Internal Affairs and Communications (MIC) has been leading "5G Field trials" with the participation of several stakeholders in the industry (including verticals from the mobile communication industry) to create new business cases for 5G. NTT DoCoMo has been carrying out some tests as part of MIC's "5G Field Trials". The main aim of the NTT DoCoMo trials has been to determine whether enhanced mobile broadband (eMBB) could achieve the necessary requirements in dense urban areas, and evaluate the performance of Massive MIMO technology. As in Korea, Japan regards its extensive fibre optic coverage as a key strategic advantage in ensuring the necessary facilities support for the role out of 5G. Some telecommunication carriers expressed their willingness to a preliminary launch of a partial service using the 5G network for 2019, which is one year earlier than expected.

5.12. Korea

Korea aims to complete the deployment of one of the world's first commercial 5G mobile network in 2019, and a nationwide 5G network by 2022. A 5G trial network was launched for the PyeongChang 2018 Winter Olympics in collaboration with Korea Telecom (KT), in partnership with Intel, Samsung, Nokia and Ericsson. This included the opportunity for visitors to use 5G trial services such as Omni View, Sync View, Time Slice, 360° VR and 5G self-driving buses around PyeongChang Olympic campus. In addition, SK Telecom has already tested its connected car in 2016 and autonomous cars on the Gyeongbu Expressway in Korea, traveling 26 km at a speed of up to 80 km/hour. From December 2017 to February 2018, SK Telecom has demonstrated several immersive media services such as AR/VR and 5G connected autonomous cars with several V2X services.

Korea had plans to commence the first mobile 5G services in the first quarter of 2019 (Figure 6). The required spectrum for 5G in Korea (3.5 GHz and 28 GHz) was auctioned in 2018, with the necessary equipment planned to be available for commercial services by 2019. Indeed, on 5 April 2019, Korea started to offer commercial 5G services by the three leading MNOs (KT, SK Telecom and LGU+) using as terminal device the Samsung Galaxy S10 5G smartphone. KT will offer its 5G service at KRW 55 000 (USD 49.97) a month, with download speeds 20 times faster than 4G networks. The SK Telecom 5G plan of unlimited data is priced at KRW 80 000 per month (USD 72.7), while LG's service of 500 GB (i.e. equivalent to 60 movies) will be priced at KRW 75 000 per month (USD 68.2) (Nikkei Asian Review, 2019[5]).[53]

Figure 6. Korea's 5G roadmap

Source: Ministry of Science and ICT Korea.

Korea's 5G vision and policies are part of a broader strategy called "*Building a hyper-connective intelligent network in preparation for the Fourth Industrial Revolution*" (Box 7). The main pillars of this strategy are to achieve:

- One of the World's first commercialisation of 5G (first half of 2019), and a nationwide 5G network by 2022
- Increasing the number of IoT connected devices to 30 million by 2021 (from the currently 11.6 million)
- Building smart, safe networks based on software and Artificial Intelligence
- Guarantying ubiquitous high-speed broadband access (both urban and remote areas)

Box 7. Building a hyper-connected intelligent network in preparation for the Fourth Industrial Revolution

Korea views the further development of fixed line infrastructure as a key element of its strategy for going digital and crucial to the success of 5G. Accordingly, 10 Gbps fixed line services were launched in the latter part of 2018 and the fibre optic networks that support these services will become the core infrastructure to support 5G deployment. These advanced fibre-to-the-premises (FTTP) facilities will provide the backhaul for 5G micro-cells. By 2022, the government has set a goal for 50% of households in urban areas to be covered by 10 Gbps broadband access by 2022

In their vision for the networks to support the 4th industrial revolution, the government views 5G and 10 Gbps broadband as parts of the "central nervous system" of the "hyper connected network" and the IoT as the "peripheral nervous system" that will "sense" and collect the data necessary for the next production revolution (Figure 7).

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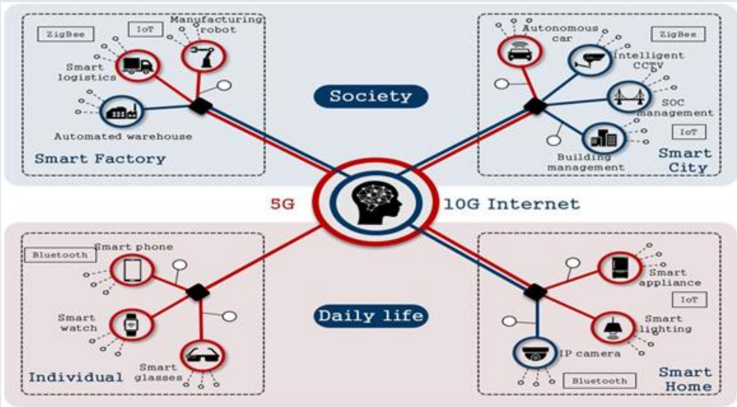
Figure 7. Korea's vision of 5G and 10 Gbps Internet as a foundation of the 4th Industrial revolution



Note: "Central nervous system" is 5G (▬▬) and 10 Gbps broadband (▬▬); the "Peripheral nervous system" is IoT (▬ ▬ ▬).
Source: Ministry of Science and ICT Korea.

A further element of Korea's strategy for introducing 5G involve quality of service (QoS) measurement (i.e. coverage, speed and so forth). The existing programme for QoS measurement and publication, conducted by the NIA, will be continued to promote the deployment and coverage of 5G through the empowerment of consumers to make informed decisions on network providers. In addition, the Ministry of Communications has provided incentives for operators to collaborate to facilitate the efficient use of telecommunication equipment and build the 5G network. In fact, in April 2018, the main SK Telecom, KT, LGU+ and SK Broadband announced an infrastructure sharing agreement for 5G expecting to save KRW 1 trillion (USD 934 million) over the next decade.[54]

The government is also working on policy measures to encourage facilities management institutions (e.g. in the field of transport) to provide certain areas of subways/tunnels to telecommunication companies to deploy facilities. In the case of co-investment (or joint construction) of networks, the aim is to have policies that provide equipment quality standards to intensify competition in urban areas, and promote joint deployment in rural regions. For example, the government is looking to improve the system for joint construction of essential facilities in the telecommunications industry based on feedback from providers undertaken in the first half of 2018.

Korea is also promoting 5G trials that aim to find and verify new business models in the telecommunications industry by integrating 5G infrastructure operators with new industry verticals (e.g. autonomous vehicles, telemedicine, etc.). The vision is to integrate regional strategic projects (Gyeongnam-drone, Daegu-healthcare, Gyeonggi-autonomous car and so forth), and carry out 5G-based trial projects in the public sector (e.g. emergency services/disaster response, medicine, administration, defence). In 2018, the budget for these trials that are part of the "Giga Korea project: 5G convergence plan" was KRW 274 billion (USD 254 million).[55] The objective is to use these trial projects to find and improve regulations hindering the creation of new convergence industries and services based on 5G services.

Source: Ministry of Science and ICT Korea.

5.13. Singapore

The rapid growth in mobile data traffic and consumers' demand for enhanced mobile broadband experience have led to an increasing emphasis on the upcoming fifth generation of mobile technology. Noting the international interest in identifying additional spectrum for 5G and developing relevant standards, the Infocomm Media Development Authority of Singapore (IMDA) engaged interested stakeholders in a public consultation on the issue on 23 May 2017. Through the public consultation, IMDA hoped to seek views and comments on the various aspects of 5G technology development and spectrum requirements. IMDA had also organised a 5G workshop to provide a platform for the industry to deliberate on the potential 5G use cases and to exchange views on the commercial, regulatory and infrastructural issues that are imperative to facilitate the deployment of such use cases (IMDA, 2019[132]).

To facilitate 5G technology and service trials by the industry, IMDA has waived the frequency fees for interested companies until 31 December 2019. 5G trials conducted by mobile network operators (MNOs) in Singapore have demonstrated promising capabilities, having achieved throughputs of more than one Gbps with an extremely low latency of less than one millisecond. The lower regulatory barrier had enabled some of the MNOs to build a live trial 5G network and explore the potential benefits and applications of 5G. Trials conducted in a real-world environment will also assist the industry in better understanding how 5G will operate in Singapore's business environment and its optimum deployment scenarios. Companies that are interested in conducting 5G trials may utilise the existing IMDA's Technical Trial and Market Trial framework.[56]

Besides facilitating trials, IMDA recognises that new spectrum resources will be needed to fuel the next generation of mobile services. With the commercial deployment of 5G services and applications, IMDA has projected that the spectrum demand will increase to at least 3360MHz. IMDA has thus identified several spectrum bands that may be suitable for 5G deployments in Singapore.

In addition, the mobile industry has begun to explore technologies that enable spectrum to be aggregated across both licensed and licence-exempt bands. Such technologies would enable MNOs to increase mobile data speeds and overall network capacity. IMDA is thus considering developing regulations to support the deployment of such aggregation technologies while ensuring that deployment of technologies such as Wi-Fi can continue in licence-exempt spectrum bands in Singapore.

5.14. Spain

The development of 5G network and services in Spain is one of the main strategic objectives of the Ministry of Economy and Business (MINECO). With that purpose in mind, MINECO published the 5G National Plan for the period 2018-2020, in in December 2017. The Plan took into account the responses received to a public consultation held in July 2017.

The 5G National Plan aims to become the foundation to maximise the benefits delivered by 5G in Spain, for the telecommunication sector and more broadly overall economic and social development. The 5G national Plan is grounded on several main pillars: spectrum management, trials, fostering research in 5G and taking advantage of Spain's extensive fibre optic network coverage.

Radio electric spectrum management and planning

Spain's 5G National plan includes actions to ensure the timely availability of the different frequency bands that are required to provide communication services on 5G networks: 700 MHz, 1.5 GHz, 3.6 GHz and 26 GHz. These bands have been identified in the European Union as the best candidate to deploy 5G networks. The actions belonging to this pillar started in 2018 with:

- A recent tender process has been awarded for a section of the 3.6 GHz band (3.6 - 3.8 GHz sub-band)
- The definition of the national roadmap, for the release of the 700 MHz band and the granting of rights of use for electronic communications services on such a band, as established in the Decision (EU) 2017/899 of the European Parliament and the Council of the European Union.

Trial experiences

The 5G National Plan includes calls for projects to deploy pilots of 5G infrastructure. Such projects will allow the validation of the new 5G network capabilities, as well as the development of applications and sectoral cases for use: agriculture, tourism, connected vehicles and so forth. The calls are opened to the participation of any agent involved in digital transformation projects. The pilot experiences are aimed at promoting an early demand for experimentation with 5G technology. The first call for two pilot projects was opened in 2018.

Fostering of 5G-based research, development and innovation

The Secretary of State for the Digital Advancement (SEAD), within the MINECO, is currently running a state aid program for the promotion of research, development and innovation in Information and Communication Technologies (ICT) and the Information Society. This program is part of the National Plan for Scientific-Technical Research and Innovation. SEAD promotes 5G technology as one of the thematic priorities of the former aid program for the period 2018-2020. As an additional action, it is encouraged to validate the awarded aid projects on the experimental 5G networks of the pilot projects. SEAD has created a project office to manage and coordinate all the actions included in the 5G National Plan.

Aside from the availability of wireless infrastructure, 5G networks rely on the existence of a fixed infrastructure with high capacity and coverage. Such a requirement is already in place in Spain because of the broad coverage of fixed networks providing at least 100 Mbps. These networks covered 76% of the Spanish population in mid-2017. Spain has the largest FTTH network in Europe.

5.15. Sweden

Given many industry developments in 5G in Sweden, the Swedish Post and Telecom Authority (PTS) planned to allocate test licences for 5G trials through administrative procedures in spring 2017 (PTS, 2017[133]). During the public consultation that took place until February 2017, market players expressed support of PTS proposal on the Spectrum Plan for 5G tests, which includes trial licenses in the 3.4-3.6 GHz and 26 GHz bands (PTS, 2017[134]). In addition, Telia has announced plans to deploy 5G networks by 2018 (Telia, 2017[135]).

PTS is at present participating in the preparatory work for the ITU World Radio Conference that will take place in November 2019 (i.e. WRC-19), where there will be discussion of possible allocation of bands for the new generation of wireless services or "5G" (PTS, 2017[136]).

Industry players in Sweden are undertaking 5G trials in the millimetre wave bands, and collaborations and joint partnerships between different stakeholders are arising in order to test 5G technology and other related applications. For example, Ericsson jointly with Telia has performed outdoor testing in Kista, Stockholm (Ericsson, 2016[137]). Also, in August 2017 Telia, Boliden, Ericsson, Volvo, ABB, RISE SICS and LTU Technologies joined forces to test 5G technology for safety communications in the Kankberg underground mine in Boliden, Sweden (RR Media Group, 2017[34]). In January 2016, Telia, jointly with Ericsson, announced that by 2018 they would launch a 5G network in Stockholm and Tallinn. In November 2016, Telia announced a similar joint venture with Nokia to launch a 5G network in Helsinki (Telia, 2017[138]). Finally, in a similar manner to Italian trials focusing on logistics, Telia has worked with Ericsson and Intel, to trial 5G with a passenger cruise ship and remotely controlled excavators in Tallin, Estonia (Telecompaper, 2017[139]).

An application that is closely related to 5G and the Internet of Things is fully automated driving. Notably, Volvo is planning to offer customers fully automated vehicles by 2021, and initiated in January 2017 a massive trial of 100 self-driving vehicles tested by people from the general public in the city of Gothenburg (Nordic Business Insider, 2017[140]).

5.16. Switzerland

To foster the deployment of 5G networks in Switzerland, the Swiss Communications Regulatory Authority (ComCom) intends to make available the 700 MHz frequency band, the 1.4 GHz frequency band and furthermore the 3.5-3.8 GHz frequency band. Corresponding consultations on the award of these bands have been done during January and February 2018. The auction of the mentioned bands is planned early 2019.

The Swiss operators Salt (collaborating with Nokia) and Sunrise (together with Huawei), have presented 5G demos in December 2017 and January 2018, respectively. Swisscom has started 5G field trials together with its network supplier Ericsson in 2018.

5.17. United Kingdom

The Future Telecoms Infrastructure Review, announced in the UK Government's Industrial Strategy and published in July 2018, took an in-depth look at the telecommunication market, to understand incentives for investment in future telecommunication infrastructure and assessed whether the current market could deliver the Government's aims (UK Department for Digital, Culture, 2018[43]). This review confirms the United Kingdom Government's aspiration for the majority of the population to have 5G coverage by 2027.

The Review concluded that the Mobile Network Operators (MNOs) will be central to the successful delivery of 5G in the United Kingdom, and that 5G creates the potential for market expansion with new infrastructure and service players. That is why the Review recommends policies to encourage a shift to a 'Market Expansion Model' that maintains the benefits of competition between MNOs, while encouraging new solutions. Specifically, the Review recommends policies to:

- Reduce costs of network deployment
- Support the growth of new infrastructure deployment models that promote competition and investment in network densification

- Fund beneficial 5G-enabled use-cases through the GBP 200 million (USD 266.7 million)[57] "5G Testbeds and Trials Programme" to mitigate the risk of business models for 5G solutions
- Promote new, innovative 5G services from existing and new players, through the release of additional spectrum and spectrum authorisation.

In parallel, the Government of the United Kingdom is continuing to work with Ofcom, the communication regulator, and the industry to address mobile connectivity challenges. The Government of the United Kingdom is aware that without reliable connectivity across the country, the benefits of some of the new and innovative applications arising from 5G will not be fully realised.

5G Testbeds and Trials Programme

The "5G Testbeds and Trials Programme" (5GTT), launched in late 2017, is set to run until 2020-21. The aim is launch a series of projects across the United Kingdom to deploy new wireless infrastructure and test 5G technology in a number of sectors to create new applications and services. The programme will help identify deployment, business and technical challenges that may influence future 5G networks. The objectives of the 5GTT programme are to:

- foster the development of the United Kingdom's 5G ecosystem
- build business models for 5G by stimulating new use-cases and create the conditions needed to deploy 5G efficiently, and
- lead the way in 5G Research and Development (R&D) to drive United Kingdom's 5G leadership.

In July 2017, the British government awarded GBP 16 million (USD 21.3 million)[58] to three leading 5G research institutions in the United Kingdom (i.e. the 5G Innovation Centre (5GIC) at the University of Surrey, the University of Bristol and King's College London), to collaborate together and form a test-network to trial 5G technologies and applications. The network and its capabilities were successfully demonstrated in March 2018. Also in March 2018, the Government announced the winners of the Phase 1 funding competition (UK Department for Digital, Culture, 2018[141]). The six projects, led by industry, universities and local authorities each received between GBP 2 million (USD 2.7 million) and GBP 5 million (USD 6.6 million) in government grants and are match funded by industry. The projects' aims include exploring innovative radio technologies that will help to change rural economics, delivering low-cost healthcare solutions into homes and enhancing productivity in manufacturing.

In September 2018, the Government selected the West Midlands to be the location of a large-scale urban testbed (i.e. the Urban Connected Communities project). Up to GBP 50 million (USD 66.7 million) is currently available for the project, including GBP 25 million (USD 33.3 million) of funding from the Department for Digital, Culture, Media and Sport, plus additional industry match funding. Further announcements on a test bed focusing on rural economics, including business models that may help improve coverage in rural areas, the Rural Connected Communities project, are expected soon (Box 8). The Government published an update on the 5GTT Programme in September 2018, which outlines plans for its projects over the following twelve months (UK Department for Digital, Culture, 2018[142]) (Figure 8).

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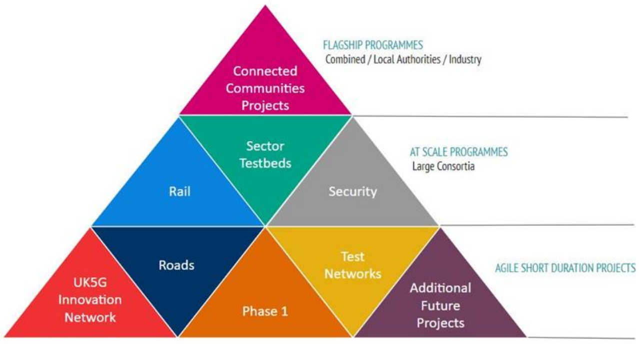
Figure 8. United Kingdom Phase I Testbeds and Trials



Source: UK Department for Digital, Culture, Media and Sport (2018), 5G Testbeds & Trials Programme Update, https://www.gov.uk/government/publications/5g-testbeds-trials-programme-update (accessed on 2 November 2018).

Box 8. 5G RuralFirst

5G RuralFirst is a co-innovation project led by Cisco. It involves a consortium of partners that includes the principal partner, the University of Strathclyde, as well as the BBC, the Agri-EPI Centre, Orkney Islands Council and Scottish Futures Trust. 5G RuralFirst is a testbed for rural 5G trials and projects; exploring and identifying new business models and use cases for connectivity deployment in rural areas. It aims to showcase the potential of 5G in rural environments.

Looking beyond the city, 5G RuralFirst has created three testbeds in the Orkney Islands, Somerset, and Shropshire, exploring different aspects of and use cases for 5G connectivity in rural areas. Specifically, these trials are demonstrating the value of connectivity to rural areas and exploring new emerging business models, across seven broad themes:

- 5G Core Network – including 5G network slicing
- 5G Radio Access Technology - pioneering band frequencies (700MHz, 3.5GHz and 26GHz) and integration of other bands including ISM (2.4GHz/5GHz) and spectrum available for sharing
- Dynamic Spectrum Access – testing the feasibility of dynamic and shared spectrum for 5G to demonstrate the benefits and operability in rural areas
- Broadcast – testing the feasibility of 5G standards to provide a more efficient distribution mechanism for broadcast – both narrowcast, and wider national broadcast.
- Agri-tech – testing the potential of 5G technologies to improve how farms grow crops and look after livestock
- Industrial IoT – testing applications for renewable energy, power generation and industrial equipment Orkney – testing a range of use cases across the islands, demonstrating and assessing the benefits to local residents in extreme and very remote rural environments.

Source: More information on the project can be found at 5Gruralfirst.org

The 5G Innovation Network (UK5G)

The 5G Innovation Network (UK5G) was created to boost and strengthen the development of the 5G ecosystem in the United Kingdom. The network is intended to facilitate coordination of activities taking place across the country in the developing 5G arena. Cambridge Wireless, in partnership with the Knowledge Transfer Network and TM Forum, run the network. They announced their advisory board, who met for the first time in April 2018. As of April 2019, the network has over 1 500 members and includes around 500 organisations, with a senior advisory board of leading industry experts overseeing the work of the network and advising the Department for Digital, Culture, Media and Sport. Spectrum

In March 2018, Ofcom published "Enabling 5G in the UK", which sets out the actions that the regulator is taking to enable 5G deployments in the United Kingdom, including ensuring that access to spectrum is not an inhibitor (Ofcom, 2018[56]). In April 2018, as part of Ofcom's effort to promote 5G, the 2.3 GHz and 3.4 GHz spectrum auctions took place. Four players (Vodafone, EE, O2 and Three) acquired spectrum in these bands (5G UK, 2018[143]). Ofcom has also announced that further spectrum in the range 3.6-3.8 GHz will be made available to be auctioned in 2019 (Ofcom, 2018[56]). Ofcom has also announced that the 700 MHz band will be auctioned in 2019.

Regarding mmWave spectrum, in July 2017, Ofcom made a Call for Inputs (CFI) to seek stakeholders' input on making the 26 GHz band available for 5G deployment in the United Kingdom (Ofcom, 2017[144]). Innovation and trial licences are available for interested parties to trial technology and business models using this spectrum in the United Kingdom. In addition, Ofcom recently published a statement confirming opening up access to 14 GHz of contiguous spectrum in the 57-71 GHz band for fixed and mobile use, including for 5G, on a licence exempt basis (Ofcom, 2018[145]).

Ofcom has commenced work to understand the connectivity demand and requirements for innovative use cases coming from different sectors, including how connectivity could help organisations and businesses meet their productivity and efficiency objectives. It recently published a discussion paper on this area, and is holding a number of industry workshops throughout 2019 (Ofcom, 2019[146]).

5.18. United States

The United States, in addition to the plans for releasing spectrum for 5G, has identified reforms to infrastructure deployment as a priority for 5G rollout. As part of the Federal Communications Commission (FCC) Strategic Plan 2018-22, the FCC has committed to "*set rules that maximize investment in broadband and promote a regulatory approach of light-touch regulation, facilities-based competition, flexible use policy, and freeing up spectrum to encourage and facilitate the development of 5G networks."* In addition as part of their strategic goal to promote innovation, one of their key performance targets is to "*Promote investment in infrastructure and 5G networks by eliminating unnecessary administrative burdens"* (FCC, 2018[147]). The FCC has also released a comprehensive strategy to "*Facilitate America's Superiority in 5G Technology*" coined as the "5G FAST Plan", and has taken a number of actions to foster 5G deployment. The plan seeks to make more spectrum available to the market, update infrastructure policy as to reduce deployment costs, and modernise regulation (FCC, 2018[148]).

In the United States, Verizon Wireless has launched fixed wireless 5G service in four cities using its proprietary 5GTF standard. In addition, several wireless operators either have conducted or are still conducting trials of mmWave spectrum for use in 5G services. For instance, Verizon ran 5G trials in 11 cities in the United States. These trials, called “pre-commercial networks”, were conducted in partnership with Cisco, Ericsson, Nokia, Qualcomm and Samsung. AT&T has introduced mobile 5G in parts of 12 cities in 2018 and has announced plans for 5G deployment in another seven cities beginning in early 2019 (PCWorld, 2018[149]).

On 3 April 2019, Verizon Wireless turned on its first 5G cell sites in two cities (Minneapolis and Chicago. At the time of writing, only one smartphone was available to work on its 5G network, the Moto Z3, which requires a USD 200 adapter to work. The company says that it will be offering a 5G Samsung Galaxy S10 5G-service in mid-May 2019 (eWeek, 2019[150]). In December 2018, AT&T had announced the launch of a mobile 5G device (AT&T, 2018[151]). The terminal device used in the AT&T network is a mobile router.

In terms of spectrum, the FCC has focused on making additional low-, mid- , and high- band spectrum available for 5G services. For example, for high bands, the United States will hold in November its first 5G spectrum auctions in 2018 in the 28 GHz and 24 GHz bands. In 2019, the FCC will auction the upper 37 GHz, 39 GHz, and 47 GHz bands. With these auctions, 5 GHz of 5G spectrum will be released into the market. For mid-range bands, that have become a target for 5G rollout given coverage and capacity features, the United States proposes to make available up to 844 MHz on the 2.5 GHz, 3.5 GHz, and 3.7-4.2 GHz bands. With respect to low-bands (useful for wider coverage and 5G deployment in rural areas), the FCC is clearing broadcasters from the 600 MHz band and acting to improve the use of other low-band spectrum for 5G services, with targeted or proposes changes to the, 800 MHz and 900 MHz bands. In addition, the FCC recognises the important role of unlicensed spectrum for 5G, and proposes to create new opportunities for the next generation of Wi-Fi in the 6 GHz and above 95 GHz band (FCC, 2018[148]). For example, the FCC has taken steps to facilitate next generation wireless technologies in spectrum above 24 GHz by making available the 64-71 GHz frequency band for unlicensed use (FCC, 2016[152]).

Finally, as mentioned previously, the FCC is updating its infrastructure policies and encouraging the private sector to invest in 5G networks by adopting new rules and clarifying existing rules to reduce obstacles for small cell deployment both at a federal and municipal level. For example, in September 2018 the FCC clarified its views regarding the amount that municipalities may reasonably charge for small cell deployment (FCC, 2018[86]).

6. Concluding remarks

There are many potential benefits from 5G, and important advances have been made in industry standards (i.e. the first phase of the 5G-NR 3GPP standard was agreed upon in June 2018). It should be noted that in the case of technology and service neutrality all spectrum bands available today could be used for 5G depending on economic considerations of the operators. However, many expect that deploying 5G networks will require smaller cell sites, complementing traditional large cell towers. This will require bringing smaller cells closer to connected devices through a process called 'network densification'. Such cells will need to be connected to backhaul, extended into rural and remote regions, underlining the need for increased investment in next generation network deployment. A broad range of communication platforms including fibre, Wi-Fi, and satellite technologies are expected to support 5G networks to varying degrees.

One key feature for the deployment of 5G networks is the likely high deployment costs (fibre backhaul, millions of small cells and so forth). Many stakeholders have noted that 5G is the first generation of wireless networks where use cases are driving technology developments, with new trials and partnerships organised to develop scenarios for use and to foster business models for 5G. In the coming years, the sector may therefore see an increase of collaboration between networks and vertical industries.

New partnerships are arising, not only among industry verticals and horizontal players, but also among countries. In the European Union, a clear example is the 5G corridors (i.e. highways) that involve the collaboration of many European countries in order to prepare for a future with fully automated vehicles that may potentially use 5G.

New regulatory issues arise with 5G, and one main concern for stakeholders relates to power density regulation (or electromagnetic limits in a given location). Other regulatory issues include the implications of "network densification" and "network slicing." In the future, the probability is high that countries will foster infrastructure-sharing agreements (inherent to the use of mmWave spectrum) for practical and cost considerations. Korea provides one example of these types of agreements where MNOs expect substantial savings by sharing 5G base stations (Telecompaper, 2018[85]).

While the technology and business cases are still rapidly evolving, some of the traditional telecommunication regulatory issues will likely become even more crucial and relevant for the successful deployment of this new generation of wireless technologies. As wireless networks become a further extension of fixed networks, due to network densification, these key regulatory issues will include: streamlining rights of way (to deploy massive numbers of small cells and backhaul connecting the cells), efficient spectrum management across all platforms, deployment and access to backhaul and backbone facilities, and new forms of infrastructure sharing.

Annex A. Sources of Country 5G auctions and trials

Table A.1. News sources of spectrum auctions

Country	Link
Australia	http://www.theage.com.au/business/media-and-marketing/australian-regulator-fasttracking-upcoming-5g-auction-at-superhigh-frequency-20170911-gyewu4.htm
Chile	https://www.telegeography.com/products/commsupdate/articles/2017/12/15/claro-chile-nokia-stage-5g-lab-trial-using-27ghz-band/index.html
Korea	https://rysavyresearch.files.wordpress.com/2017/10/2017-08-5g-americas-rysavy-lte-5g-innovation-v2.pdf
United States	https://apps.fcc.gov/edocs_public/attachmatch/DOC-347449A1.pdf
Other sources	(European Commission, 2016[153]), (Huawei Press Center, 2017[154]).

Table A.2. News sources and company press releases on 5G trials

Country	Source	Link
Australia	Melbourne Optus Trial 2016 (ARN)	https://www.arnnet.com.au/article/610221/optus-huawei-nudge-35gbps-5g-trial/
Chile	Telegeography	https://www.telegeography.com/products/commsupdate/articles/2017/12/15/claro-chile-nokia-stage-5g-lab-trial-using-27ghz-band/index.html
China	Tech Republic, RCR Wireless	https://www.rcrwireless.com/20190118/5g/zte-completes-5g-test-china-unicom https://www.rcrwireless.com/20190110/5g/zte-completes-third-phase-china-national-5g-core-network-test https://www.rcrwireless.com/20180613/5g/nokia-compltes-5g-test-part-china-national-5g-trial-tag23 https://www.techrepublic.com/article/in-china-5g-trials-zte-hits-massive-19-gbps-network-speeds/
Hungary		https://www.ericsson.com/en/news/2017/10/ericsson-and-magyar-telekom-demostrate-first-5g-link-in-hungary https://www.telekom.hu/about_us/press_room/press_releases/2018/july_02 https://bbj.hu/news/vodafone-performs-hungarys-first-5g-live-video-broadcast_155408 Nokia Bell Labs, Budapest projects: https://hipa.hu/on-the-verge-of-5g-nokia-is-developing-the-thinking-network-of-the-future-in-budapest BME research project: "Mobile 5G wave propagation tester system": https://www.bme.hu/news/20170816/Research_team_at_Faculty_of_Electrical_Engineering_and_Informatics_wins_space_tender?language=en
Ireland	RTE Ericsson Vodafone	https://www.rte.ie/news/business/2018/0207/938967-vodafone-5g/ https://www.ericsson.com/en/news/2018/2/ericsson-and-vodafone-run-first-live-demo-of-pre-standard-5g-in-ireland https://n.vodafone.ie/aboutus/press/vodafone-hosts-irelands-first-live-5g-test.html
Japan	MIC, NTT Docomo, KDDI (NEC), Softbank (ZDNet)	News sources and company press releases on 5G trials in Japan such as NTT DOCOMO and KDDI MIC Field Trials: https://www.ituaj.jp/wp-content/uploads/2018/10/nb30-4_web.pdf NTT: https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/rd/technical_journal/bn/vol20_1/vol20_1_000en.pdf https://www.nttdocomo.co.jp/english/corporate/technology/rd/tech/5g/5g_trial/ https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201810fa7_s.html KDDI: https://www.nec.com/en/press/201802/global_20180215_01.html Softbank: https://www.zdnet.com/article/softbank-partners-with-zte-on-5g-trials/
Korea	KT	https://m.corp.kt.com/eng/html/biz/services/vision.html;

	SKT	https://news.samsung.com/us/sk-telecom-samsung-successfully-completed-4g-5g-network-interworking-trial-seoul/
Spain	BN Americas	https://www.bnamericas.com/en/news/ict/telefonica-to-trial-5g-in-two-spanish-cities/
South Africa	Ericsson	https://www.ericsson.com/en/news/2018/1/5g-in-south-africa
Sweden	Fierce Wireless RR Media Group	https://www.fiercewireless.com/europe/telia-ericsson-trial-5g-live-outdoor-network, https://www.rrmediagroup.com/News/NewsDetails/newsID/15896
Switzerland	Swisscom Salt Sunrise	https://www.swisscom.ch/en/about/medien/press-releases/2018/02/20180222-mm-5G-2018.html https://www.salt.ch/media/press/files/2018/1/25/fa5ff6bc-9c08-4713-b69c-a19d2e43c21c/309/Salt_5G%20-%20Salt%20and%20Nokia%20showcase%20mobile%20network%20of%20the%20future.pdf https://www.sunrise.ch/fr/spotlight/2018/02/record-du-monde-5g-sunrise-huawei.html
United Kingdom	Vodafone EE	https://mediacentre.vodafone.co.uk/news/vodafone-first-full-5g-in-the-uk/ https://newsroom.ee.co.uk/ee-brings-5g-to-the-uk-for-the-first-time-with-switch-on-of-live-5g-site-in-canary-wharf-trial/
United States	ZDNet SDX Central Qualcomm	https://www.zdnet.com/article/verizon-trials-5g-in-washington-dc-with-nokia/ https://www.sdxcentral.com/5g/definitions/5g-trials/ https://www.qualcomm.com/news/releases/2017/01/03/qualcomm-ericsson-and-att-announce-collaboration-5g-new-radio-trials
Global Trials (February 2018)		VIAVI Report on the State of 5G: https://www.viavisolutions.com/fr-fr/node/59268

End Notes

1 The IMT-2020 requirements were developed within ITU-R Working Party 5D. See Recommendation "ITU-R, M.2083 - IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond" (ITU, 2015[9]).

2 The reason for some operators to opt for keeping 2G networks, while fading out 3G, is the need to support legacy machine-to-machine (M2M) and internet of things (IoT) connections that run on 2G (Capacity Media, 2017[175]). This is particularly the case for several European operators such as Vodafone Europe, Telenor of Norway and T-Mobile Czech Republic (Telegeography, 2017[3]).

3 Usually 4G is understood as 4G-Long Term Evolution (LTE)-Advanced, however, technically speaking there are other standards (e.g. WiMAX Rel. 2) that also fulfil the IMT-Advanced criteria. Moreover, 4G is frequently used as a "marketing designation", also referring to LTE and WiMAX.

4 The IMT-2020 requirements were developed within ITU-R Working Party 5D. See Recommendation "ITU-R, M.2083 - IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond" (ITU, 2015[9]). The accompanying spectrum for 5G is expected to be finalised in 2019 in the ITU's World Radio Communications Conference (WRC 19), having been first discussed at WRC 12. WRC-19 is invited to consider additional spectrum allocations to the mobile service on a primary basis and to consider identification of frequency bands for the terrestrial component of IMT.

5 See also GSMA, "The 5G era: Age of boundless connectivity and intelligent automation", 2017

6 Meanwhile, the potential future integration of non-terrestrial radio technologies, including satellite, could extend coverage, boost resiliency, and extend communications to moving platforms including aircraft, ships, trains, and land-based vehicles (OECD, 2017[11]).

7 The exchange rate used is from OECD.Stat of 1100.56 KRW/USD for the year 2018.

8 Autonomous driving may not rely on the availability of any mobile network. However, with information received through networks autonomous driving may become more efficient. More examples of different uses and the most important network requirements can be found in Table 1 of the Ericsson report "5G Systems: enabling digital transformation" (Ericsson, 2017[1]).

9 For more in depth information on the roles of satellites in communication networks, please refer to 2017 CISP work on the topic (OECD, 2017[11]).

10 Satellite technologies have a role in connected and automated vehicles that ranges from GPS/mapping to potential use for ensuring ubiquitous coverage, system software updates, among others.

11 For more information on fully automated vehicles, as a critical IoT application, please refer to previous OECD work on the subject "IoT Measurement and Applications" (OECD, 2018[179]). This report in page 38 provides a diagram of the levels of automation (i.e. Level 1-5) as defined by the Standard J3016 of the Society of Automotive Engineers. Under this definition, a human can intervene up to level three of automation. For example, the UK government labels Levels 1-3 of automation as "assisted driving" and only Level 4 and 5 as "automated driving" (UK Government, 2016[157]).

12 "The latest agreements see Spain and Portugal signing a letter of intent to establish two joint corridors between Vigo and Porto, and Merida and Evora which will allow connected automated driving to be tested across borders. In addition, Italy and the three presidents of the Tyrol – Sudtirol – Trentino Euro region also confirmed their intention to work with other interested member states on the development of the 5G corridor on the Brenner Pass motorway" (Mobile World Live, 2018[29]).

13 Using the exchange rate from OECD.Stat of 0.85 EUR/USD for the year 2018.

14 Satellite technologies, especially next-generation systems, hold the promise to alleviate some of this burden, particularly in areas where fixed wireless backhaul and fibre deployment may be unlikely.

15 A femtocell is a small, low-power cellular base station, typically designed for use in homes or small businesses.

[16] Austria notes that in their market they still observe some significant substitution between fixed and wireless networks. In the 3.4-3.8 GHz auction that took place in 2018, tighter caps are applied for those operators that own a large fixed network. Please refer to Section 3.3 on page 19-22 at https://www.rtr.at/en/inf/Konsult5GAuktion2018/Appendix_competition_meausures.pdf. Since T-Mobile bought the largest cable network operator (UPC), such a cap was also imposed on T-Mobile.

[17] Research undertaken by Verizon, based on FCC data, suggests that at speeds of at least 25 Mbps downstream and 3 Mbps upstream, Comcast is the only option for 30 million households and Charter Communications is the only choice for 38 million households (Ars Technica, 2018[45]).

[18] In terms of costs of fixed wireless alternatives versus wired broadband, the costs depend on population density, the spectrum band used for the fixed wireless solution, among other things. For example, the Arris and CableLabs report they tested a 3.5 GHz deployment and a 6-metre tower broadcasting wireless solution and found that it would cost annually USD 3 725, i.e. around USD 75 per client considering a service group of 50 households. The report then compares figures from a fibre supplier, Corning, where estimated deployment costs are around USD 1 153 to deploy fibre in a "dense" area (defined as roughly 880 households per square mile) with the cost increasing to USD 2 499 in areas where there are only 72 households per square mile (Arris and CableLabs, 2017[47]).

[19] WRC-19 is invited to consider additional spectrum allocations to the mobile service on a primary basis and to consider identification of frequency bands for the terrestrial component of IMT. Only bands above 24 GHz will be identified at WRC-19, while bands below 6 GHz have already been identified by previous WRCs. Many countries, including the USA and Korea, have already made spectrum available for 5G services.

[20] In Europe, the European Conference of Postal and Telecommunications Administrations (CEPT) has concluded the development of the harmonised technical conditions for deployment in 2018. The European level implementation of the CEPT technical conditions for the 3.4- 3.8 GHz band, and the harmonisation of this band at the European Union level should have concluded by the end of 2018.

[21] In Denmark, flat licenses can be issued to mobile operators in a large area, and they are not required to report the location of the particular base stations. Therefore, there is not much of a difference with a license-exempt regime in this regard. Rules are established to ensure a fair use of the licenses and prevent interference to other services and users.

[22] Unlicensed spectrum refers to frequencies not licensed to any specific party, but rather open for use by any equipment which meets the required minimum standard for interference-free use (i.e. Wi-Fi and short range devices such as Transport and Traffic Telematics (TTT) and Dedicated Short Range Communication (DSRC) devices).

[23] Using the OECD.Stat exchange rate of Q1 2019 equivalent to 0.876 EUR/USD.

[24] Please see BEREC Guidelines, paragraph 101 (footnote 26): "*Network-slicing in 5G networks may be used to deliver specialised services*"

[25] " […] *in accordance with Article 3(5) or an IAS in accordance with Article 3(1) - (4), including the traffic management rules in Article 3(3. To clarify that 5G services can be delivered over specialised services using network slicing, BEREC added a new footnote 26 to the final Guidelines. Therefore, ISPs are free to offer new services and business models in the environment of a 5G network whilst adhering to the principles laid down in the Regulation"* (BEREC, 2016[68]). Please see BEREC Consultation Report, BoR (16) 128, p. 30.

[26] For example, BEREC has plans of an industry consultation on how 5G network slicing may influence net neutrality. See https://www.telecompaper.com/news/berec-plans-industry-consultation-on-5g-network-slicing-impact-on-net-neutrality--1231623

[27] AGCom, the communications regulator in Italy, has said that one of the most relevant regulatory questions that arise with 5G, as a consequence of the panorama in which the service determines the quality of the needed network, is the creation of the basic "slices" and the control of the virtual networks composed through such slices. AGCom notes that some observers think that one or more "vertically integrated operators" must keep such control, in order to optimise resources; others believe that it is much more important to assure neutrality in creating the slices, while the control of the composed networks must in any case be kept by the relating service providers.

[28] 3GPP for Release 16 of the 5G standard is now considering two study items exploring the use cases and requirements of incorporating non-terrestrial systems (i.e. satellites and High Altitude Pseudo Satellites).

[29] Noting that this may not be the most accurate proxy for fibre coverage, as the two measures are not necessarily equal. For example, Canada in Figure 4 shows having 12% fibre broadband subscriptions as of

end-of 2017, while it has reported 37% FTTH coverage as of end-of 2017. The reason the 12% may be low is because cable companies still have a stronghold on the subscriber market and the FTTH coverage is relatively new.

30 Cable broadband networks are also being upgraded to provide higher speed services through the adoption of advancing Data over Cable Service Interface Specification (DOCSIS) standards and, like xDSL, through deeper deployment of fibre in these networks.

31 In commenting on the investment schedule, Verizon's CEO said that 5G requires network densification, and their aim is to have "fibre to every lamppost in the United States" (CNBC, 2017[78]).

32 It should be noted that not all 5G deployments will rely on mmWave spectrum, as Europe and other countries intend to use 3.5 GHz frequency bands.

33 An example of rights of way concerns raised by operators in the United States is that one company said it took an average of months to get a location for a small cell up and running (RCR Wireless, 2016[163]).

34 The 5G trials will operate in the 28 GHz band, for which Arqiva has a national license in the United Kingdom and 'small cell' locations to provide high speed fixed wireless over short distances.

35 The exchange rate used is from OECD.Stat March 2018 equivalent to KOR/USD 1071.55. The corresponding amount in USD is 933 million.

36 1 trillion KRW taking into account a KRW/USD exchange rate of 1070.5 for the year 2017 (the latest OECD official figures on Exchange rates).

37 EUR 56 billion. Taking into account a EUR/USD exchange rate of 0.95 for the year 2016, the year the study was conducted (though published in 2017).

38 EUR 141 billion. Taking into account a EUR/USD exchange rate of 0.95 for the year 2016, the year the study was conducted (though published in 2017).

39 The amount in EUR takes into account the OECD.Stat EUR/USD exchange rate of 0.83 for the year 2017.

40 EUR 200 billion. Taking into account a EUR/USD exchange rate of 0.95 for the year 2016.

41 The amount in USD takes into account the OECD.Stat exchange rate for 2017 of 1.305 AUD per USD.

42 The exchange rate used is from OECD.Stat of 1.3 CAD/USD for the year 2018.

43 To this end, European Union member countries have to ensure that such rights are valid for a duration of at least 15 years, plus an extension period of at least five years.

44 This provision also introduces the possibility for right holders to request renewal of their rights.

45 See also www.bnetza.de/mobilebroadband

46 Using the OECD.Stat exchange rate of Q1 2019 equivalent to 0.876 EUR/USD.

47 A map showing 5G trials as well as research initiatives in Germany can be found at http://www.bmvi.de/DE/Themen/Digitales/Frequenzen-Mobilfunk-und-Digitalradio/5G/5GKarte/5g-karte.html

48 A list of test beds in Germany for automated and assisted driving including the Franco-German-Luxembourg digital test bed can be found at http://www.bmvi.de/EN/Topics/Digital-Matters/Digital-Test-Beds/digital-test-beds.html

49 Regarding the two pioneer bands, 3.6-3.8 GHz and 26.5-27.5 GHz, the cited law establishes that these bands should be made available by 1st December 2018, without prejudice to the FSS (Fixed Satellite Service) systems for the first band and to the Earth's exploration services via satellite (EESS) for the second band. The latter has been done to assure that pre-commercial 5G trials become operational in the 3.7-3.8 GHz band segment.

50 The 700 MHz band availability in Italy is scheduled for 2022, due to the large presence of broadcasting services, but an anticipated release of the channels 50-53 are envisaged to allow the development of the 5G projects of neighboring countries (France).

51 The exchange rate used is from OECD.Stat of 0.85 EUR/USD for the year 2018.

52 According to Italy, the "obvious" candidate for this combined lot is "Iliad" a French telecommunications operator that is going to provide mobile services also in Italy and will also benefit from the spectrum made

available by the recent merger procedure (- M.7758 - Hutchison Europe Telecommunications /VimpelCom Luxembourg Holdings).

[53] The exchange rate used is from OECD.Stat of 1100.56 KRW/USD for the year 2018.

[54] Taking into account a KWN/USD exchange rate of 1070.5 for the year 2017 (the latest OECD figures).

[55] Idem.

[56] See Licence for The Provision of Telecommunication Services form the Infocomm Media Development Authority (IMDA) in Singapore: https://www.imda.gov.sg/regulations-licensing-and-consultations/licensing/licences/licence-for-the-provision-of-telecommunication-services

[57] Using the exchange rate from OECD.Stat of 0.75 GBP/USD for the year 2018.

[58] Idem.

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COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

5G for Europe: An Action Plan

{SWD(2016) 306 final}

1. Timely deployment of 5G: a strategic opportunity for Europe

Twenty-four years after the successful introduction of the 2G (GSM) mobile networks in Europe, another revolution is in sight with a **new generation of network technologies**, known as 5G, opening prospects for new digital economic and business models. 5G is not fully standardised yet but its key specifications and technological building blocks are already being developed and tested. 5G is seen as a game changer, enabling industrial transformations[1] through **wireless broadband services provided at gigabit speeds[2],** the support of new types of applications **connecting devices and objects** (the Internet of Things), and versatility by way of software virtualisation allowing innovative **business models across multiple sectors** (e.g. transport, health, manufacturing, logistics, energy, media and entertainment). While these transformations have already started on the basis of existing networks, they will need 5G if they are to reach their full potential in the coming years.

The Commission strategy for the Digital Single Market (DSM strategy)[3] and the Communication *Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society*[4] underline the importance of very high capacity networks like 5G as a key asset for Europe to compete in the global market. Worldwide 5G revenues should reach the equivalent of €225 billion in 2025[5]. Another source indicates that the benefits of 5G introduction across four key industrial sectors may reach €114 billion/year[6].

The Commission launched in 2013 a Public-Private-Partnership (5G-PPP) backed by 700 million euro of public funding with the aim of making sure that 5G technology is available in Europe by 2020. However, research efforts alone will not be sufficient to ensure Europe's leadership in 5G. A wider effort is needed to make 5G and the services that will flow from it a reality, in particular for the emergence of a European "home market" for 5G.

The proposed European Electronic Communications Code[4] will support the deployment and take-up of 5G networks, notably as regards assignment of radio spectrum, investment incentives and favourable framework conditions, while the recently adopted rules on open Internet[7] provide legal certainty as regards the deployment of 5G applications. This communication complements and leverages this new regulatory framework through a set of targeted actions. These draw on multiple consultations, events with stakeholders[8], a targeted survey,[9] several studies,[10] industry consultations[11], and early results from the 5G-PPP[12]. It

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1 5G-PPP, 5G Vision, https://5g-ppp.eu/roadmaps/

2 5G should offer data connections well above 10 Gigabit per second, latency below 5 milliseconds and the capability to exploit any available wireless resources (from Wi-Fi to 4G) and to handle millions of connected devices simultaneously. Please see section 3 of the accompanying Staff Working Document.

3 https://ec.europa.eu/digital-single-market/en/digitising-european-industry

4 https://ec.europa.eu/digital-single-market/en/connectivity-european-gigabit-society

5 https://www.abiresearch.com/press/abi-research-projects-5g-worldwide-service-revenue/

6 Studying automotive, health, transport and energy sectors: https://ec.europa.eu/digital-single-market/en/news/study-identification-and-quantification-key-socio-economic-data-strategic-planning-5g

7 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2120&from=en

8 See: e.g. https://5g-ppp.eu/event-calendar/#.

9 https://ec.europa.eu/digital-single-market/en/news/have-your-say-coordinated-introduction-5g-networks-europe

10 See footnotes 5 and 6.

11 *Notably the 5G Manifesto for timely deployment of 5G in Europe*, 7 July 2016: http://ec.europa.eu/newsroom/dae/document.cfm?action=display&doc_id=16579.

12 5G-PPP, *5G Empowering Vertical Industries*: https://5g-ppp.eu/roadmaps/

presents an action plan for timely and coordinated deployment of 5G networks in Europe through a partnership between the Commission, Member States, and industry[13].

2. The need for a coordinated approach

Since major research efforts are underway worldwide, it is essential to avoid incompatible 5G standards emerging in different regions. If Europe is to help shape a global consensus as regards the choice of technologies, spectrum bands and leading 5G applications effective, EU coordination and planning on a cross-border basis will be needed. The launch of commercial 5G services will also require substantial investments, the availability of a suitable amount of spectrum, and close collaboration between telecom players and key user industries. Network operators will not invest in new infrastructures if they do not see clear prospects for a solid demand and regulatory conditions that make the investment worthwhile. Equally, industrial sectors interested in 5G for their digitisation process may want to wait until the 5G infrastructure is tested and ready.

In this context, a lack of coordination between national approaches concerning the roll-out of 5G networks would create a significant risk of fragmentation in terms of spectrum availability, service continuity across borders (e.g. connected vehicles) and implementation of standards. As a result, it would delay the creation of a critical mass for 5G-based innovation in the Digital Single Market. This is particularly evidenced by the initial delay in the deployment of 4G in Europe: in 2015, more than 75% of the US population had access to 4G/LTE versus only 28% of the EU population[14]. Despite the fact that the gap is steadily narrowing, there are still major differences between Member States. This is why the Commission is proposing this action plan, as a means of fostering the adequate coordination. It aims to build momentum for investment in 5G networks and to create new innovative ecosystems, thus enhancing European competitiveness and delivering concrete benefits to society.

The Commission has identified the following key elements for the plan:

- Align roadmaps and priorities for a coordinated 5G deployment across all EU Member States, targeting early network introduction by 2018, and moving towards commercial large scale introduction by the end of 2020 at the latest.
- Make provisional spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference (WRC-19), to be complemented by additional bands as quickly as possible, and work towards a recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz.
- Promote early deployment in major urban areas and along major transport paths.
- Promote pan-European multi-stakeholder trials as catalysts to turn technological innovation into full business solutions.
- Facilitate the implementation of an industry-led venture fund in support of 5G-based innovation.
- Unite leading actors in working towards the promotion of global standards.

[13] The Commission's intention to develop a 5G action plan was previously announced in the Communication *Digitising European industry* and in the Communication on *ICT standardisation priorities*.

[14] IDATE DigiWorld Yearbook 2016 & GSMA Report "The Mobile Economy in Europe 2015". The delayed deployment of 4G networks in Europe has often been attributed to a lack of cross-border coordination in Europe.

3. Keeping Europe ahead in the 5G race: key areas for action[15]

3.1. A common EU timetable for the introduction of 5G

An ambitious 5G introduction timeline is essential for Europe to have a leading position and to take early advantage of the new market opportunities enabled by 5G, not only in the telecom sector, but in the whole economy and society. Digitisation of European industry should be initiated today on the basis of available resources (notably 4G/LTE, Wi-Fi or satellite) and will be boosted by the gradual adoption of 5G from 2018 onwards. The Commission will assist Member States in the context of their national broadband plans and the Future Internet Forum (FIF) and in collaboration with industry through the 5G-PPP to establish common objectives and concrete steps for testing and deploying 5G [16].

Action 1 — The **Commission** will work with **Member States** and **industry stakeholders** towards the voluntary establishment of a **common timetable** for the **launch of early 5G networks by the end of 2018, followed by the launch of fully commercial 5G services in Europe by the end of 2020**. The common timetable should be developed as quickly as possible. The EU timetable should be driven by the following key objectives:

- Promoting **preliminary trials,** under the 5G-PPP arrangement, to take place **from 2017 onwards,** and **pre-commercial trials** with a clear EU cross-border dimension **from 2018**.
- Encouraging **Member States** to develop, **by end 2017, national 5G deployment roadmaps** as part of the **national broadband plans**[17].
- Ensuring that **every Member State will identify at least one major city to be "5G-enabled" by the end of 2020**[18] **and that all urban areas and major terrestrial transport paths have uninterrupted 5G coverage by 2025**[19].

3.2. Unlocking bottlenecks: making 5G radio spectrum available

The deployment of 5G networks requires the timely availability of a sufficient amount of harmonised spectrum. A major new requirement specific for 5G is the need for large contiguous bandwidths of spectrum (up to 100 MHz) in appropriate frequency ranges to provide higher wireless broadband speeds. Such bandwidths are only available in spectrum above 6 GHz.

Therefore, the designation of new frequency bands above 6 GHz is on the agenda of the World Radio Conference 2019 (WRC-19), based on a list of candidate bands identified at WRC-15, subject to ITU studies[20], with the aim of targeting the widest possible global harmonisation.

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[15] All Commission actions likely to have significant impacts will be prepared in line with its Better Regulation standards (e.g. with evaluations, consultation, and impact assessment where appropriate).

[16] Subject to the timely availability of commercial 5G solutions.

[17] As set out in the Communication *Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society*.

[18] As a means to promote the effective establishment of all necessary pre-conditions in all Member States before 2020.

[19] These is the same 2025 connectivity target as set out in the Communication *Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society*. Please see also Action 4.

[20] ITU-R Resolution 238, WRC-15.

Pioneer spectrum bands

Member States and the Commission, working together in the Radio Spectrum Policy Group (RSPG), have recognised the importance of the early identification of common EU-wide pioneer spectrum bands to enable 5G take-up as early as in 2018. This is indispensable to give proper guidance to industry and keep the EU on a par with spectrum availability in other regions of the world.

This first set of such pioneer bands should include a mix of spectrum with different characteristics to address the versatile 5G requirements. The identified bands should also have a potential for global harmonisation and take advantage of the sizeable amount of harmonised spectrum already allocated in the EU for wireless broadband below 6 GHz. The spectrum mix should include:

- Spectrum below 1 GHz, focussing on the 700 MHz band: its availability by 2020, as proposed by the Commission, being critical for 5G success[21].
- Spectrum between 1 GHz and 6 GHz, where EU-wide harmonised bands are already available and licensed in a technology neutral way across Europe. In particular, the 3.5 GHz band[22] seems to offer high potential to become a strategic band for 5G launch in Europe.
- Spectrum above 6 GHz, for new and wider bands to be defined, in line with the WRC-19 milestone.

This approach is supported by industry[23], and considered as an adequate response to the developing spectrum plans in competing economies.

Action 2 — The **Commission** will work with **Member States** to identify **by the end of 2016** a provisional list of **pioneer spectrum bands** for the **initial launch of 5G services**. Taking due account of the RSPG Opinion in preparation[24], the list should include frequencies in at least three ranges of the spectrum: below 1 GHz, between 1 GHz and 6 GHz, and above 6 GHz, to account for the diverse application requirements of 5G.

Additional spectrum bands

The set of pioneer spectrum bands should be complemented in a next step to reflect 5G spectrum requirements in the longer term. This step should concentrate on identifying 5G spectrum bands above 6 GHz, focusing on the bands on the agenda for WRC-19, while also assessing further opportunities for economies of scale at international level. The potential for spectrum sharing, including under licence-exempt use, should be maximised as it generally supports innovation and market entry, in line with the objectives of the legislative proposals set out in the proposed European Electronic Communications Code. A particular challenge will be to anticipate the diverse 5G use cases in order to properly satisfy all key spectrum requirements.

[21] Proposal for a Decision of the European Parliament and of the Council on the use of the 470-790 MHz frequency bands in the Union, COM (2016) 43 final.

[22] The 3.5 GHz band designates the frequency range from 3.4 GHz to 3.8 GHz subject to the Commission Implementing Decision 2014/276/EU of 2 May 2014 on amending Decision 2008/411/EC on the harmonisation of the 3400 - 3800 MHz frequency band for terrestrial systems capable of providing communications services in the Community.

[23] See the companion Staff Working Document, section 7.

[24] Document RSPG 16-031Final, see http://rspg-spectrum.eu/public-consultations.

Action 3 — The **Commission** will work with **Member States** to:

- Agree **by end of 2017** on the **full set of spectrum bands** (below and above 6 GHz) **to be harmonised for the initial deployment of commercial 5G networks in Europe**, based on a planned RSPG opinion on 5G spectrum. The final spectrum harmonisation at EU level will be subject to the usual regulatory process once relevant standards have been developed.
- Work towards a **recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz**, taking due account of the opinions of BEREC and RSPG. An early indication of technical options and feasibility should be available through CEPT studies by end 2017.

3.3. Leveraging fixed and wireless: a very dense network of 5G access points

Addressing the interplay between fibre and wireless deployment requirements

The planned 5G networks are expected to serve up to one million connected devices per square kilometre, about a one thousand fold increase as compared to today. This dramatic surge in the number of devices will also increase traffic per network access point, which will require increasingly smaller cells[25] to deliver the planned connectivity performance[26] and an increase in the density of antennae deployed.

The small cells will also have to be connected efficiently to the rest of the network with high capacity backhaul communications since the aggregated volume of data that will transit through these small cells will reach several gigabits per second. In most cases, these will be fibre links, while other high capacity wireless backhauling could also be used.

The path towards 5G and the 2025 connectivity objectives for Europe outlined in the Communication *Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society* will therefore rely on more general deployment of high-capacity networks across the continent. The earlier core broadband networks are rolled out the sooner 5G will be available on a large scale.

The magnitude of the required investments can only be met with a closer cooperation between Member States, the financial community and the European Investment Bank (EIB) to mobilise private and public support, and notably to alleviate risks of a digital divide. This will require public and private actors as well as providers and users of connectivity to develop common implementation roadmaps.

On this basis, the Commission calls for a voluntary coordination of implementation roadmaps between relevant public and private actors, in particular to coordinate investments in cellular base stations and fibre infrastructures.

Reducing the cost of installing access points

A simplification of the deployment conditions for dense cellular networks would reduce costs and support investments. The proposed European Electronic Communications Code aims to

[25] A cell is the area which is served by a single network access point.
[26] 5G-PPP, *View on 5G Architecture*, highlighting the requirement for 100 Gb/s to the aggregation point: https://5g-ppp.eu/white-papers/

remove deployment barriers for the installation of small cells, subject to meeting common technical requirements.

Member States should work to eliminate these barriers in the interests of speedy and cost-effective deployment. In addition, other administrative aspects sometimes create unnecessary burdens for the installation of small cells, such as local planning procedures, high site rental charges, the variety of specific limits on electromagnetic field (EMF) emissions and of the methods required to aggregate them [27].

Therefore, the Commission will further encourage best practice by national, regional and local authorities in the deployment conditions for small access points..

Action 4 — As part of the development of the 5G national roadmaps, the Commission will work with the **industry, the Member States**, and other s**takeholders** to:

- Set **roll-out and quality objectives** for the monitoring of the progress of **key fibre and cell deployment scenarios**, to meet the target of at least **all urban areas[28] and all major terrestrial transport paths[29]**, having **uninterrupted 5G coverage by 2025.**
- Identify **immediately actionable best practice to increase the consistency of administrative conditions and time frames to facilitate denser cell deployment,** in line with the relevant provisions of the proposed European Electronic Communications Code.

3.4. Preserving 5G Global Interoperability: standardisation challenges

Standards at the heart of innovation

Standards are of paramount importance to ensure the competitiveness and interoperability of global telecommunication networks. The communication *ICT standardisation priorities for the Digital Single Market*[30] sets out a clear path to foster the emergence of global industry standards under EU leadership for key 5G technologies (radio access network, core network) and network architectures. It also recognises the particular challenges raised by the need to bring together communities of stakeholders with very different standardisation cultures in order to enable the innovative use cases of key industries,

Lately, the international standardisation agenda for 5G has quickly moved forward. The first phase foresees the early availability of standards for ultra-fast mobile broadband solutions[31].

27 The regional or local limits are sometimes significantly lower than the limits set by existing EU regulations Directive 2013/35/EU - electromagnetic fields of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC).

28 As per definition: http://ec.europa.eu/eurostat/statistics-explained/index.php/European_cities_%E2%80%93_the_EU-OECD_functional_urban_area_definition

29 Motorways and national roads, and railways, in line with the definition of Trans-European Transport Networks. Where appropriate 5G will operate in seamless co-existence with technologies already being deployed, in particular short-range communication for vehicle-to-vehicle and vehicle-to-infrastructure (ITS-G5), under a complementarity principle.

30 COM(2016) 176 final.

31 The 3rd Generation Partnership Project (3GPP) qualifies ultra-fast mobile broadband as mobile systems capable of delivering speeds of 20 gigabits per second, at least uni-directionally, and without specific latency requirements.

A second phase should rapidly deliver the standards for other use cases, such as those for industrial applications, and, crucially, make available standards promoting open innovation and opportunities for start-ups.

From an EU strategy perspective, the main challenges identified are as follows:

- The timely availability of 5G standards which are globally accepted, including possible acceleration of the work in 3GPP.
- The initial focus on ultra-fast broadband services should ensure compatibility with further development of standards for innovative use cases related to massive deployment of connected objects and the Internet of Things. The emergence of parallel, potentially conflicting, specifications developed outside global standardisation bodies must be avoided.
- The development of standards for specific needs should be promoted on the basis of experimental evidence, taking advantage of international cooperation and a multi-stakeholder approach. Standards should not overlook potential disruptive use cases (e.g. meshed connectivity).
- The standards must address the future evolution of the overall network architecture and need for "flexibility", in particular in response to new use cases arising in key industrial sectors. These aspects require due consideration for open innovation and opportunities for start-ups.

Member States and industry should therefore endorse, and promote, a comprehensive and inclusive approach to 5G standardisation.

Action 5 — The **Commission calls on Member States and the industry to commit to the following objectives regarding the standardisation approach**:

- Ensure the **availability of the initial global 5G standards by the end of 2019 at the latest**, so as to enable a timely commercial launch of 5G, and paving the way **for a wide range of future connectivity scenarios** beyond ultra-fast broadband.
- Promote efforts to support a **holistic standardisation approach** encompassing both **radio access** and **core network challenges**, including due consideration for disruptive use cases and open innovation.
- Establish appropriate cross-industry partnerships, by the end of 2017, to support **the timely definition of standards backed by industrial user experiments,** including through the leveraging of international cooperation partnerships, in particular for the **digitisation of industry**.

3.5. 5G innovation in support of growth

Stimulating new connectivity-based ecosystems through experiments and demonstrations

The acceleration of the digitisation process in several key industrial sectors based on 5G connectivity, as well as the advent of novel business models, will require closer partnerships between the concerned sectors and the telecommunication sector. While a few markets will naturally lead innovation[32] and attract most of the initial investments, a number of sectors recognise the need to run pilot trials to increase predictability, reduce investment risks, and

[32] See section 5 of the accompanying Staff Working Document.

validate both the technologies and the business models. Experiments are also needed to provide input for the standardisation organisations.

Against this background, the Commission proposes to put greater emphasis on pilots and experiments in the run-up to 5G, notably through the 5G-PPP. In addition, the Commission will work towards the **deployment of selected 5G trials with a clear EU dimension from 2018**. The Commission counts on the trial results to be able to identify and address specific sectorial policy issues and seek the active support of Member States to resolve them whenever they constitute a major obstacle to high value applications relying on 5G[33].

Where possible, 5G experiments should make use of facilities already developed in the context of activities conducted in Member States[34]. The Commission will also work with a **Focus Group**[35] including players in relevant industrial sectors to assess results and carry out gap analysis of 5G trials in Europe. Finally, there is a need to ensure that hardware, terminals[36] and devices based on 5G connectivity are available in due time before 2020 to encourage uptake and demand.

Action 6 — To foster the emergence of digital ecosystems based on 5G connectivity, the **Commission calls upon the industry** to:

- **Plan for key technological experiments to take place as early as in 2017,** including the testing of new terminals and applications through the 5G-PPP, demonstrating the benefit of 5G connectivity **for important industrial sectors**.
- **Present detailed roadmaps by March 2017 for the implementation of advanced pre-commercial trials** to be promoted at EU level (trials in key sectors must be launched in 2018 in order to ensure Europe leadership in the context of the accelerated global agenda for the introduction of 5G).

The public sector as an early adopter and promoter of 5G connectivity-based solutions

Public services may be an early adopter and a promoter of 5G connectivity-based solutions, encouraging the emergence of innovative services, contributing to a critical mass of investment, and addressing issues of importance for society. For instance, such a role could involve migrating public safety and security services from existing proprietary communications platforms[37] to commercial 5G platforms which will be even more secure, resilient and reliable[38].

Action 7 — The Commission encourages Member States to consider **using the future 5G infrastructure** to improve the performance of **communications services used for public**

33 See section 6 of the accompanying Staff Working Document.
34 The Future Internet Forum of Member States (FIF) could also support such EU synergies given the national dimension of many of the potential applications of 5G.
35 Such Focus Group has to be defined in collaboration with the concerned industry sectors, starting from the existing CEO Round Table on 5G.
36 Not only smart phones but also a full range of Internet of Things and connected devices (cars, drones, urban furniture, etc).
37 e.g. TETRA, GSM-R.
38 According to network technology suppliers, the new platforms could be a virtual slice on a shared 5G public network or a separate network using standardised 5G technology and appropriate parameters, or a combination of both.

safety and security, including shared approaches in view of the future procurement of advanced broadband public protection and disaster relief systems.[39] Member States are encouraged to include this consideration in their national 5G roadmaps.

A venture financing initiative to stimulate 5G innovation and take-up

5G networks will lower market-entry barriers for customised communications service in multiple sectors, by giving controlled access to real or virtual network resources without the need to own a whole network infrastructure[40]. As a consequence, new innovation models, and new ecosystems, should arise on top of communication services, following a model similar to that of cloud computing platforms, or even the Internet. This also means that service experimentation by "trial and error" will play a bigger role than in the traditional, more linear research and development model that has dominated network innovation so far. This new environment should create opportunities for smaller companies and start-ups.

In order to trigger the new 5G innovation ecosystems, industry suggested setting up a specific **5G venture financing facility**[41]**,** to support **innovative European start-ups**[42] aiming to develop 5G technologies and related new application **across industrial sectors**. This could foster substantial digital innovation at European scale, beyond connectivity. The modalities for this financing capacity will have to be further specified to determine the appropriate financial instruments and avoid overlaps with venture financing opportunities already available for the digital sector.

Action 8 — The Commission will work with the industry and the EIB Group[43] to identify the objectives, possible configuration, and modalities for a **venture financing facility**, possibly linked with other digital start-up actions. The **feasibility should be assessed by the end of March 2017**, taking into account the possibility to enhance **private funding by adding several sources of public funding** in particular from the European Fund for Strategic Investments (EFSI) and other EU financial instruments.

4. Conclusion

The European Union is at the beginning of an important journey to develop the backbone of digital infrastructure that will support future competitiveness. It has already taken bold steps to develop world-class 5G technological know-how. It is now time to move up a gear and reap the benefits of public and private investment for the economy and society. The 5G action plan adopts an ambitious approach and requires united and sustained commitment of all parties: the EU institutions, the Member States, industry and the research and financial communities. The

[39] PPDR infrastructure typically supports services for the police and fire brigades.
[40] Network slicing. This technology also allows to provide various levels of service quality and reliability over the same physical network.
[41] *5G Manifesto for timely deployment of 5G in Europe*.
[42] The proposed financing facility is different from the broadband fund proposed in the Communication *Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society*, as it focuses on innovation financing and smaller actors.
[43] Including the European Investment Fund (EIF), which has special responsibility within the EIB Group regarding the financing of small and medium enterprise (SMEs).

impact of the proposed plan will be further enhanced by the combined effect of the "connectivity" targets set out in the Communication *Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society* and the proposed measures of the European Electronic Communications Code.

The European Parliament and the Council are called upon to endorse this 5G Action Plan.

Subsecretaría de Telecomunicaciones

Gobierno de Chile

DEFINE ÁREAS SENSIBLES DE PROTECCIÓN PARA EFECTOS DE LA APLICACIÓN Y CUMPLIMIENTO DE LA LEY N° 20.599 /

RESOLUCIÓN EXENTA N° 3084 /

SANTIAGO, 11 JUN 2012

VISTOS:

a) El Decreto Ley N°1.762, de 1977, que creó la Subsecretaría de Telecomunicaciones;

b) La Ley N° 18.168, General de Telecomunicaciones, modificada por la Ley N° 20.599, publicada en el Diario Oficial con fecha 11.06.12;

c) La Ley General de Urbanismo y Construcciones, Decreto con Fuerza de Ley N°458, de 1978, del Ministerio de la Vivienda y Urbanismo, también modificada por la Ley N° 20.599;

DIVISION JURIDICA V° B° ABOGADO SUBTEL

d) La Ley N° 17.301, que crea la Junta Nacional de Jardines Infantiles, y sus modificaciones y el D.S. N° 138, de 2005, del Ministerio de Educación, que reglamenta aspectos de la misma; la Ley N° 20.370, General de Educación, cuyo texto refundido, coordinado y sistematizado fue fijado por el D.F.L. N° 2, de 2010, el D.S. N° 548, de 1988, que Aprueba normas para la planta física de los locales educacionales que establecen las exigencias mínimas que deben cumplir los establecimientos reconocidos como cooperadores de la función educacional del Estado, según el nivel y modalidad de la enseñanza que impartan, y el D.S. N° 315, de 2010, del mismo Ministerio, que Reglamenta requisitos de adquisición, mantención y pérdida del reconocimiento oficial del Estado a los establecimientos educacionales de educación parvularia, básica y media; el Decreto N° 334, de 1983, el D.S. N° 161, de 1982, Reglamento de Hospitales y Clínicas, el D.S. N° 140, de 2004, Reglamento de los Servicios de Salud, y el D.F.L. N° 1, de 2005, todos del Ministerio de Salud; el DFL N° 4/20.018, de 2006, del Ministerio de Economía, Fomento y Turismo, que aprueba el texto refundido, coordinado y sistematizado de la Ley General de Servicios Eléctricos; y la R.E. N° 9, del 14 de marzo de 2005, del Ministerio de Economía, Fomento y Reconstrucción, que fijó la Norma Técnica con exigencias de Seguridad y Calidad de Servicio para el Sistema Interconectado del Norte Grande y Sistema Interconectado Central, publicada en el Diario

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Oficial con fecha 21.03.05, y sus modificaciones posteriores, en especial la última, realizada mediante R.E. N° 68, de 10.03.10, del mismo Ministerio de Energía, publicada en el Diario Oficial con fecha 17.03.10;

e) La Resolución N° 1.600, de 2008, de la Contraloría General de la República, que Fija Normas sobre Exención del Trámite de Toma de Razón, y;

Y CONSIDERANDO:

a) Que, el inciso sexto del artículo 116° bis E de la Ley General de Urbanismo y Construcciones, en adelante la LGUC, establece, dentro del conjunto de restricciones al emplazamiento de torres soporte de antenas y sistemas radiantes de transmisión de telecomunicaciones contemplado en dicho artículo y en los siguientes de dicha ley, que "*Tampoco podrán emplazarse torres soporte de antenas y sistemas radiantes de transmisión de telecomunicaciones, dentro de establecimientos educacionales públicos o privados, salas cuna, jardines infantiles, hospitales, clínicas o consultorios, predios urbanos donde existan torres de alta tensión, ni hogares de ancianos u otras áreas sensibles de protección así definidas por la Subsecretaría de Telecomunicaciones, ni en sitios ubicados a una distancia menor a cuatro veces la altura de la torre de los deslindes de estos establecimientos, con un mínimo de 50 metros de distancia, salvo que se trate de aquellas torres soportes de antenas y sistemas radiantes de transmisión de telecomunicaciones a que se refieren los artículos 116 bis G y 116 bis H de esta ley o sean requeridas por dichos establecimientos para sus fines propios.*"

b) Que, por su parte, la Ley N° 20.599, la que precisamente introdujo el régimen legal antes señalado a la LGUC y modificó también la Ley N° 18.168, contempla en sus disposiciones cuarta y quinta transitorias, exigencias adicionales y alternativas, respectivamente, a las exigencias contempladas en el régimen permanente introducido por la misma, y que están directamente referidas a dichas áreas sensibles de protección;

c) Que, en virtud del mandato contemplado en la disposición legal transcrita en el Considerando a) de esta resolución, corresponde a esta Subsecretaría de Estado definir las áreas sensibles de protección y el sentido y alcance de los establecimientos a ellas referidos;

d) Que, para tal efecto, las definiciones contempladas en lo resolutivo de la presente norma, han sido elaboradas en base a las definiciones sectoriales correspondientes al ámbito de atención de cada uno de dichos establecimientos, y en uso de mis atribuciones,

RESUELVO:

Artículo 1.- Apruébase la siguiente resolución que define áreas sensibles de protección y establecimientos a ellas directamente asociados.

Artículo 2.- Para efectos de lo previsto en el inciso sexto del artículo 116° bis E de la LGUC y artículos cuarto transitorio, inciso décimo tercero, y quinto transitorio, ambos de la Ley N° 20.599, se entenderá por:

a) **Establecimiento educacional público o privado:** Aquellos descritos en el artículo 1° letra a) del Decreto Supremo N° 548, de 1988, del Ministerio de Educación, cuyo artículo segundo establece los requisitos para ser considerados como tales, y referidos a los tres niveles educativos señalados en los artículos 18°, 19° y 20° de la Ley N° 20.370. Asimismo, se incluyen aquellos establecimiento educacionales correspondientes al nivel Diferencial o Especial a que se refiere el artículo 23° de la Ley N° 20.370 y contemplados en el artículo 7° del citado decreto.

b) **Sala cuna:** Establecimiento o lugar correspondiente al 1° Nivel de la educación parvularia a que se refiere el artículo 5° del D.S. N° 315, de 2010, del Ministerio de Educación, ubicado en forma anexa o independiente del lugar de trabajo de las madres, en el cual dichas mujeres puedan alimentar a sus hijos menores de dos años y dejarlos mientras se encuentran trabajando, de conformidad a lo previsto en el artículo 33° de la Ley N°17.301 y 203° del Código del Trabajo.

c) **Jardín infantil:** Establecimiento que –de conformidad al artículo 3° de la Ley N° 17.301, complementada en lo pertinente por el D.S. N° 138, de 2005, del Ministerio de Educación-, atiende niños durante el día, hasta la edad de su ingreso a la Educación General Básica, proporcionándoles una atención integral que asegure una educación oportuna y eficiente. Incluye a los Jardines Infantiles Comunitarios.

d) **Hospital:** Establecimiento que –en virtud de lo señalado en el artículo 3°, inciso primero, del D.S. N° 161, de 2006, del Ministerio de Salud- atiende a pacientes cuyo estado de salud requiere atención profesional médica y de enfermería continua, organizado en servicios clínicos y unidades de apoyo diagnóstico y terapéuticos diferenciados.

e) **Clínica:** Establecimiento que -en virtud de lo señalado en el artículo 3°, inciso segundo, del D.S. N° 161, de 1982, del Ministerio de Salud- presta atención hospitalaria, sin disponer de servicios clínicos y unidades de apoyo diferenciados.

f) **Consultorio:** Establecimiento que –de conformidad a lo previsto en el artículo 36 del D.S. N° 140, de 2004 y en el artículo 18° del D.F.L. N°1, de 2005, ambos del Ministerio de Salud- tiene por objeto satisfacer las necesidades de atención ambulatoria del nivel primario de la población a su cargo, en un determinado territorio urbano o rural.

g) **Torres de alta tensión:** Aquellas estructuras soportantes de líneas de transporte de energía eléctrica de aquellas a que refiere el artículo 73° de D.F.L. N° 4/20.018, de 2006, que fija el texto refundido, coordinado y sistematizado de la Ley General de Servicios Eléctricos, y cuyo nivel de tensión corresponda al señalado en el artículo 1-7 N° 83 de la Norma Técnica con exigencias de Seguridad y Calidad de Servicio para el Sistema Interconectado del Norte Grande y Sistema Interconectado Central.

h) **Hogar de ancianos:** Establecimiento o centro que –de conformidad al D.S. N° 334, de 1983, del Ministerio de Salud- se encuentra destinado a la atención de personas cuya condición física o mental demande cuidados permanentes, sin presentar patologías que exijan control médico, procedimiento de apoyo clínico, tratamiento oral o parenteral permanentes, continuos o discontinuos, y que cumplan con los demás requisitos reglamentarios.

Artículo 3.- Sólo se considerarán en la aplicación de la normativa citada en el artículo 2° precedente, aquellos establecimientos antes definidos cuyo funcionamiento haya sido autorizado por la autoridad competente, sectorial y local, según corresponda, y que cuenten, de ser el caso, con patente otorgada por la respectiva municipalidad.

ANÓTESE, COMUNÍQUESE Y PUBLÍQUESE EN EL DIARIO OFICIAL

JORGE ATTON PALMA
Subsecretario de Telecomunicaciones.

SUBSECRETARIO
SUBSECRETARÍA DE TELECOMUNICACIONES

EUROPEAN COMMISSION
Directorate-General for Communications Networks, Content and Technology

Future Networks
Future Connectivity Systems

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COCOM Working Group on 5G

Working Document

Subject: **Report on the exchange of Best Practices concerning national broadband strategies and 5G "path-to-deployment"**

COCOM Working Group on 5G

Working Document

Report on the exchange of Best Practices
concerning national broadband strategies and 5G "path-to-deployment"

Contents

COCOM Working Group on 5G[1]

Working Document

**Report on exchange of Best Practices
concerning national broadband strategies and 5G "path-to-deployment"**

Introduction and background

Purpose and objectives

The purpose of this Report is to summarise the exchanges of best practices conducted during the work of the COCOM Working Group on 5G. It identifies the most common strategic elements being considered by Member States when setting out their 5G plans. It also addresses the EU perspective whenever relevant. This strategic reflection is understandably a "work in progress" in a majority of Member States. However, the current summary also offers some specific directions, and suggested way forward, whenever they were considered relevant by a majority of Working Group members.

This Report could also be seen as a “starting point” which may lead to a permanent platform for more regular exchanges in the future as it is expected that the “state of the art” in this field will continuously evolve in the coming years[2]. The European 5G Observatory[3] recently established by the Commission may provide a useful mechanism to deepen the exchanges at EU level.

The basis for this exchange of Best Practices can be found in the context of the Commission Communication "*Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society*"[4], where the Commission calls on Member States to review progress of their National Broadband Plans and update them with a time horizon beyond 2020, in line with the strategic objectives for 2025 set out in this Communication and in the 5G Action Plan[5], namely:

- Gigabit connectivity for all main socio-economic drivers such as schools, transport hubs and main providers of public services as well as digitally intensive enterprises.
- All urban areas and all major terrestrial transport paths will have uninterrupted 5G coverage.
    - Intermediate objective for 2020: 5G connectivity as a fully-fledged commercial service in at least one major city in each Member State, building on first commercial introduction in some Member States in 2018. In line with this policy objective, it is expected that Member States, in the context of their national 5G strategy, will identify and make public which city, or group of cities, will fulfil that objective for the 5G launch in 2020.
- All European households, rural or urban, will have access to Internet connectivity offering a downlink of at least 100 Mbps, upgradable to Gigabit speed. This objective is to be seen against the wider ambition that there should be access to mobile data connectivity throughout the territory, in all places where people live, work, travel and gather.

[1] Also referred to in this document as “COCOM Working Group on 5G”, and occasionally as the “Working Group”.
[2] For example, the UK Government has publicly committed to providing regular updates to outline their progress in delivering against its 5G strategy recommendations.
[3] https://ec.europa.eu/digital-single-market/en/european-5g-observatory
[4] Commission Communication: Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society – 14 September 2016 - COM(2016)587 and Staff Working Document - SWD(2016)300.
[5] Commission Communication: "5G for Europe: An Action Plan" - COM(2016)588 and Staff Working Document - SWD(2016)306.

Furthermore, the 5G Action Plan foresees several actions for Member States to address in their National Broadband Plans, namely:

- *Encouraging Member States to develop national 5G deployment roadmaps*[6] *as part of the national broadband plans (action 1).*
- Asking *Member States to consider using the future 5G infrastructure to improve the performance of communications services used for public safety and security and encouraging them to include this consideration in their national 5G roadmaps* (action 7).

Political background

Since the adoption by the Commission of the two Communications referenced above, the European Parliament and Member States have expressed their support for the overall strategy, namely through:

- The European Parliament resolution of 1 June 2017 on "Internet connectivity for growth, competitiveness and cohesion: European Gigabit Society and 5G"[7]. This welcomed the Commission's proposal to "draw up a 5G Action Plan aimed at making the EU a world leader in the deployment of standardised 5G networks from 2020 to 2025 as part of a wider developed strategy for a European Gigabit Society".
- The Ministerial Declaration on "Making 5G a success for Europe"[8] which was signed at an informal meeting of competitiveness and telecommunications ministers on 18 July in Tallinn, Estonia. The declaration sought to establish a common baseline on future 5G standards and confirm the willingness of Member States to position Europe as the lead market for 5G. The declaration emphasises the setting up of a strategic dialogue to exchange experiences at a high level and discuss all issues related to the fostering of wireless applications throughout the Union.
- The follow-up agreement on the "joint roadmap for the development of 5G networks"[9]. The roadmap lays out major agreed 5G activities and their time frame, in line with the deployment objectives of the Commission's 5G Action Plan.

In parallel, the negotiations with the Council and European Parliament regarding the proposed European Electronic Communications Code (EECC) have progressed significantly and, at the time of the finalisation of this report, there is a final political agreement on the substance of the Directive to be adopted. Despite the fact that this COCOM activity and the finalisation of the EECC proposal have been conducted in parallel, this report takes already into account, insofar as possible, the expected impact of the measures foreseen in the now agreed EECC.

Once in effect, the EECC will set framework conditions that will facilitate the deployment of future networks, especially 5G networks, and stimulate investments across the Union, i.e. with the needed scale and network effects required for successful take-up of 5G services.

Another significant political development over the last year, which should help unlock one of the most promising innovative and valuable applications of advanced 5G connectivity, are the commitments taken by Member States and the Commission to cooperate on large-scale testing and deployment of 5G corridors for Connected and Automated Mobility. In its recent Communication on the road to automated mobility: An EU strategy for mobility of the future [10], the Commission set out

[6] Also referred to as national 5G "path-to-deployment".
[7] 2016/2305(INI)
[8] https://www.eu2017.ee/sites/default/files/inline-files/Ministerial%20declaration%205G_final_0.pdf
[9] https://www.mkm.ee/sites/default/files/8.a_b_aob_5g_roadmap_final.pdf
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0283&from=EN

the policy objective to develop – in cooperation with Member States – a network of pan-European 5G cross-border corridors for the large scale testing and early deployment of advanced connectivity infrastructure supporting connected and automated mobility. Prior to this, 27 Member States agreed to develop large scale testing along European highways (cross-border corridors) at the Digital Day in Rome in March 2017. At the Digital Day 2018 in Brussels and at the Digital Assembly in Sofia, several Member States took additional steps to extend the 5G European network by signing regional agreements on 5G corridors. Following those agreements, a pan-European network of 5G corridors is now emerging (9 corridors already agreed, with hundreds of kilometres of highways) where driving tests will be conducted up to the stage where a car can operate itself without a driver present under certain conditions (third level of automation).

Taking these political developments into account, the work of this COCOM Working Group 5G should be viewed as a follow-up of these shared political ambitions and objectives regarding the timely 5G deployment across the Union.

Status of 5G in the context of National Broadband Plans

All Member States have adopted a National Broadband Plan (NBP) and a few Member States are close to reaching the Digital Agenda for Europe (DEA) targets[11] or their national targets respectively. The Member States' NBPs differ significantly regarding their content as there is no one-size-fits-all solution: while some Member States currently do not have a single document that can be regarded as stand-alone NBP, all do have an overall strategic approach for the deployment of Next Generation Access (NGA) networks[12] that has been implemented. As a result, there is already a wealth of best practices available regarding fixed broadband deployment.

The situation is not yet as advanced regarding the development of national 5G roadmaps, or national 5G "path-to-deployment"[13]. This is understandable since the role and importance of mobile connectivity has increased rapidly since 2010 at the beginning of the development of the initial NBPs. In addition, 5G technology is still in standardisation phase and large-scale commercialisation of products is not expected before 2019 (on the basis of the "early drop" 3GPP standard release of December 2017).

However, several Member States have already published preliminary proposals and plans to facilitate the rollout of 5G networks[14]. This was possible because the expected key functionalities and target performance of 5G technologies are now largely known and/or considered sufficiently predictable. A key advantage of such national 5G plans, or government roadmaps, is that they provide an opportunity to clarify the roles and responsibilities of the various stakeholders, allowing them to move forward more efficiently, in a clearer awareness of the general environment, thereby enhancing investment certainty and facilitating the planning of actions of all involved stakeholders. However, these plans are likely to have to be adjusted and updated to take account of, amongst other things, the actual product availability on the market and, even more importantly, the expected evolution of 5G technology throughout the next decade. The "5G" that is likely to be rolled out initially is expected to be only a subset of the more mature 5G technology that is planned to be

[11] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52010DC0245R%2801%29

[12] As defined in EC Recommendation 2010/572/EU on regulated access to Next Generation Access Networks (NGA)

[13] Eight member States already make a reference to the 2025 5G/Gigabit Society targets in their NBP or have a 5G plan, and 10 Member States plan to publish an update of their NBPs between 2018 and 2019.

[14] The list of references to existing 5G strategies in Member States on 1 July 2018 is included at the end of this document.

deployed by 2025 and later[15], potentially enabling deeper digital transformation, and continuously seizing new market opportunities and building new ecosystems.

At the time of the finalisation of this Report, eight countries had already published a strategy for 5G infrastructure deployment (Austria, Belgium, France, Germany, Luxembourg, Spain, The Netherlands, and the UK), and two countries had launched formal public consultations regarding forthcoming 5G roadmap elements (Poland, and Finland[16]). One Member State (Italy) has already implemented a number of initiatives for the deployment of 5G, in particular regarding spectrum assignment procedures and the support of ambitious trials, in anticipation of the adoption of the comprehensive plan. Sweden has addressed some key 5G aspects in their “Broadband Strategy – A Completely Connected Sweden by 2025”. In addition, Luxembourg is expected to issue its 5G strategy by the end of July 2018, and a number of countries are collaborating in the context of a Nordic-Baltic 5G strategy.

Structure of this report

The scope of the work of the Working Group 5G is relatively wide. Therefore, it was decided to group the topics into six main chapters identifying what has been considered as the most strategic elements for 5G roadmaps, from a policy-setting perspective. Some of the issues are crosscutting by nature and are therefore addressed in multiple parts of the document, from different angles. It should be noted that the scope of 5G plans is likely to vary from Member State to Member State and not all elements are therefore relevant for all Member States.

[15] It is expected that 5G commercial products available by 2020 will be based on the first release of the 5G standards (3G PP Release 15). Subsequent releases are likely to give rise to products with increasingly rich characteristics and superior performance, which will reach the market by stages over the next decade.

[16] Finland: Consultation on a new draft national strategy for digital infrastructure launched at end May 2018. It deals with both fibre and 5G deployment in a combined new National Broadband Plan and 5G roadmap.

1) National 5G roll-out plans: strategy setting, policy objectives, and monitoring

This chapter addresses the higher-level strategic policy challenges identified by the Working Group to support 5G infrastructure deployment from a national perspective in a European context. In particular, it aims to highlight the importance of:

- Effective coordination between investments in fixed and mobile infrastructures due to the close inter-dependencies between advanced 5G cells and the fixed backhaul infrastructure necessary to support high capacity / high performance data traffic.
- The implementation of appropriate approaches for maximising 5G service coverage (also in synergy with existing 4G/3G/2G services) as well as enabling the delivery of required levels of service quality wherever beneficial in order to meet the demand from new users in vertical industries. In particular, it is expected that 5G capacity and performance may vary across geographic areas, reflecting different demand characteristics (of various applications) and costs of deployment. In this context, service quality monitoring, in combination with geographical coverage mapping, may become essential tools to ensure monitoring and facilitation of 5G network deployment progress.
- The identification of opportunities to provide broadband access, based on new 5G capabilities, in less densely populated areas, as well as a corollary benefit of 5G deployment along transport paths (e.g. through backhauling of 5G Fixed Wireless Access solutions to fibre used primarily to serve mobile connectivity along highways). Possibly, the use of satellite technology to provide some 5G services in remote areas.

a) Adaptation of National Broadband Plans to the new 5G connectivity targets

One of the strategic EU connectivity objectives for 2025, as set out in the 5G Action Plan, is for all urban areas and all major terrestrial transport paths to have uninterrupted 5G coverage, while the objective for 2020 is 5G connectivity available as a fully-fledged commercial service in at least one major city in each Member State[17]. This 2025 objective is also tightly related to the objective of deployment of Very High-Capacity (VHC) networks to provide all the significant socio-economic drivers with Gigabit connectivity (in the meaning of the Communication on “Towards a European Gigabit Society”), i.e. in particular schools, transport hubs, digitally intensive enterprises, local authority buildings.

Given their role in the backhauling of 5G cells, fibre networks become increasingly important for achieving the corresponding 5G targets, as well as for the development of new 5G wireless applications, including connected and automated mobility.

These new applications require ambitious National Broadband Plans, based on massive deployment of optical fibre that will contribute to 5G readiness, including where appropriate in rural areas. While not all Member States see an urgent need to upgrade their National Broadband Plan, most have already reviewed them, or foresee doing so. They are seeking to bring their Plan into line with new ambitions regarding 5G and national 5G targets, in light of the 2025 strategic objectives, as well as to support the full implementation of the 5G Action Plan. As part of this review, a few Member States are proposing a detailed mapping of current and planned broadband infrastructures (and the

[17] The minimum of one major city by Member State is in fact a requirement set out to ensure that Member States will have put in place all necessary pre-requisites for 5G launch, in particular spectrum authorisations. In practice, it is expected that most countries will have launched some commercial 5G services in several cities and possibly several regions by end 2020.

presence of fibre in particular[18]). In doing so, it is also possible to identify areas where 5G and/or VHC network quality may be a credible ambition[19].

Among the most promising use cases for advanced 5G connectivity is Connected and Automated Mobility (CAM). Connectivity will be key to integrate connected vehicles (fully or partially automated) in the overall transport system. On multiple occasions, the Commission has publicly noted that, while most of the investment should come from the private sector, the EU and Member States may contribute to the financing of infrastructure in “challenge” areas and provide regulatory approaches that foster private investments needed in vehicles and communication infrastructure. A key step in support of the development of this use case would be the inclusion in national 5G roadmaps of a clear approach to stimulate the large scale testing of CAM services and fast rollout of mobile 5G access along the appropriate portions of highways (the 5G corridors).

A number of existing and planned 5G roadmaps were reviewed by the Working Group, and the following main elements were identified as the most common strategic elements currently considered by Member States when adapting their national broadband plan with respect to the 2025 objectives for 5G and VHC network deployment:

- The setting of specific national connectivity objectives building on the EU objectives.
- The use of methodologies to monitor and report the progress of infrastructure deployment against the national and EU objectives, with a suitable level of “granularity”[20].
- The role and the forms of public and private investments, and how these are connected:
  - The expected timing and the size of these investments.
  - The expected business and investment models.
- Cooperation opportunities with neighbouring Member States and at European level to establish or facilitate joint investment plans as regards cross-border infrastructure (e.g. 5G corridors for connected and automated mobility, joint solutions involving satellite services such as 5G on board planes).
- The publication of a description of the competences and responsibilities of the entities in charge of planning and implementation of the various parts of national plans.

The Commission services informed the Working Group that the newly established European 5G Observatory has been tasked to provide a regular status of the progress of deployment of 5G networks in Europe and to perform a comparison with other Regions. As part of this mission, the Observatory will also provide a status of progress of national plans against the EU-level 5G Action Plan. These findings will be made available in order to facilitate the sharing of information. The Commission further suggested that the COCOM could have a role to play to facilitate the collection and validation of national data performed in the context of the mission of the Observatory.

b) The growing importance of broadband infrastructure mapping

The geographical mapping of Quality of Service (QoS) and of planned future private investments in infrastructure constitutes an important "evidence base" for ex-ante and ex-post monitoring of state

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[18] It is noted that this exercise is subject to confidentiality rules regarding business information in relation to private investment plans.

[19] For example, the Spanish government announced recently (early 2018) an ambitious plan "Plan 300x100" to boost its support for the deployment of very high speed broadband networks for the period 2018 - 2021. The ultimate goal is to reach 95% coverage of the population by extending 300 Mbit/s access to 100 % of the population centres (Plan 300x100). Population centres include a set of at least 10 buildings or more and, as an exception, less than 10 buildings as long as there are more than 50 inhabitants.

[20] This is a fast developing topic, in particular in the context of the BEREC / RSPG work on developing methodologies to monitor VHC network deployment and the open discussion with regards the topic in the EECC.

aid measures for network roll-out, to avoid competitive distortions and crowding out of private investment by public interventions. In fact, the importance of geographical mapping and monitoring goes well beyond this regulatory purpose as it is also needed to assess the technical feasibility and economic viability of future advanced commercial services with demanding Key Performance Indicators (KPIs). More generally, the mapping of infrastructure, investment, demand and types of service, constitute a necessary basis for decision-making in the fields of policy, regulation, implementation and monitoring of progress.

Given the increasing connectivity needs for future 5G applications in vertical industries (such as factories of the future, energy, transport, automotive, media and entertainment, e-health), the importance of QoS monitoring may become even more relevant in the future, especially for mission critical applications. This may even build confidence among investors and enable new connectivity-dependent applications in vertical industries, to ensure that networks can meet the demanding new requirements to make such advanced opportunities possible at appropriate locations.

Very high speeds (download and upload) and low latency are already defined as key capabilities of 5G. However, these attributes might not be sufficient to monitor the Quality of Service of 5G in the future. Additional attributes might become important, such as jitter, area traffic capacity, density of devices, reliability, position accuracy, and other relevant error–related parameters, in line with the VHC network concept introduced in the EC communication for a European Gigabit Society (COM (2016) 587)[21] and now legally defined in the Article 2 of the forthcoming EECC. It is to be noted that operators may consider that some of the implementation-specific information in this context as confidential and it therefore has to be treated accordingly.

Several Member States have already taken initial steps into the direction of geographical mapping, for example:

- In Austria, the Broadband Atlas and State Aid Map (BBA2020) under consideration will give a concrete outlook of possible future developments addressing both planning needs and state aid mapping requirements. The proposed system is GIS[22] based and has a resolution of one hundred meters (micro raster data). It is the smallest available statistic database with demographic data (inhabitants, buildings and households) made available from Statistic in Austria. It provides a comprehensive mapping of mobile and fixed network coverage, as well as of areas covered by the resulting projects of the state aid programme. At the moment, only network operators having their own infrastructure and residential products participate on a voluntary basis (it will however become obligatory in Austria in the future). They provide their data on the “Upload Portal” twice a year. It is possible to upload GIS data or draw the broadband coverage with the help of tools managed on the Upload Portal by the Ministry of Transport (BMVIT).
- The Netherlands have recently completed a first iteration of a map displaying the available maximum download speeds for fixed networks, down to the level of individual addresses in the full territory of the Netherlands. The map can be used by local and regional authorities to identify which locations within their borders do qualify for state aid measures in relation to the financing of Next Generation Access (NGA) network. The map distinguishes between available download speeds of 0-30 Mbps, 30-100 Mbps, and 100+ Mbps. The map was created using data provided voluntarily by the network owners themselves, or mined from

[21] Very high-capacity network" means an electronic communications network which either consists wholly of optical fibre elements at least up to the distribution point at the serving location or which is capable of delivering under usual peak-time conditions similar network performance in terms of available down- and uplink bandwidth, resilience, error-related parameters, and latency and its variation. Network performance can be considered similar regardless of whether the end-user experience varies due to the inherently different characteristics of the medium by which the network ultimately connects with the network termination point.
[22] Geographic Information System.

their public databases where necessary. The Netherlands are looking to further develop this map, for example by providing an interface through which network owners can provide updates for the map, and by doing tests to check whether the stated maximum speeds are also available in practice. Online publication of the map is due later in 2018.

- France has initiated numerous actions regarding mobile coverage and quality of service. Specific laws were passed in 2015 and 2016, giving the French NRA the ability to define operators' obligations regarding coverage map definitions, for both fixed and mobile networks, the ability for the French NRA to conduct field measurements to ensure reliability of this data, financed by operators, and to publish all coverage data (especially GIS) in open data. The French NRA implemented two main decisions, one for mobile networks (in 2016) and one for fixed networks (in 2018). New coverage map definitions for voice services were set, in order to distinguish between three coverage levels: very good coverage, good coverage and limited coverage areas, ensuring mobile coverage maps were more reliable and closer to consumer experience. In order to facilitate access to all mobile coverage and QoS data, a dedicated website[23] was launched in 2016, gathering all coverage maps for all of the 4 MNOs, for all technologies (2G, 3G, 4G), and all QoS field measurements yearly conducted by the French NRA. Coverage maps can be "zoomed in" up to a very small scale (streets/houses), with 50 meters resolution (resolution used by MNOs when modelling their coverage maps). Coverage rates (both population and territory) are published on the same website, for each MNO and each technology. Besides coverage maps, mobile QoS tests (voice calls, SMS, DL and UL speeds, video streaming, web browsing) are available on the same website, for transportation (all high speed trains, all highways, all subways, main road and trains) as well as for residential areas (more than 1700 cities measured, both in very dense areas, intermediate cities and very rural cities). All these QoS rates and results are publicly available, alongside geographical data on the same website (as well as in open data). Gathering all this coverage and QoS data on the same website is part of data driven regulation policy promoted by the French NRA. It provides easily accessible and comparable information to consumers regarding availability and estimated coverage. It both empowers consumers to make commercial decision and help drafting targeted public policies, based on more accurate diagnostic.

There are also interactive maps available in a number of other Member States, for example:

- Belgium: Maps detailing both mobile coverage and the availability of fixed broadband are available in Belgium. The regulator is currently working at the publication of coverage maps including 3 coverage levels (very good, good and limited) in order to ensure mobile coverage maps become more reliable and closer to consumer experience. Maps also display the fixed broadband coverage broken down by bandwidth category, at national municipalities, sub-municipalities and sectorial levels.
- Denmark: Maps detailing both mobile coverage and the availability of fixed broadband[24].
- Germany: The Broadband Atlas commissioned by the Federal Ministry of Transport and Digital Infrastructure[25] displays the broadband coverage situation on a national level, in the individual federal states and in all regions and municipalities - broken down by technology and bandwidth category. The focus of the Broadband Atlas in Germany is the availability for private households. Since 2015, information on the geographic availability of commercial broadband services has also been collected. It is based on surveys commissioned by the Federal Ministry of Transport and Digital Infrastructure. The database consists of the

[23] https://www.monreseaumobile.fr/
[24] https://tjekditnet.dk/
[25] http://www.bmvi.de/DE/Themen/Digitales/Breitbandausbau/Breitbandatlas-Karte/start.html

broadband coverage data of the around 350 participating telecommunications companies, which made available their data on a voluntary basis.

- Hungary[26]: NMHH's Internet speed measuring website (Szélessáv.net) provides objective data about the quality parameters of Hungarian broadband services and offers substantiated and independent information to users to help them make informed decisions about service providers and services.
- Italy: Data are available on an interactive database, sorted by region/municipalities and for different speed classes[27].
- Poland: The Polish NRA maintains an inventory of existing networks and availability of services (the Information System on Broadband Infrastructure (SIIS). The system collects, processes, and presents shared information on telecommunications infrastructures, public telecommunications networks, and buildings allowing co-location[28]. In addition to the data collected through the various third parties, a tool for measuring the Quality of Service (QoS) is being tested. This tool should soon provide public information about the real bandwidth and quality of service available to consumers.
- Spain: Maps detailing the availability of basic broadband[29].
- UK: Ofcom publishes an annual Connected Nations report, and periodic updates to this through the year, with accompanying visualisation tools[30] and mobile apps[31]. These provide accessible and comparable information to consumers regarding availability and estimated speeds for superfast and ultrafast fixed broadband and for mobile networks.

c) The impact of ongoing work on quality and coverage of broadband

There are already several public, as well as private, initiatives across Europe aiming at monitoring and measuring the availability and, to variable extent, the quality of broadband services using individual mapping systems. In order to take advantage of these existing data, the European Commission (DG Connect) has launched a new mapping platform compiling data collected from different individual systems, and presenting them along three categories of quality of service (QoS), both for fixed and mobile technologies. The results are included in one interactive Europe-wide map structured as follows: calculated availability of service, network performance of existing infrastructure (QS1); measured provision of service, excluding end user environment (QS2); and measured provision of service, including end user environment, i.e. user experience (QS3).

The Working Group noted these efforts towards a common mapping platform, as outlined above, and discussed the following aspects for consideration:

- There would be an advantage to avoid the use of different methodologies to map broadband coverage and to seek for the adoption of a common methodology on **QS1**. Recognising this need, the Commission services have announced plans, following consultation with National Regulatory Authorities (NRAs) and Member States' Ministries, to complete work by the beginning of 2019 on a single methodology for mapping basic broadband, NGA and VHC network coverage, and for carrying out public consultations on future investments (as foreseen in the relevant articles of the forthcoming EECC, namely the articles 20, 22, 22a, which are referring in particular to future BEREC Guidelines to be developed).

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[26] https://szelessav.net/en/
[27] http://bandaultralarga.italia.it
[28] https://wyszukiwarka.uke.gov.pl/ (data is also available for download)
[29] http://www.minetad.gob.es/telecomunicaciones/banda-ancha/cobertura/consulta/Paginas/consulta-cobertura-banda-ancha.aspx
[30] https://checker.ofcom.org.uk/
[31] https://www.ofcom.org.uk/phones-telecoms-and-internet/advice-for-consumers/advice/ofcom-checker

- With regard to **QS2**, the Commission services also announced that a further initiative may be taken soon in order to develop, in consultation with the relevant Member States' authorities and the industry, a common methodology for QS2 within the framework of the next phase of the EU mapping broadband platform (2019-onwards).
- In addition, the BEREC Net Neutrality Working Group is developing a common methodology with regard to **QS3**, to enable users themselves to measure quality of experience/services. The aim is to conclude this work and develop a BEREC platform over the course of the next three years (2018-2020) to measure quality of (experience) services (in line with the provisions of the forthcoming EECC as well as the rules on Net Neutrality, and with proper reference to users' rights).

BEREC adopted a preliminary report in October 2017 on monitoring mobile coverage, with the ambition to agree on a common position on monitoring of mobile coverage to be adopted in 2018, following a public consultation. In the remaining part of the year, the BEREC Mobile and Roaming Working Group will continue to focus most of its work on coverage obligations in two main work streams: the above-mentioned common position on monitoring mobile coverage and a best practices report on coverage obligations, in view of considering their suitability for 5G. These various complementary strands of work are expected to assist Member States' authorities in gathering suitable data to support the application of relevant regulations, the development of policy at EU, national and regional level including the National Broadband Plans, and the implementation of EU and national-funded projects including those receiving state aid.

The Working Group also noted that, as from 2020 onwards, the EC has announced plans to carry out additional work for the development of common methodologies on mapping infrastructure and demand with a view to complement the ongoing work on mapping quality of services and investment.

d) Suggestion for the next steps

On the basis of the discussions in the Working Group, the following elements have been highlighted:

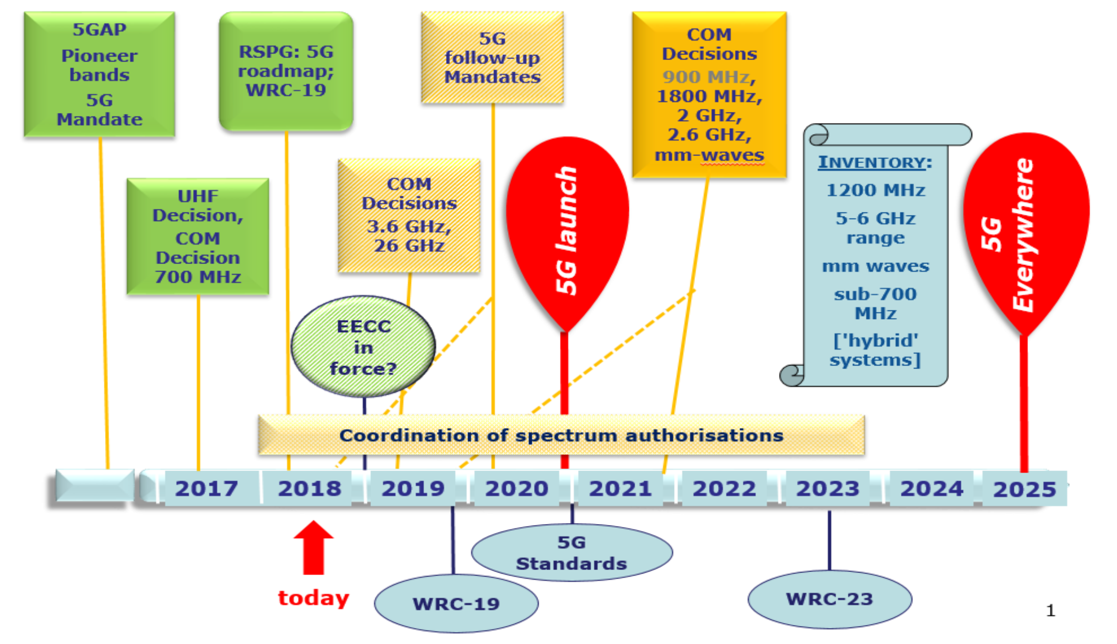
- A continuous exchange of best practices between Member States, starting from the main strategic elements identified above, may provide useful insights to adapt national broadband plans to meet the 2020 and 2025 EU strategic connectivity objectives for 5G.
- There is a potentially significant advantage to develop a common approach in Europe for measuring the quality of broadband services, including next generation mobile services. A promising way forward is the collaboration between Member States to establish common methodologies in the context of BEREC as well as the concurrent Commission's efforts to develop an EU mapping platform for measuring quality of broadband services. The wider EU scale can provide more reliable statistical data for the benchmarking and assessment of supporting policies and regulations.

2) Access to spectrum resources for timely 5G deployment

a) Strategic elements

A key element of national 5G plans is the publication of a transparent *schedule of effective spectrum availability ("spectrum plan"[32])* to ensure predictability for investments. National spectrum plans are expected to take account of, and be aligned with, the EU priorities set out in the 5G Action Plan, the related *EU-level 5G spectrum roadmap developed by the Commission (please see the figure below)* on the basis of the RSPG's strategic spectrum roadmap for 5G for Europe[33], the Commission Mandates to CEPT[34], and EU-level measures already in force (UHF band Decision and relevant Implementing Decisions). In this regard, the proposed EECC (Art. 53a) will enhance the availability of relevant 5G pioneer bands for effective use by mandating their timely authorisation with a common deadline. This provision specifies that, by 31 December 2020, Member States must allow the use of the 3.6 GHz and a sufficient portion of the 26 GHz bands to facilitate the rollout of 5G. It is in addition to the common EU deadline of 30 June 2020 for the release of the 700 MHz band[35].

Figure: EU-level 5G spectrum roadmap[36]



[32] Please note that, in the terminology used in this document, the "spectrum plan" is different from what is usually called the "national frequency table". The latter designates which frequencies are used for given services, while the "spectrum plan" refers to a spectrum (availability) roadmap – i.e. which 5G-ready band is used when and how.
[33] Consisting of the Opinion on Spectrum Related Aspects for Next-Generation Wireless Systems (5G) (RSPG16-032 final) and the Second Opinion on 5G networks (RSPG18-005 final).
[34] Such as document RSCOM16-40rev3 regarding the Mandate to CEPT to develop harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the Union.
[35] Decision (EU) 2017/899
[36] This is an evolving roadmap, initially presented by DG Connect at the CEPT-EC workshop on WRC-19 (12 May 2017), s. https://ec.europa.eu/digital-single-market/en/news/slides-joint-european-commission-cept-workshop-wrc-19 (Panel 1).

It is considered an advantage if spectrum plans clarify from the onset, where possible, *the authorisation process* (including deadlines) and provide indications on particularly relevant award characteristics (e.g. authorisation modes, possible connectivity quality requirements, expected license duration, etc.). This could include all three pioneer bands[37] as the initial 5G spectrum mix, and possibly other EU-harmonised bands below 6 GHz according to the CEPT mandates in support of 5G rollout as of 2020[38]. Another element is the availability of sufficient temporary spectrum usage rights (local or national) for pilot trials.

In most cases, the design of a spectrum authorisation procedure has market shaping effects, albeit to various extents, e.g. through spectrum caps, wholesale obligations or conditions related to spectrum sharing. Therefore, making an explicit linkage between the design of the authorisation procedures and the wider 5G deployment objectives should bring more consistency with regards the overall 5G strategy and provide increased transparency and certainty to market players.

b) Urgency to make pioneer bands available for effective use

Technical experts recognise that large blocks of contiguous spectrum could facilitate efficient spectrum use for delivering high transmission speed and capacity. At the same time, this would ease the implementation of EU net neutrality rules by operators since it would reduce the spectrum scarcity and potential impact on Internet Access Services. In line with the RSPG recommendation and supporting CEPT work, the spectrum plan should present relevant national measures (if needed) for the defragmentation of the primary 3.6 GHz band (3.4-3.8 GHz) to prepare it for 5G by making it possible to use large contiguous blocks of spectrum[39]. According to CEPT Report 67 in response to the Commission mandate, the spectrum should be provided in a manner allowing for at least 3x50 MHz of contiguous spectrum (more blocks could be considered in the case of competition issues where there are more than 3 operators in a market). Industry has indicated that there could be benefits to broadband spectrum users (mainly mobile operators) of using even wider channels (such as up to 80 MHz or 100 MHz for enhanced broadband services) as well as narrower channels to satisfy particular market demand. In regards to the pioneer 26 GHz band, contiguous blocks of spectrum of at least 200 MHz[40] should be considered for enhanced broadband services (please see CEPT Report 68), and possibly up to 1 GHz, according to industry needs. It appears as a good practice that the spectrum plan presents the approach to a progressive assignment of the 26 GHz band (subject to market demand), starting initially with at least 1 GHz in line with the RSPG recommendation[41] and pursuant to Art. 54 of the EECC (whereby the deadline for authorising at least 1 GHz of this band for 5G use, subject to market demand, is end of 2020).

In the view of the Working Group, national spectrum plans should consider spectrum authorisation models adapted to the characteristics of the different 5G bands, including the consideration of enabling the emergence of vertical applications. The assessment should as far as possible address the full range of options from general authorization, to individual rights (possibly with different geographical scope) and including spectrum sharing, spectrum leasing or trading and innovative or

[37] 700 MHz, 3.6 GHz and 26 GHz frequency bands.

[38] The deadline for 700 MHz band release for wireless broadband use in the Union according to Decision (EU) 2017/899 is mid-2020 (justified exceptions possible by mid-2022). According to the provisionally agreed article 53a of the EECC, by 31 December 2020, MS shall, where necessary in order to facilitate the rollout of 5G, take all the appropriate measures to reorganize and allow the use of 3.6 GHz band and allow the use of at least 1 GHz of the 26 GHz band.

[39] Some Member States face specific constraints to achieve the objective of larger blocks, including the need to ensure coordination with non EU countries using the band for different services. In particular, eastern non-EU countries use the 3.6 GHz band for fixed services. This may be compounded by the need to defragment the band in a context of existing long term licenses. For example, Poland is experiencing both challenges.

[40] CEPT Report 68 also foresees, if required to ensure the full use of the band, the subdivision in smaller block sizes in multiples of 50 MHz adjacent to other spectrum users

[41] Please see Recommendation 9 in RSPG18-005 FINAL and Recommendation 7 in RSPG16-032 FINAL.

hybrid approaches. Models for some "verticals" (in addition to services delivered by public mobile networks based on "network slicing"[42]) may include the facilitation of direct access to dedicated spectrum for verticals for private 5G networks (e.g. for energy distribution or industrial automation) or licence-exempt spectrum use for the massive IoT[43]. In this regard, the RSPG is working on sharing national practice on spectrum authorisation and collecting evidence from industry. The forthcoming RSPG opinion on 5G implementation challenges will also provide recommendations on connectivity for verticals.

Best practices available suggest that spectrum plans should outline the decision-making process for the authorisation regime for 5G bands[44] based on criteria for the determination of the selection procedure and authorisation conditions (such as those attached to individual rights of use). Such criteria could include radio propagation characteristics, coexistence requirements with incumbent services and related sharing approach, anticipated usage scenarios and related service quality requirements for pan-European services, as well as the degree of scarcity and the geographic territory related to it.

c) Support to 5G Fixed Wireless Access as a complementary 5G ecosystem

It is anticipated that Fixed Wireless Access (FWA)[45] will be an attractive 5G use case, in particular in relation to the opportunity opened up by the new millimetre wave spectrum technology. It could offer advantages in both urban settings (based on dense small cells close to dwellings) as well as in rural areas to overcome the deployment challenge of fibre. FWA could thereby contribute directly to reaching the 2025 connectivity objective for 100 Mbps (upgradable) for all households.

The capital expenditure for 5G deployment is highly volume-sensitive[46]. Therefore, the achievement of economies of scale is essential to reduce overall costs for consumers and businesses and, as a result, facilitate faster adoption and wider dissemination of the technology. This challenge is likely to be solved rapidly for classical 5G use cases such as the mobile broadband access to Internet and video content in a global consumer market context. However, it may be more difficult to reach critical mass in the case of an emerging applications such as 5G-based Fixed Wireless Access as a substitute to fibre connections.

At the special session of the Working Group on 5G Fixed Wireless Access on 12 April 2018, leading vendors[47] emphasised that FWA could become a viable business case if it is fully part of the wider 5G ecosystem based on 5G mobile services. In particular, vendors underlined the role of potential synergies between 5G fixed and 5G mobile access as well as vertical use cases, which could reinforce each other and give rise to economies of scale.

In this context of generating scale effects for 5G FWA, the following main elements have been identified by the Working Group with regard the preparation of national spectrum plans:

- Taking into account synergies and/or convergence between spectrum approaches in Member States to speed up economies of scale regarding new use cases, and in particular 5G

[42] "Network slicing" allows a single physical network to be sliced into multiple virtual networks that can support different levels of service quality, or different service types.
[43] Internet of Things.
[44] The overarching plan can include only an outline, leaving the details to the technical and implementation supporting documents.
[45] Fixed wireless access is a service which provides high-speed internet utilizing wireless radio technology.
[46] "The 5G value chain in the US will invest an average of $200 billion annually to continually expand and strengthen the 5G technology base within network and business application infrastructure; this figure represents nearly half of total US federal, state, and local government spending on transportation infrastructure in 2014", "The 5G economy: How 5G technology will contribute to the global economy" by IHS Economics / IHS Technology, January 2017.
[47] Ericsson, Qualcomm, Nokia, Samsung.

Fixed Wireless Access, as part of the 5G ecosystem for enhanced mobile broadband services as well as vertical industry applications.

- Providing access to large spectrum bandwidths for wireless broadband operators so as to enable anticipated business models, and allow for true fibre substitution.
- Considering synergies with spectrum bands used for FWA in other regions of the world, for example the opportunity of taking advantage of economies of scale arising from a "tuning range" within the 26-28 GHz bands[48], while promoting and progressively enlarging usage of the 26 GHz band to stimulate large-scale demand effects, in line with the RSPG Opinion on WRC-19[49].

d) Impact of Service Quality on spectrum authorisation conditions

Wireless service quality, e.g. for mission-critical use, is an essential factor for 5G take-up, and it may be influenced by spectrum authorisation conditions insofar as they address relevant technical service parameters. In order to take into account the vertical industry specificities of 5G, one possible solution for Member States could be to consider such technical requirements, to the extent they are sufficiently defined, in the form of *key performance indicators* (KPIs) on a per-service basis as part of potential coverage/quality obligations on operators of 5G networks. However, some Member States' representatives in the Working Group disagree with this view, as they consider that such requirements are unclear at the moment, or highly speculative, and that competitive forces in the market can hopefully deliver the required connectivity without government intervention.

In any case, given the uncertainty on 5G, and more generally the next generation,service evolution and related spectrum use, such an approach should be open for adaptation. Relevant 5G and next generation services with a clear pan-European dimensionneeding specific KPIs (such as latency or reliability) are already emerging in the following sectors: automotive (connected cars), utilities (smart grids) or the healthcare (health monitoring and diagnosis). In this regard, Member States could address ways to ensure service quality through a potential need for coverage/quality obligations and the approach to their definition, measurement and enforcement, in the light of the ongoing work within the RSPG.

e) EU level coordination

A consistent EU-level approach could benefit the aforementioned issues, in particular for pan-European services and an EU-wide ecosystem. It could be enhanced by stepping up the informal dialogue between Member States on these matters to complement obligations under EU law. The following issues have been identified as potentially relevant for *EU-wide sharing of best practice*:

- Authorisation models suitable for verticals. Quality-of-service requirements (e.g. KPIs regarding latency, throughput, reliability) for services with a single market dimension such as connected transport (automotive, rail, drones) and the preferred approach to their implementation (role of regulations vs. market /standard-based approach).
- Method for the calculation of EMF exposure levels , including their cumulative effect in relation to the multiple frequency ranges inherent to 5G small cell deployment (please see also chapter 3), as well as their light authorisation regime based on individual permit exemption, in line with the EECC [50].

[48] For example, the likely market development that the upper 1GHz of the pioneer 26 GHz band in Europe, also supported by China, India, Brazil and some other countries (South Korea) , and the so-called 28 GHz band to be used in South Korea, Japan or in the US, could be supported by a single chipset.
[49] Section 4.2 of RSPG18-023
[50] National EMF limits remain subject to Council Recommendation 1999/519/EC

The elements of a spectrum plan addressing the above issues are dependent, to a variable degree, on EU-level policy and regulatory developments (e.g. the EU-level 5G spectrum roadmap, RSPG deliverables, implementation of net neutrality rules, and the forthcoming EECC). In particular, the Working Group supports the view that member States should address such elements in a way that contributes to the development of a common knowledge base and the exchange of best practices. Best practices and consistent approaches should also be discussed with interested stakeholders at a workshop at the appropriate point in time.

In conclusion of the discussions on spectrum issues, the Working Group notes:

- The importance for Member States to develop a comprehensive spectrum plan**,** taking into account agreed EU-level deliverables, which addresses the authorisation of use for 5G pioneer bands, service quality requirements, and other possible elements in need of EU level coordination.
- RSPG's ongoing work on spectrum implementation challenges for 5G deployment (2018-2019) and recognises in this context the importance of its work on identifying common approaches for the authorisation of 5G pioneer bands (Final RSPG Report/Opinion planned for April 2019).
- The relevance of the Commission’s initiative, in cooperation with BEREC and with involvement of the RSPG, to propose by mid-2019 a common and complete methodology for defining and measuring the quality of broadband services.

3) Reducing the cost of building up local 5G connectivity (small cells)

a) Introduction

The densification of cellular networks is an essential characteristic of 5G development, most likely resulting in a significant increase in small cell deployment. In particular, small cell deployment can improve the quality of service by decreasing the average number of users in a given cell, while increasing available capacity per user. However, there are still a number of barriers of a regulatory or administrative nature relating to small cell deployment. A combination of measures could improve industry's ability to deploy denser networks quickly and lowering deployment costs. These could include not only the definition of a set of characteristics of small cells in Europe that will be exempt from any individual town planning permit or other individual prior permit (as foreseen in the forthcoming EECC), but also the increased flexibility in spectrum authorisation and licensing models, and adopting a proportionate regime for installation of the equipment when a permit is required.

Several Member States are already progressing with improvements and simplifications that can influence favourably the timing and cost of deploying small cells, even in advance of the implementation of the related provision of the EECC (e.g. Germany, UK, FR[51]). A recent proposal by the US federal authorities to reduce the cost of installation of 5G small cells in the US[52] is further evidence of rapid developments in this area.

b) Small cell related regulation foreseen in the European Electronic Communications Code

Anticipating the need for smaller cells in 5G, the Commission has sought to facilitate the deployment of small-area wireless access points by pursuing the objectives set out in the forthcoming European Electronic Communications Code (EECC). The relevant articles of the EECC are summarised below:

- Article 2 defines a small-area wireless access point as *"a low power wireless network access equipment of small size operating within a small range, using licenced radio spectrum or licence-exempt radio spectrum or a combination thereof, which may or may not be part of a public terrestrial mobile communications network, and be equipped with one or more low visual impact antennae, which allows wireless access by users to electronic communications networks regardless of the underlying network topology be it mobile or fixed"*.
- Under Article 56, competent authorities shall not unduly restrict the deployment of small-area wireless access points and Member States shall seek to ensure that any rules governing the deployment of small-area wireless access points are nationally consistent. In particular, authorities shall not subject the deployment of small-area wireless access points meeting the characteristics laid down by an implementing decision of the Commission, to any individual town planning permit or other individual prior requirements. Such Commission decision should specify the physical and technical characteristics of these small-area wireless access points, such as maximum size, weight and where appropriate emission power. Competent authorities may however require permits for the deployment of small-area wireless access points on building or sites of architectural, historical or natural value protected in accordance with national law or where necessary for public safety reasons.

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[51] One of the four work streams described in the French national 5G strategy is the support to 5G infrastructure deployment including the definition by the national regulatory authority of best practices guidelines (for local authorities) aimed at facilitating and speeding up the deployment of 5G networks and small cells in particular
[52] https://www.fcc.gov/document/fcc-acts-speed-deployment-next-gen-wireless-infrastructure

While the physical and technical characteristics of the small-area wireless access points which will benefit from the "light deployment regime" of the EECC are still to be specified, those small-area wireless access points are likely to share similar characteristics in regards to range, power, and installation height and weight. In this regard, it is essential to assess the effect of denser deployment on the compliance with electromagnetic field limits, which are relevant for the protection of human health.

c) Analysis

A 5G small cell is generally described as a fully featured low power radio access node that can operate in licensed or unlicensed spectrum.

Moreover, the Global 5G Forum defines the term 'small cells' as *"an umbrella term for operator-controlled, low-powered radio access nodes operating in licensed or unlicensed spectrum. Small cells typically have a range from 10 meters to several hundred meters"*[53].

The construction of small cells as well as the granting of permits for the deployment of small-area wireless access points for that purpose are subject to a variety of regulatory regimes in a number of national legislations in the Union, as illustrated by the selected examples below.

- In the UK, the "Town and Country Planning" (General Permitted Development) (England) (Amendment Order 2016) defines "*small cell system" as an antenna which may be variously referred to as a femtocell, picocell, metrocell or microcell antenna, together with any ancillary apparatus, which (a) operates on a point to multi-point or area basis in connection with an electronic communications service (as defined in section 32 of the Communications Act 2003(a)); (b) does not, in any two-dimensional measurement, have a surface area exceeding 5,000 square centimetres; and (c) does not have a volume exceeding 50,000 cubic centimetres, and any calculation for the purposes of paragraph (b) or (c) includes any power supply unit or casing, but excludes any mounting, fixing, bracket or other support structure*".
- Greek law defines the following *1) Small-scale stations installations and low nuisance antenna structures: Low-electromagnetic emissions and environmental nuisance antenna structures with the necessary components and associated radio equipment, of small weight and small dimensions, whose total effective isotropic radiation power (e.i.r.p.) does not exceed 164 Watt, are exempted from any permit requirement (town planning, environmental or others), provided that they comply with certain conditions- typically these include structure height up to 4 meters. Special authorizations are required only for installation in conservation areas. 2) 'Microcell' is "a cell site defined by the standard of the European Telecommunications Standards Institute (ETSI)" and 3) 'Microcellular system': An antenna system consisting of the following elements: the radio equipment, used for the cell site coverage and the apparatus required for the power supply of the 'Microcellular system'*.
- The approach in the Netherlands is simpler: Mobile telecom antennae of less than 5 meters in height are exempted from any environment authorisation provided that they comply with certain conditions, which are set by Decree. Except for installation in monuments and protected facades, the antennae (e.g. UMTS, GSM) shorter than 5 meters calculated from the bottom of the installation, do not require any authorisation for the construction and its functioning. Some of these exempted antennae are nevertheless subject to general operational conditions set in agreements entered into by mobile operators, the association of Dutch municipalities and the ministries for economic affairs and for environment.

The above examples illustrate the diversity of approaches in the Union. However, since the number of small cell deployments could significantly exceed those of macro deployments in 5G, the small cell

[53] https://www.smallcellforum.org/about/about-small-cells/small-cell-definition/

deployment processes will have to be simpler and more cost-effective as compared to traditional macro site deployment processes.

Industry stakeholders have expressed their wishes to see improvement in these processes to be able to innovate with new business models, possibly supporting new types of cell ownership (e.g. third party hosting of small cells or private residential small cells) and new configurations to provide access to these new access points by duly allowed mobile subscribers. Optimally, the improved approach should aim at a higher degree of EU harmonisation according to interested operators and vendors.

Such a more aligned set of rules and processes could be established starting from those set out in Article 56 of the forthcoming EECC for small cells. It should also consider additional aspects of mobile network deployment, mutatis mutandis, such as site/base stations requirements (by NRA or local authorities), radiofrequency compliance, site planning and access right-of-way and property, and even possibly a more consistent framework of fees and charges. In addition, the generic conformity assessment procedures in place (possibly revised for 5G) must continue to be applicable for the equipment and exemption-based installations.

In most Member States, planning permission, and more generally use of land and buildings, are subject to control by local government and authorities. Often such authorities derive their powers from national constitutional law and local democracy. It is of course recognised that measures for the deployment of 5G should not override fundamental constitutional and democratic concerns in Member States (i.e. be fully in accordance with national law and consistent with EU law). However, there could be a benefit to put in place institutions and procedures (tailored to specific national circumstances) encouraging local authorities to facilitate small cell deployment. For example, regional broadband coordinating offices could be set up so that local authorities can draw on existing expertise. This could bring together representatives of local stakeholders for discussion and dissemination of best practices on a national level. Some Members States consider that, in these circumstances, an alternative proper information campaigns, transparency about local rules or fees and charges, and a degree of voluntary harmonisation, is a better way forward.

The public sector may also play a useful role in providing sites for hosting 5G installations. Furthermore, the Article 56a of the forthcoming EECC requires public authorities to make available sites on publicly owned property and infrastructure on reasonable terms. This approach has already been pioneered by the UK's 5G strategy, published in March 2017, which stated that a more radical approach to opening up Government buildings and land for mobile infrastructure development could be needed for the purposes of supporting 5G infrastructure. Therefore, the UK Government has taken steps to address this and published a Digital Infrastructure Toolkit that sets out the terms for access to central government buildings.

There is already a significant amount of good practices available in relation to small cells in the context of 4G/LTE where initial measures have already been adopted by some Member States, e.g. the use of generic permits, harmonised planning permissions, "one stop shop" application procedures, tacit approvals and databases of qualified candidate site locations. The effectiveness of these procedures could be examined in the light of the overriding requirements of the EECC, once adopted, while recognising that they do vary widely between Member States in accordance with national law.

Regarding the compliance with Electro Magnetic Fields (EMF) limits, the existing European Community (EC) Recommendation 1999/519/EC, based on the Guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 1998, provide the basic restriction rules and reference levels for general public and occupational exposure.

Nevertheless, some Member States have adopted limits that are specific/local and more stringent than those of the international community or the above-mentioned Recommendation.

Therefore, taking in consideration various national approaches, an additional coordination step forward, may be necessary, namely to identify the most coherent and effective EMF calculation method and to promote it more consistently across the EU. In the same context, it is worth noting that the forthcoming EECC, in its article 45, pursues consistency and predictability throughout the Union regarding the way the use of radio spectrum is authorised in protecting public health on the basis of Council Recommendation 1999/519/EC.

In this respect, the recent adoption by the International Telecommunication Union of the Supplement 14 to its ITU-T K-series of Recommendations, titled "The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment"[54], may create a new momentum towards a more consistent global approach to EMF limits.

d) Proposed next steps for consideration

The Working Group discussed the following as a possible common basis for the way forward:

- Accelerate the work on small cells by relevant policy advisory and expert groups in order to address at least the main obstacles listed in this chapter, including a more coherent approach to EMF limits, in compliance with high health protection standards. This would allow a voluntary adoption by Member States of all or parts of the future conclusions of BEREC and/or RSPG, in time for 5G deployment, and ahead of any further harmonised EU measures developed as a follow-up of the EECC.
- Establish an overview of national approaches for the protection against non-ionizing radiation which include calculation methods and measurement tools, information for the General Public/Awareness campaigns (in cooperation with various authorities: health, environmental, ICTs, local city councils), and general cost/benefit analysis for different EMF limits (national/local) which will be an assessment of the key success indicator.
- Identify best approaches to promote access to public property as a strategic policy initiative to facilitate the installation of small cells (e.g. lamp posts).

[54] https://www.itu.int/rec/T-REC-K.Sup14-201805-I

4) Public financing support to 5G deployment

a) Objectives of public funding intervention in the 5G context

Broadband communication has become a key factor of economic and social development and influences many aspects of our lives. Mobile devices play a central role as an entry point to the digital society for citizens and the mobile connectivity catalyse digital transformation across vertical industries.

From an infrastructure perspective, fixed and mobile broadband share a large part of the overall ecosystem. Mobile broadband access in a 5G context will require access to an efficient (fixed) backhaul infrastructure to support the high data capacity needed (mainly fibre networks). Therefore, the extension of the target of 100 Mbps connection to all households by 2025, as proposed in the Communication on the Gigabit Society, has to be seen against the wider ambition that there should be access to mobile data connectivity mobility "wherever people live, work, gather, or travel". Equally, 5G Fixed Wireless Access solutions may provide new ways to give access to fixed broadband services in areas currently not benefitting from very high speed (fixed) broadband networks. Therefore, complementary public investments in the extension of mobile networks, traditionally considered as private-sector investment only, are also likely to be needed, to support, or to backhaul, fixed wireless access solutions capable of contributing to the achievement of the EU connectivity targets.

In terms of achieving the overall EU connectivity targets, the Gigabit Society Communication has already underlined the need for a total private and public investment of approximately EUR 500 billion by 2025, a significant share being directly related to 5G deployment. While the main part of this effort will be led by private investments, the Communication also identifies an estimated shortfall in total investment of EUR 155 billion, if current investment trends are continued. Appropriate forms of public financing may therefore be essential to close this gap.

The UK Government announcement in November 2016 of an investment of GBP 1 billion (EUR 1.12 billion) to boost the UK’s digital infrastructure. This is a particularly illustrative example of this reinforced commitment for complementary public financing as incentive for private investments.

Furthermore, public financing support in this context should not only be seen in the strict scope of 5G infrastructures: the deployment of pre-5G infrastructure elements (notably fibre and physical infrastructure, including in support for 4G) also represents an important contribution towards 5G rollout, and hence a long term competitive assets. The progressive integration of fixed and mobile connectivity from all successive “generation” of communications networks into a seamless communications environment will eventually contribute to the overall “5G readiness” of a country.

In this respect, physical infrastructure and fibre networks deployed using public funding to address current market failures could also fall within the scope of the national 5G strategies if they can be used to backhaul 5G infrastructure providing the level of connectivity targeted by the initial public aid. For instance, backhaul infrastructure built to allow the deployment of NGA[55] connectivity in an area where only basic broadband was available could possibly be used to support the deployment of 5G services as long as the performance of the 5G connectivity could qualify as NGA. Another possible scenario is to foster a step change towards VHC networks in places where some access technologies, such as VSDL, LTE or fixed Wireless, already provide reliable NGA services at 30 Mbps, but the connections are far from reaching speeds of 1 Gbps. From a State Aid perspective, these eligible areas are currently treated as grey NGA areas, but in order to facilitate the achievement of the EU

[55] Next Generation Access.

connectivity objectives set in the Communication on the Gigabit Society, some Member States have called for a new State Aid category of white VHC areas, defined by a reliable provision of at least 100 Mbps, to be considered. The public funding would only be allowed where a clear step change is achieved by the new more advanced deployed infrastructure. While such an additional category is not set out in the current Broadband State Aid guidelines, those guidelines do allow for public support to step change investments in grey NGA areas under specific conditions. The Commission is likely to provide some further guidance in this regard by way of individual cases addressing this issue that are currently pending for decision.

From an EU-wide perspective, a common factor to all deployment scenarios is that there is a need for increased capital investment in the network infrastructure along transport paths, to meet the 2025 objective of uninterrupted 5G coverage along the main roads. The anticipated applications in the transport domain require much better coverage and higher communications capacity in comparison to those of today, and this can be provided by fibre networks linked to high capacity wireless access points.

Any infrastructure built to address the above-mentioned purpose could also serve a more general purpose of providing backhaul or access connectivity in the area concerned. In those cases, the possibility to open this infrastructure for such use will be subject to the usual assessment of state aid for the roll out of backhaul for broadband networks. Such public funding of backhaul infrastructure should only take place where it is demonstrated that existing backhaul infrastructure is insufficient to cater for the needs of 5G networks and it should be carried out in such a way that it minimises the distortion of competition with any already existing private networks.

In conclusion, the starting principle in Member States is that investment in the next generation of telecoms infrastructures should be led by the private sector with the public sector helping to create favourable investment conditions. However, public financing of current and future mobile/wireless and fixed broadband infrastructures, as a complementary and non-overlapping complement to private investments, may be key to achieving the EU 5G connectivity objectives. It is worth underlining that, in most cases, there is no necessity, nor even relevant needs, to finance the full network but rather focus on strategic and/or re-usable/long term infrastructure elements assuring the overall “5G readiness” (in many instances mainly fibre deployment). Stronger interventions, such as for non-spots or uninterrupted coverage of highways in challenge areas, need to be clearly justified, e.g. with specific public interest objectives, and having regard to other regulatory tools to promote coverage (e.g. Article 59(3) EECC).

b) Sources of financing

The Digital Single Market Mid-Term Review took stock of EU funding and financing for broadband. The general setup of public financing for mobile connectivity in the current Multi-annual Financial Framework (MFF) is limited as there are no programmes that explicitly foresee funding mobile network rollout.

Under the current MFF, European Structural and Investment Funds (ESIF) are supporting broadband roll out with approximately EUR 6 billion of EU funding, including fixed wireless access solutions.

In addition, a budget of EUR 8.2 billion has been approved under the European Fund for Strategic Investments (EFSI) for broadband-related projects. The Connecting Europe Broadband Fund (CEBF), which was set up end of June 2018, is capitalising on a EUR 100 million CEF[56] higher risk contribution, alongside funding from EFSI, as well as national promotional banks and a private investor, and is expected to trigger additional investments in broadband deployment including in less densely populated areas amounting to about EUR 1 to 1.7 billion between 2017 and 2021. However, apart from some exceptions, the EFSI funds are under-used for mobile connectivity projects, which are

[56] Connecting Europe Facility.

usually financed in different ways. Similarly, the EUR 6 billion mobilised under the European Structural and Investment Funds (ESIF) for the period 2014-2020 remains modest compared to the size of the overall connectivity investment gap (i.e. the €155 billion shortfall identified in the Gigabit Society Communication), despite the efforts which have been deployed.

Therefore, the Commission proposal for the next MFF, in particular through the CEF, provides significant new opportunities for the funding of digital infrastructures, more adapted to the specific needs of the sector, including actions to support deployment of 5G along major transport paths.

In the meantime, national funding remains the main source of public financing to address policy objectives. During the period 2009-2017, the Commission approved state aid for broadband amounting to EUR 38 billion, including several extensive national and regional broadband schemes. The application of State Aid Rules in the broadband sector has also benefited from the introduction in 2014 of a new broadband category in the General Block Exemption Regulation (GBER). Member States have already adopted 85 broadband State aid measures benefitting from the GBER.

The Working Group also noted that the Communication "Towards a Gigabit Society" signals the intention of the Commission to take into account the foreseeable evolution of long-term demand and the strategic objectives set in this Communication when assessing the "step change" approach of the Broadband State Aid Guidelines in grey NGA areas. The Commission services have stated that they will consider favourably efficient blended financing that contributes to lower the aid intensity and to reduce risks of distorting competition, as part of its assessment of State aid interventions.

c) Categories for public financing of mobile connectivity

Supporting mobile connectivity for all citizens and businesses

As long as full broadband coverage, whether based on fixed or mobile services as understood in the context of national and EU connectivity targets, is not achieved through private undertakings, public intervention in challenge areas can be considered and be part of national broadband and 5G strategies. Wide-scale financing initiatives (e.g. schemes coordinated nationally or involving several Member States) can have the advantage of being more attractive to private operators (e.g. core/backhaul fibre operators, satellite operators, etc.), mainly due to the scale effect and more effective risk distribution. The aspect which is generally considered as the most strategic to ensure the “5G readiness” of the network infrastructure are the investments in fibre to support the roll-out of VHC networks which are needed to backhaul both fixed and mobile advanced connectivity. In this context, the effective implementation of all of the provisions of the EU Broadband Cost-Reduction Directive[57] also contribute to optimising these investments.

To anticipate the adequate public share of those investments, the Commission suggested to the Working Group that national plans should first contain an assessment of the gap of investments necessary to reach the EU connectivity objectives, based on a mapping of existing private and public infrastructures and their quality of service[58]. As outlined also in chapter 1, this should be based on standard broadband indicators[59] and a proper consultation of private actors regarding planned investments. The Working Group discussed this approach but could not be conclusive on its relevance and feasibility in the context of NBP and 5G roadmaps. Member States have already started such reflection in the context of the BEREC-RSPG report on facilitating mobile connectivity in

[57] Directive 2014/61/EU: https://ec.europa.eu/digital-single-market/en/news/directive-201461eu-european-parliament-and-council.
[58] In line with article 22 of the [Proposal for a] Directive of the European Parliament and of the Council establishing the European Electronic Communications Code].
[59] As defined in the Guide to Very High Capacity investment [To be updated by end of 2018].

"challenge areas"[60] and agreed to continue the discussion on the identification of "investment gaps" in a format to be agreed.

Assuming that investment gaps can be properly identified, possible public interventions can then be foreseen on the basis of sustainable investment models that (i) enhance competition as well as affordability and provides access to open, quality and future proof infrastructure and services; (ii) adjust the form(s) of financial assistance to the market failure(s) identified; and (iii) allow for the complementary use of different forms of financing from EU, national or regional sources.

This is a complex financial domain. Therefore, Member States may consider providing specific technical assistance to third parties, including for example through the Broadband Competence Offices[61], to reinforce the capacity of local stakeholders and advise project promoters.

In general, cases that can be considered from a public intervention's perspective include, but are not limited to:

i. Areas that are not commercially viable for mobile rollout and with no connectivity at all (neither fixed not mobile) where public funding could be justified in most cases.
ii. Areas that are not commercially viable for fully-fledged 5G mobile rollout, but where at least an NGA infrastructure exists. In this case, public funding for 5G mobile networks might be justified. However, competition considerations could prevent public intervention, or subject it to conditions if the fibre rollout to the base stations could is also to be used to provide NGA services in the same area (thereby risking overbuilding private infrastructure previously deployed).
iii. Areas that are commercially viable: public intervention would not be justified for larger-scale deployment in the absence of market failure.

Recent public initiatives, mainly focussing on covering "non-spots" (areas not covered by mobile voice/SMS services), have been initiated in order to complete territorial mobile coverage (e.g. UK, Germany). It is also seriously considered by other Member States (e.g. the Netherlands). Several Member States have expressed the view that imposing these types of obligations through an award (like in the UK and Germany) is a best practice since it creates a mechanism that efficiently prices the cost of such an obligation through a competitive process, therefore providing greater benefits for consumers.

A recent example of the use of specific coverage obligations in auctions is the auction of the 800 MHz band in Germany, where licenses foresaw that the deployment in densely populated areas had been conditioned to the commitment to deploy LTE in rural areas, and again at the occasion of the auction of the 700 MHz band, where conditions where included to ensure coverage of transport routes and other areas.

Other Member States put directly emphasis on extending the coverage of fibre, assuming that the quality of mobile coverage will benefit from the increased density of fibre deployment. In Spain for example, the former funding program PEBA-NGA has been upgraded with a new draft plan to meet the ambitious objective of bringing 300 Mbps broadband connectivity to the main population centres and 95% of each province population. It is called the "300x100" plan and is endowed with a total budget of EUR 525 million for the period 2018-2021.

In Portugal, all mobile operators have the legal obligation to cover, by a given date, a specific set of parishes defined in the 2012 auction process. Such coverage obligations have to be met with the use of frequencies in the 800 MHz and 900 MHz bands. Each operator must communicate the

[60] https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/7574-berec-and-rspg-joint-report-on-facilitating-mobile-connectivity-in-challange-areas
[61] https://ec.europa.eu/digital-single-market/en/broadband-competence-offices

performance delivered. Additionally, further obligations were specified in the context of the renewal of the frequencies 1920-1980 MHz / 2110-2170 MHz in 2015/2016, where a defined set of parishes representing 75% of the population, must be provided with a mobile broadband service that allows data transmission speed of 30 Mbit/s (maximum download speed).

Some Member States have made, or are envisaging to make, use of indirect measures. For example, French Government, Arcep (NRA) and mobile operators reached an agreement that aims to ensure the availability of high standard mobile coverage for every person in France. The French Government has made achieving regional development targets a priority in the terms and conditions attached to the 900, 1800 and 2100 MHz band frequency licenses that are set to expire between 2021 and 2024, and for which Arcep will be conducting a reassignment procedure in 2018. As new licences for this spectrum are not set to come into force until 2021 to 2024, mobile operators have made commitments for the interim period to be added in 2018 to the terms of their existing licenses, in order to significantly improve the user experience of mobile coverage in every part of the country.

Other Member States are considering direct public interventions to support mobile connectivity. For example, the UK government is planning to commission the building of over 250 base stations as part of its new Emergency Service Network (ESN) Extended Area Service[62]. In addition, the UK Ofcom has suggested that operators acquiring some of the new licences as part of the award for 700 MHz should be required to offer extended geographic coverage[63], including through taking account of publicly procured infrastructure such as the ESN Extended Area Service sites, which would be available at a much lower cost.

Large-scale public financial support initiatives are also gaining momentum in other parts of the world. For example, in the US, the FCC Mobility Fund (Phase II) auction will provide up to USD 4.5 billion to mobile operators that are building out 4G LTE networks to underserved rural markets. Network operators that will receive the support from this auction will have to build out 4G LTE mobile service that will deliver at least 10 Mbps to customers in markets that lack access to unsubsidised 4G LTE.

An alternative approach that is also worth considering is the potential of network sharing to render private investments more viable in some less attractive areas. The preliminary BEREC draft report on network sharing adopted in June 2018[64] is a first step in the collaboration between Member States to identify best practices on mobile infrastructure sharing arrangements. It should facilitate the enhancement of mobile connectivity, in particular with regards to the rollout of 5G networks, whilst protecting and promoting competition.

In general, it is considered as a good practice for Member States to encourage synergies between the use of broadband funding programmes (e.g. national funding and ESIF) in order to maximise effectiveness. Such synergies could be further developed as part of national broadband and 5G strategies.

Supporting 5G connectivity along major transport routes

The recent Commission proposal for the future Connecting Europe Facility (CEF) programme includes important support to the funding of "5G corridors" for Connected and Automated Driving, as part of the indicative budget of €3 billion for telecommunications infrastructure for the period 2021-2026, possibly in combination with ESIF funds in specific areas. This will be a major discussion topic with Member States for the establishment of the next MFF in the area of connectivity. According to the Commission's internal calculations, up to 25% of the future 5G infrastructure along transport paths

[62] https://www.gov.uk/government/publications/the-emergency-services-mobile-communications-programme
[63] Namely, 92 percent in England and Northern Ireland while raising their levels to 83 percent and 76 percent in Wales and Scotland respectively.
[64] https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/8164-berec-report-on-infrastructure-sharing

may not be economically viable without public support. This is a much higher public funding need for mobile infrastructure than historic trends. Therefore, public support regarding these new deployment requirements to meet the need of vertical industries should be considered as an integral part of national 5G strategies.

Supporting the use of 5G for Fixed Wireless Access (5G FWA)

Fixed Wireless Access (FWA) solutions are already capable of contributing to the achievement of the 2020 connectivity targets. Several Member States have already developed guidance and methodologies to assess the level of connectivity provided by wireless technologies, notably LTE, and their eligibility for public funding. However, as discussed earlier in this report, the lack of a common methodology across the EU is a major obstacle, including when it comes to State Aid assessment.

Public support to FWA solutions is in line with the State Aid Broadband Guidelines that recognise the possibility under certain conditions to support with State Aid the roll out of an NGA network in an area where one or more basic broadband networks are already available and the possibility that the last mile of such subsidized Next Generation Access Network relies on wireless technologies[65] as part of an advanced fixed wireless network[66].

As indicated above, 5G technology is expected to improve significantly the contribution of Fixed Wireless Access solutions to broadband access in both urban and rural areas, and help to reach the 2025 connectivity objective of 100 Mbps (upgradable) for all households. Within this context, the deployment of 5G FWA could also be supported in areas where they would bring a step change in comparison to existing broadband networks.

As compared to 4G (LTE), where spectrum bands used for fixed and mobile services are segmented, the 5G ecosystem could provide an integrated solution for mobile and fixed access, creating significant economies of scale. The availability of cost-effective 5G FWA solutions could improve the economics of extending broadband access and reduce the required investments. Some vendors claim that 5G FWA solutions may be 30% to 60% cheaper than deploying fibre to the home (FTTH) in some circumstances. Therefore, several Member States have expressed interest in seeing 5G FWA being considered by operators to accelerate the pace towards their national broadband objectives, whether in rural areas or even in grey zones or for specific purposes (e.g. vertical industry applications). France has been an early pioneer of such FWA solutions and has just decided to allow the so-called “Wimax” licensees in 3.5 GHz to deploy fixed LTE services in selected challenge areas until 2026, awaiting suitable 5G solutions.

In the case of 5G, an advantage is that the extension of fixed broadband access may also give rise to an extension of mobile coverage by re-using and thus sharing the costs of the same backhauling facilities. While this is a positive potential development, several Member States have reported that it is important to monitor competition effects resulting from publicly-supported FWA deployment, even in cases of market failures, due to the above-mentioned possibility of parallel use by operators of the established base station infrastructure for additional commercial mobile services.

Supporting 5G innovation, pilot projects and trials, and 5G capacity building

This category of public financing needs is already largely fulfilled through the existing national and EU funding mechanisms for Research & Innovation. In particular, there are close to EUR 200 million of

[65] See Footnote 71.

[66] Since the wireless medium is ‘shared’ (the speed per user depends on the number of connected users in the area covered) and is inherently subject to fluctuating environmental conditions, in order to provide reliably the minimum download speeds per subscriber that can be expected of an NGA, next generation fixed wireless networks may need to be deployed to a certain degree of density and/or with advanced configurations, such as directed or multiple antennas. Next generation wireless access based on tailored mobile broadband technology must also ensure the required quality of service level to users at a fixed location while serving any other nomadic subscribers in the area of interest.

EU funding earmarked for that purpose for the period 2018-2020 under the 5G-PPP framework of Horizon 2020. However, Member States are encouraged to integrate an explicit element in their national 5G deployment strategy to ensure coherence of national implementations.

Overview of typical public financing options (including EU sources)

Public Policy Objective	**Type of investment**	**5G Infrastructure investment priorities**	**Related Gigabit Society goals**[67]
Mobile connectivity for all citizens, wherever they live, work, gather or travel	Private investment in commercially viable areas. Possible public intervention in commercially non-viable areas subject to non-existing NGA infrastructure in certain areas	Dense cellular with fibre connection (5G or 4G upgradable to 5G), Satellite in very remote areas	Extended 100 Mbps upgradable to Gigabit target
Uninterrupted 5G coverage of all major transport routes (roads/ railways)	Private investment in commercially viable areas, Public intervention in commercially non-viable areas	Fibre to Roadside/Rail infrastructure, dense 5G cells	5G transport target
5G Innovation and 5G Capacity building New infrastructure and services, verticals	Private investment in commercially viable areas, Supported by R&I grants, Supported by deployment grants or financial instruments	5G overlay (Fibre, SDN/industrial platforms/hubs)	5G urban target Extended 100 Mbps upgradable to Gigabit target, e.g. connecting SMEs Gigabit target, connecting all socio-economic drivers, e.g. business parks
Ensure high-speed broadband coverage to all households (5G contribution)	Private investment in commercially viable areas, Public intervention in commercially non-viable areas	5G FWA (with fibre backhaul), Satcom (both as alternative to FTTH)	100 Mbps for all upgradable to Gigabit target

[67] 5G target 2025 (urban and transport), household coverage 100 Mb/s 2025 with wider ambition for mobile

5) Facilitating 5G Innovation and new Use Cases

a) Introduction

National 5G roadmaps can be instrumental to provide a critical "push" for the development of innovative use cases for 5G, taking into account the EU strategy that promotes 5G deployment in support of the creation of innovative ecosystems for vertical industries beyond the mere leveraging of 5G enhanced broadband functionalities. These extended use cases are expected to require the introduction of a multiplicity of new access and core network technologies in relation to 5G whose functional and business properties still require significant validation, involving notably vertical industry users.

In addition, establishing common approaches towards innovative pan-European 5G use cases (e.g. in the context of Connected Cars) and sharing of national experiences is of high relevance to facilitate a coordinated introduction of 5G in Europe, taking into account the multiplicity of stakeholders.

A prominent example is Italy's simultaneous launch of a large number of 5G trial projects addressing around 150 different "use cases", or business applications[68]. It should be noted that all those public and private trials conducted in Italy, while politically supported by the state, are entirely financed by the private operators.

In Spain, the 5G national broadband plan includes specific calls for projects to deploy pilot 5G infrastructures. Such projects will allow the validation of the new 5G network capabilities, as well as the development of applications and sectorial use cases: agriculture, tourism, connected vehicle, etc.

As part of its nationally coordinated programme of 5G testbed facilities and application trials, the UK Government has allocated GBP 200 million (EUR 225 million) so far, including funding for a large scale 5G test network created by the University of Bristol, King's College London and the 5G Innovation Centre at the University of Surrey. A 5G testbed and trial funding competition for innovative radio technologies, and many more planned trial and testbed activities for the period 2018-2021.

In France, the national 5G strategy plan aims to support the development of new use cases in priority sectors (industry, health, agriculture), and pays special attention to the emergence of industrial pilots. In order to encourage the creation of consortiums for the implementation of pilot projects, the French government will rely on the Industry National Council[69]. Moreover, the government and the national regulatory authority will co-host meetings involving actors of specific value chains in priority sectors in order to facilitate the emergence of collaborative projects. The national regulatory authority (Arcep) opened in January 2018 a "5G pilot"[70] window for all the players along the 5G value chain, in order to allow them exploring new use cases, deepen understanding of systems for cohabitation between players, and test out business models. Arcep wants to give to the entire 5G value chain the ability to tackle the issues surrounding these future networks under real world conditions, beyond simply obtaining a technical validation of network equipment. Operators, as well as future professional users of the band, often referred to as "verticals", should be able to work together on these pilots. Arcep's "5G pilot" window is open to any player interested in 5G and wanting to perform their first rollouts. To do so, Arcep can issue temporary frequency authorisations to develop 5G pilots, notably in the 3.6 GHz and 26 GHz bands.

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[68] http://www.sviluppoeconomico.gov.it/index.php/it/213-normativa/notifiche-e-avvisi/2036226-5g-avviso-pubblico-per-progetti-sperimentali

[69] Conseil national de l'industrie (CNI)

[70] https://www.arcep.fr/index.php?id=8571&no_cache=1&no_cache=1&tx_gsactualite_pi1%5Buid%5D=2119&tx_gsactualite_pi1%5BbackID%5D=26&cHash=b9046864c82ce08ebebc240f271ef97f&L=1

b) Flagship case of Cross-border corridors for Connected and Automated Mobility

As underlined earlier, Connected and Automated Mobility is probably the most strategic of the new vertical use cases where 5G technology is expected to be a catalyst for innovation and major factor of transformation. Therefore, the Working Group agreed that it deserves particular attention when developing 5G strategies. Indeed, 5G test corridors cannot be established without the essential cooperation of Member States as public authority, ranging from the availability of appropriate portions of highways for testing, adaptation of road signage, establishment of special road and communication infrastructure, availability of test licenses, or authorisations, for both operations and spectrum use, cooperation from local authorities and police forces, etc.

c) Relevant measures for general consideration

The following categories of measures have been recognised to contribute to facilitating 5G innovation objectives and should be considered when developing national 5G roadmaps:

- Making adequate experimental licenses/authorisations available, including temporary rights to use spectrum, allowing research and experiments. Promoting the establishment of national 5G testbeds and innovation platforms.
- Supporting European 5G Flagship innovative use cases, such as through the provision of cross border 5G corridors to facilitate real environment testing of CAM (see above) or through the testing of PPDR 5G solutions.
- Provide support to standard setting activities, when relevant, with a view to contribute to the common EU-level priorities.
- Taking advantage of the EURO Championship of football in 2020 as a major showcase opportunity to promote key 5G use case (the event will be hosted by 13 European cities).
- Monitor trials and pilot projects with vertical industries to identify possible issues related to sectorial regulatory regimes that may constitute barriers for the take-up of new solutions. As an example, a cross-government “barrier busting" task force has been established in the UK.
- Sharing best practices with other Member States.
- Promoting relationships between the telecommunications sectors and vertical industries[71].

The European 5G Observatory will also provide, as part of its platform, regular information on trials and pilot projects taking place in Member States.

d) Importance of innovative approaches towards 5G security

Security for 5G is currently an important research topic and the importance of ensuring that 5G networks will be safe and secure is rightfully addressed in several Member States’ plans and documents. However, the Working Group has not identified at this stage any major actions that would be specifically related to 5G network security in national initiatives. It is noted however that the UK Government has announced a GBP 10 million (EUR 11.3 million) funding to create facilities where the security of 5G networks can be tested and proven, working with its National Cyber Security Centre.

[71] For example, Germany has set up a "5G Dialog Forum" in September 2016 to support exchanges between stakeholders and to act as a "door opener" for companies to participate actively in the development of 5G-based applications in collaborative projects.

In most cases, references to a security strategy are part of a wider initiative regarding cybersecurity or linked to horizontal privacy and confidentiality aspects. Therefore, it is suggested to further explore the Member States' intentions concerning this topic and identify specific issues for discussion if needed. Any proposed way forward should address specifically the challenge of network deployment and be of a strategic nature to justify an additional fully-fledged item in national 5G roadmaps.

In the meantime, the Commission proposed that the Security Working Group of the 5G Public Private Partnership be requested to inform the Member States and the Commission of any 5G specific issues that could require action at EU level, as well as to collect information on state-of-the-art experience on 5G security developments.

e) Suggestions going forward

As a result of the above review of best practices by the Working Group, it is suggested that:

- National 5G roadmaps seek to include a clear focus on innovation and on experimental/trial/pilot actions whose results may be shared and made available to the wider European community of stakeholders, notably through the European 5G Observatory (while respecting commercially confidential information of private operators).
- Follow-up workshops be organised to share the return of experience of Member States on innovative take up approaches for 5G as well as to take stock on possible sectoral regulatory barriers to 5G which could have an impact at EU level.
- The Commission services continue to support the work of the relevant Working Group of the 5G PPP (the Working Group on 5G security) and entrust this Working Group with the task of collecting and sharing information state-of-the-art experience on 5G security developments, in liaison with ENISA and national cyber security authorities as appropriate.

6) Public use cases enabled by 5G (focus on public safety services)

a) Potential of public uses case as "lead service" for 5G

The possible use of 5G technology to fulfil specific communication needs of public sector verticals for advanced broadband services opens many opportunities for Europe leadership in 5G innovation as well as for the delivery of better public services at a lower cost.

However, such approach also implies complex technical, legal, organisational, economic and political issues. Before drawing any conclusions, these aspects need to be thoroughly studied and analysed, with the involvement of the national operators of mission critical infrastructure and of all other relevant stakeholders.

This is especially important because the potential use of 5G commercial infrastructure for Public Protection & Disaster Recovery (PPDR), or Emergency Service Networks (ESNs), would require departing from the currently widespread practice of setting-up separate dedicated infrastructures for mission critical public applications. Until such time as 5G/4G public networks have proven to be truly capable of delivering mission-critical services, either on their own or by a combination of public and proprietary infrastructures, resistance to change should be anticipated on the part of public authorities, who do not want to put PPDR users at risk. Therefore, any cooperative initiative to seize the 5G opportunities, whether at EU level or between a group of interested Member States, should be supported by appropriate impact assessment, taking into account of various situations existing in Member States. The possible implementation scenarios, including the transition phase, should be carefully evaluated so that the new way of providing radio communications services does not put a risk the ability of PPDR services to carry out their important missions. In addition, the benefits of using 5G technology must be clear and convincing.

b) Outcome from the exchange of best practices in the Working Group

The Working Group conducted the exchange of best practices and views both in a dedicated sub-group (work stream 3) as well as in the context of a special workshop with the participation of key PPDR vendors and interested public users (Workshop on 5G and PPDR services held on 11 April 2018)[72].

The key challenges identified, and main conclusions drawn, in the context of this activity are highlighted below:

- The PPDR sector should "streamline" their requirements by identifying clearly its core common needs, and present them in a more structured way, as a community, to the key technology suppliers. This can be facilitated by organising groups of users to ensure a high degree of collaboration with equipment vendors and commercial mobile operators.
- While most economies of scale will result from the use of mainstream cellular technologies and harmonised spectrum compatible and/or shared with standard commercial spectrum bands, the achievement of a critical volume for end user PPDR terminals is still required to ensure the availability of economically-sustainable chipsets for PPDR-enhanced communications (estimated in the order of magnitude of 1 million units, out of the current total of 5 to 10 million PPDR terminals in Europe).
- There is consequently a potential "chicken-and-egg" situation with regard to the achievement of a critical mass of PPDR-complaint devices: the lack of economies of scale delaying the take-up of 5G PPDR solutions. Vendors are of the opinion that only an

[72] The report of the dedicated workshop on 5G and PPDR services is available on the space reserved for the COCOM WG 5G on the circa web site.

evolutionary approach can address this issue, whereby specific subsets of PPDR services could first migrate and experiment new 5G functionalities before seeking for larger procurement commitments from the user community.

- There is a need to reinforce the technical PPDR expertise available in Standard Development Organisations (SDOs), in particular 3GPP and ETSI), to accelerate the pace of standardisation work.
- Some type of public co-financing of additional infrastructure may be necessary to ensure the desired extensive geographical network coverage of key specialised PPDR services. This would also create a more sustainable business model to attract commercial mobile operators.

In addition, the Working Group acknowledges the significant work that has already been done, e.g. in the BroadMap project[73] which concluded that public safety communication capability will likely be shared with commercial carriers in most cases in the future[74], and the work achieved within the Public Safety Communications Europe Forum[75].

c) Possible way forward

The Working Group first notes that a comprehensive multi-stakeholder dialogue is needed to gather better insights into the current state, and likely evolution, of this critical domain and to capture the needs and concerns of security actors and other stakeholders. In parallel, there is also a need to foster a wider consensus across Member States on what could be the relevant role and scope of 5G to provide advanced PPDR broadband functionalities for safety services, including those considered mission-critical, and to address the issue of economies of scale and cost reduction.

The Working Group also acknowledges that plans by Member States to seize 5G opportunities for broadband PPDR evolutions should address the technology development side (supply side), including actions to support RDI projects where appropriate[76], to address business prospects of commercial mobile operators, as well as the demand side including the evaluation and preparation of **deployment scenarios** of the planned 5G technology and all relevant transition aspects.

In practical terms, the Working Group suggests that interested countries consider the following common elements as a basis for the next steps in their 5G PPDR cooperation strategy:

- Build confidence on the user side by gathering facts from the existing pioneer commercial implementations, namely in the UK (Emergency Services Mobile Communication Programme) and in the US (FirstNet), by providing government support to trials and innovative procurement initiatives, by migrating targeted public users to acquire know-how, etc.
- Involve network operators in the discussion of financing models (e.g. sharing capacity[77], subsidising coverage extension possibly by tailoring spectrum license conditions).
- Address adoption of/transition to PPDR broadband solutions as part of 5G national roadmap

[73] http://www.broadmap.eu/

[74] Please refer to the final deliverables for additional information at http://www.broadmap.eu/download-final-deliverable . BroadMap also helped defining a pre-commercial procurement project 'BroadWay', which involves public sector buyers in 11 Members States, leading to a TRL8 pilot in 2021, to be validated by almost 50 first responder practitioners representing 23 countries.

[75] http://www.psc-europe.eu/ . In particular in the policy paper titled "Mission Critical Policy Gap": https://www.psc-europe.eu/library/psce-policy-papers/mission-critical-policy-gap/download.html

[76] e.g. some emergency services relying on PSTN/ISDN have to find a new mode of reliable communication soon, as this will be turned off.

[77] E.g. by using License Shared Authorisation arrangements.

reflection (EC could support with study and identification of common elements, paving the way for interoperability across borders).

- Consider framing the transition to the new infrastructure by aiming at a voluntary and/or indicative target sunset time frame in Europe for older generations of PMR systems used for public safety services (TETRA and assimilated). This should be subject to proper impact assessment and provided that maintenance of legacy can be guaranteed for these systems until a set switch-off date. It should also be linked to the assurance that alternative (4G/5G) solutions will be commercially available and offer sufficient territorial coverage.

Already adopted national 5G strategies

Austria: https://www.bmvit.gv.at/5g

Belgium: https://www.bipt.be/nl/operatoren/radio/gebruiksrechten/lopende-toekomstige-toewijzingsprocedures/mededeling-van-de-raad-van-het-bipt-van-10-september-2018-met-betrekking-tot-de-introductie-van-5g-in-belgie

France: https://www.arcep.fr/fileadmin/reprise/dossiers/programme-5G/Feuille_de_route_5G-DEF.pdf (only French version available on 16/07/2018))

Germany: https://www.bmvi.de/SharedDocs/EN/publications/5g-strategy-for-germany.pdf?__blob=publicationFile

Italy:
http://www.sviluppoeconomico.gov.it/index.php/it/component/content/article?id=2019963

http://www.sviluppoeconomico.gov.it/index.php/it/213-normativa/notifiche-e-avvisi/2036226-5g-avviso-pubblico-per-progetti-sperimentali

http://www.sviluppoeconomico.gov.it/index.php/it/comunicazioni/servizi-alle-imprese/tecnologia-5g/bando-5g

Luxembourg: https://digital-luxembourg.public.lu/sites/default/files/2018-09/Luxembourg_5G_strategie.pdf

Spain:
http://www.minetad.gob.es/telecomunicaciones/5G/Documents/plan_nacional_5G_en.pdf

The Netherlands:
https://www.government.nl/documents/reports/2018/07/13/connectivity-action-plan

UK: https://www.gov.uk/government/publications/next-generation-mobile-technologies-a-5g-strategy-for-the-uk ; https://www.gov.uk/government/publications/next-generation-mobile-technologies-an-update-to-the-5g-strategy-for-the-uk ; and the recent “Review for the Future Telecoms Infrastructure” is also relevant: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727889/Future_Telecoms_Infrastructure_Review.pdf

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ICNIRP
INTERNATIONAL COMMISSION ON
NON-IONIZING RADIATION PROTECTION

ICNIRP GUIDELINES

FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 kHz TO 300 GHz)

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GUIDELINES FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 kHz to 300 GHz)

International Commission on Non-Ionizing Radiation Protection (ICNIRP)[1]

Abstract—**Radiofrequency electromagnetic fields (EMFs) are used to enable a number of modern devices, including mobile telecommunications infrastructure and phones, Wi-Fi, and Bluetooth. As radiofrequency EMFs at sufficiently high power levels can adversely affect health, ICNIRP published Guidelines in 1998 for human exposure to time-varying EMFs up to 300 GHz, which included the radiofrequency EMF spectrum. Since that time, there has been a considerable body of science further addressing the relation between radiofrequency EMFs and adverse health outcomes, as well as significant developments in the technologies that use radiofrequency EMFs. Accordingly, ICNIRP has updated the radiofrequency EMF part of the 1998 Guidelines. This document presents these revised Guidelines, which provide protection for humans from exposure to EMFs from 100 kHz to 300 GHz.**
Health Phys. 118(5):483–524; 2020

INTRODUCTION

THE GUIDELINES described here are for the protection of humans exposed to radiofrequency electromagnetic fields (EMFs) in the range 100 kHz to 300 GHz (hereafter "radiofrequency"). This publication replaces the 100 kHz to 300 GHz part of the ICNIRP (1998) radiofrequency guidelines, as well as the 100 kHz to 10 MHz part of the ICNIRP (2010) low-frequency guidelines. Although these guidelines are based on the best science currently available, it is recognized that there may be limitations to this knowledge that could have implications for the exposure restrictions. Accordingly, the guidelines will be periodically revised and updated as advances are made in the relevant scientific knowledge. The present document describes the guidelines and their rationale, with Appendix A providing further detail concerning the relevant dosimetry and Appendix B providing further detail regarding the biological and health effects reported in the literature.

PURPOSE AND SCOPE

The main objective of this publication is to establish guidelines for limiting exposure to EMFs that will provide a high level of protection for all people against substantiated adverse health effects from exposures to both short- and long-term, continuous and discontinuous radiofrequency EMFs. However, some exposure scenarios are defined as outside the scope of these guidelines. Medical procedures may utilize EMFs, and metallic implants may alter or perturb EMFs in the body, which in turn can affect the body both directly (via direct interaction between field and tissue) and indirectly (via an intermediate conducting object). For example, radiofrequency ablation and hyperthermia are both used as medical treatments, and radiofrequency EMFs can indirectly cause harm by unintentionally interfering with active implantable medical devices (see ISO 2012) or altering EMFs due to the presence of conductive implants. As medical procedures rely on medical expertise to weigh potential harm against intended benefits, ICNIRP considers such exposure managed by qualified medical practitioners (i.e., to patients, carers and comforters, including, where relevant, fetuses), as well as the utilization of conducting materials for medical procedures, as beyond the scope of these guidelines (for further information, see UNEP/WHO/IRPA 1993). Similarly, volunteer research participants are deemed to be outside the scope of these guidelines, providing that an institutional ethics committee approves such participation following consideration of potential harms and benefits. However,

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ICNIRP declares no conflict of interest.

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occupationally exposed individuals in both the clinical and research scenarios are defined as within the scope of these guidelines. Cosmetic procedures may also utilize radiofrequency EMFs. ICNIRP considers people exposed to radiofrequency EMFs as a result of cosmetic treatments without control by a qualified medical practitioner to be subject to these guidelines; any decisions concerning potential exemptions are the role of national regulatory bodies. Radiofrequency EMFs may also interfere with electrical equipment more generally (i.e., not only implantable medical equipment), which can affect health indirectly by causing equipment to malfunction. This is referred to as electromagnetic compatibility, and is outside the scope of these guidelines (for further information, see IEC 2014).

PRINCIPLES FOR LIMITING RADIOFREQUENCY EXPOSURE

These guidelines specify quantitative EMF levels for personal exposure. Adherence to these levels is intended to protect people from all substantiated harmful effects of radiofrequency EMF exposure. To determine these levels, ICNIRP first identified published scientific literature concerning effects of radiofrequency EMF exposure on biological systems, and established which of these were both harmful to human health[3] and scientifically substantiated. This latter point is important because ICNIRP considers that, in general, reported adverse effects of radiofrequency EMFs on health need to be independently verified, be of sufficient scientific quality and consistent with current scientific understanding, in order to be taken as "evidence" and used for setting exposure restrictions. Within the guidelines, "evidence" will be used within this context, and "substantiated effect" used to describe reported effects that satisfy this definition of evidence. The reliance on such evidence in determining adverse health effects is to ensure that the exposure restrictions are based on genuine effects, rather than unsupported claims. However, these requirements may be relaxed if there is sufficient additional knowledge (such as understanding of the relevant biological interaction mechanism) to confirm that adverse health effects are reasonably expected to occur.

For each substantiated effect, ICNIRP then identified the "adverse health effect threshold;" the lowest exposure level known to cause the health effect. These thresholds were derived to be strongly conservative for typical exposure situations and populations. Where no such threshold could be explicitly obtained from the radiofrequency health literature, or where evidence that is independent from the radiofrequency health literature has (indirectly) shown that harm could occur at levels lower than the "EMF-derived threshold," ICNIRP set an "operational threshold." These are based on additional knowledge of the relation between the primary effect of exposure (e.g., heating) and health effect (e.g., pain), to provide an operational level with which to derive restriction values in order to attain an appropriate level of protection. Consistent with previous guidelines from ICNIRP, reduction factors were then applied to the resultant thresholds (or operational thresholds) to provide exposure restriction values. Reduction factors account for biological variability in the population (e.g., age, sex), variation in baseline conditions (e.g., tissue temperature), variation in environmental factors (e.g., air temperature, humidity, clothing), dosimetric uncertainty associated with deriving exposure values, uncertainty associated with the health science, and as a conservative measure more generally.

These exposure restriction values are referred to as "basic restrictions." They relate to physical quantities that are closely related to radiofrequency-induced adverse health effects. Some of these are physical quantities inside an exposed body, which cannot be easily measured, so quantities that are more easily evaluated, termed "reference levels," have been derived from the basic restrictions to provide a more-practical means of demonstrating compliance with the guidelines. Reference levels have been derived to provide an equivalent degree of protection to the basic restrictions, and thus an exposure is taken to be compliant with the guidelines if it is shown to be below either the relevant basic restrictions or relevant reference levels. Note that the relative concordance between exposures resulting from basic restrictions and reference levels may vary depending on a range of factors. As a conservative step, reference levels have been derived such that under worst-case exposure conditions (which are highly unlikely to occur in practice) they will result in similar exposures to those specified by the basic restrictions. It follows that in the vast majority of cases, observing the reference levels will result in substantially lower exposures than the corresponding basic restrictions allow. See "Reference Levels" section for further details.

The guidelines differentiate between occupationally-exposed individuals and members of the general public. Occupationally-exposed individuals are defined as adults who are exposed under controlled conditions associated with their occupational duties, trained to be aware of potential radiofrequency EMF risks and to employ appropriate harm-mitigation measures, and who have the sensory

[3]Note that the World Health Organization (1948) definition of "health" is used here. Specifically, "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

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and behavioral capacity for such awareness and harm-mitigation response. An occupationally-exposed worker must also be subject to an appropriate health and safety program that provides the above information and protection. The general public is defined as individuals of all ages and of differing health statuses, which includes more vulnerable groups or individuals, and who may have no knowledge of or control over their exposure to EMFs. These differences suggest the need to include more stringent restrictions for the general public, as members of the general public would not be suitably trained to mitigate harm, or may not have the capacity to do so. Occupationally-exposed individuals are not deemed to be at greater risk than the general public, providing that appropriate screening and training is provided to account for all known risks. Note that a fetus is here defined as a member of the general public, regardless of exposure scenario, and is subject to the general public restrictions.

As can be seen above, there are a number of steps involved in deriving ICNIRP's guidelines. ICNIRP adopts a conservative approach to each of these steps in order to ensure that its limits would remain protective even if exceeded by a substantial margin. For example, the choice of adverse health effects, presumed exposure scenarios, application of reduction factors and derivation of reference levels are all conducted conservatively. The degree of protection in the exposure levels is thus greater than may be suggested by considering only the reduction factors, which represent only one conservative element of the guidelines. There is no evidence that additional precautionary measures will result in a benefit to the health of the population.

SCIENTIFIC BASIS FOR LIMITING RADIOFREQUENCY EXPOSURE

100 kHz to 10 MHz EMF Frequency Range: Relation Between the Present and Other ICNIRP Guidelines

Although the present guidelines replace the 100 kHz to 10 MHz EMF frequency range of the ICNIRP (2010) guidelines, the science pertaining to direct radiofrequency EMF effects on nerve stimulation and associated restrictions within the ICNIRP (2010) guidelines has not been reconsidered here. Instead, the present process evaluated and set restrictions for adverse health effects *other than* direct effects on nerve stimulation from 100 kHz to 10 MHz, and for all adverse health effects from 10 MHz to 300 GHz. The restrictions relating to direct effects of nerve stimulation from the 2010 guidelines were then added to those derived in the present guidelines to form the final set of restrictions. Health and dosimetry considerations related to direct effects on nerve stimulation are therefore not provided here [see ICNIRP (2010) for further information].

Quantities, Units and Interaction Mechanisms

A brief overview of the electromagnetic quantities and units employed in this document, as well as the mechanisms of interaction of these with the body, is provided here. A more detailed description of the dosimetry relevant to the guidelines is provided in Appendix A, "Quantities and Units" section.

Radiofrequency EMFs consist of oscillating electric and magnetic fields; the number of oscillations per second is referred to as "frequency," and is described in units of hertz (Hz). As the field propagates away from a source, it transfers power from its source, described in units of watt (W), which is equivalent to joule (J, a measure of energy) per unit of time (t). When the field impacts upon material, it interacts with the atoms and molecules in that material. When a biological body is exposed to radiofrequency EMFs, some of the power is reflected away from the body, and some is absorbed by it. This results in complex patterns of electromagnetic fields inside the body that are heavily dependent on the EMF characteristics as well as the physical properties and dimensions of the body. The main component of the radiofrequency EMF that affects the body is the electric field. Electric fields inside the body are referred to as induced electric fields (E_{ind}, measured in volt per meter; V m^{-1}), and they can affect the body in different ways that are potentially relevant to health.

Firstly, the induced electric field in the body exerts a force on both polar molecules (mainly water molecules) and free moving charged particles such as electrons and ions. In both cases a portion of the EMF energy is converted to kinetic energy, forcing the polar molecules to rotate and charged particles to move as a current. As the polar molecules rotate and charged particles move, they typically interact with other polar molecules and charged particles, causing the kinetic energy to be converted to heat. This heat can adversely affect health in a range of ways. Secondly, if the induced electric field is below about 10 MHz and strong enough, it can exert electrical forces that are sufficient to stimulate nerves, and if the induced electric field is strong and brief enough (as can be the case for pulsed low frequency EMFs), it can exert electrical forces that are sufficient to cause dielectric breakdown of biological membranes, as occurs during direct current (DC) electroporation (Mir 2008).

From a health risk perspective, we are generally interested in how much EMF power is absorbed by biological tissues, as this is largely responsible for the heating effects described above. This is typically described as a function of a relevant dosimetric quantity. For example, below about 6 GHz, where EMFs penetrate deep into tissue (and thus require depth to be considered), it is useful to describe this in terms of "specific energy absorption rate" (SAR), which is the power absorbed per unit mass (W kg^{-1}). Conversely, above 6 GHz, where EMFs are absorbed more superficially (making depth less relevant), it is useful to describe exposure in terms of the density of absorbed power over area (W m^{-2}), which we refer to as "absorbed power density" (S_{ab}). In these guidelines, SAR is specified over different masses to better match particular adverse health effects; SAR_{10g} represents the power absorbed (per kg) over a 10-g cubical mass, and whole-body average SAR represents power absorbed (per kg) over the entire body. Similarly, absorbed power density is specified over different areas as a function of EMF frequency. In some situations, the rate of energy deposition (power) is less relevant than the total energy deposition. This may be the case for brief exposures where there is not sufficient time for heat diffusion to occur. In such situations, specific energy absorption (SA, in J kg^{-1}) and absorbed energy density (U_{ab}, in J m^{-2}) are used, for EMFs below and above 6 GHz, respectively. SAR, S_{ab}, SA, U_{ab}, and E_{ind} are the quantities used in these guidelines to specify the basic restrictions.

As the quantities used to specify basic restrictions can be difficult to measure, quantities that are more easily evaluated are also specified, as reference levels. The reference level quantities relevant to these guidelines are incident electric field strength (E_{inc}) and incident magnetic field strength (H_{inc}), incident power density (S_{inc}), plane-wave equivalent incident power density (S_{eq}), incident energy density (U_{inc}), and plane-wave equivalent incident energy density (U_{eq}), all measured outside the body, and electric current inside the body, I, described in units of ampere (A). Basic restriction and reference level units are shown in Table 1, and definitions of all relevant terms provided in Appendix A, in the "Quantities and Units" section.

Radiofrequency EMF Health Research

In order to set safe exposure levels, ICNIRP first decided whether there was evidence that radiofrequency EMFs impair health, and for each adverse effect that was substantiated, both the mechanism of interaction and the minimum exposure required to cause harm were determined (where available). This information was obtained primarily from major international reviews of the literature on radiofrequency EMFs and health. This included an in-depth review from the World Health Organization on radiofrequency EMF exposure and health that was released as a draft Technical Document (WHO 2014), and reports by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR 2015) and the Swedish Radiation Safety Authority (SSM 2015, 2016, 2018). These reports have reviewed an extensive body of literature, ranging from experimental research to epidemiology, and include consideration of health in children and those individuals thought to be sensitive to radiofrequency EMFs. To complement those reports, ICNIRP also considered research published since those reviews. A brief summary of this literature is provided in Appendix B, with the main conclusions provided below.

As described in Appendix B, in addition to nerve stimulation (described in ICNIRP 2010), radiofrequency EMFs can affect the body via two primary biological effects: changes in the permeability of membranes and temperature rise. Knowledge concerning relations between thermal effects and health, independent of the radiofrequency EMF literature, is also important and is described below. ICNIRP considers this appropriate given that the vast majority of radiofrequency EMF health research has been conducted

Table 1. Quantities and corresponding SI units used in these guidelines.

Quantity	Symbol[a]	Unit
Absorbed energy density	U_{ab}	joule per square meter (J m^{-2})
Incident energy density	U_{inc}	joule per square meter (J m^{-2})
Plane-wave equivalent incident energy density	U_{eq}	joule per square meter (J m^{-2})
Absorbed power density	S_{ab}	watt per square meter (W m^{-2})
Incident power density	S_{inc}	watt per square meter (W m^{-2})
Plane-wave equivalent incident power density	S_{eq}	watt per square meter (W m^{-2})
Induced electric field strength	E_{ind}	volt per meter (V m^{-1})
Incident electric field strength	E_{inc}	volt per meter (V m^{-1})
Incident electric field strength	E_{ind}	volt per meter (V m^{-1})
Incident magnetic field strength	H_{inc}	ampere per meter (A m^{-1})
Specific energy absorption	SA	joule per kilogram (J kg^{-1})
Specific energy absorption rate	SAR	watt per kilogram (W kg^{-1})
Electric current	I	ampere (A)
Frequency	f	hertz (Hz)
Time	t	second (s)

[a]*Italicized* symbols represent variables; quantities are described in scalar form because direction is not used to derive the basic restrictions or reference levels.

using exposures substantially lower than those shown to produce adverse health effects, with relatively little research addressing adverse health effect thresholds from known interaction mechanisms themselves. Thus, it is possible that the radiofrequency health literature may not be sufficiently comprehensive to ascertain precise thresholds. Conversely, where a more extensive literature is available that clarifies the relation between health and the primary biological effects, this can be useful for setting guidelines. For example, if the thermal physiology literature demonstrated that local temperature elevations of a particular magnitude caused harm, but radiofrequency exposure known to produce a similar temperature elevation had not been evaluated for harm, then it would be reasonable to also consider this thermal physiology literature. ICNIRP refers to thresholds derived from such additional literature as *operational* adverse health effect thresholds.

It is important to note that ICNIRP only uses operational thresholds to set restrictions where they are lower (more conservative) than those demonstrated to adversely affect health in the radiofrequency literature, or where the radiofrequency literature does not provide sufficient evidence to deduce an adverse health effect threshold. For the purpose of determining thresholds, evidence of adverse health effects arising from all radiofrequency EMF exposures is considered, including those referred to as 'low-level' and 'non-thermal', and including those where mechanisms have not been elucidated. Similarly, as there is no evidence that continuous (e.g., sinusoidal) and discontinuous (e.g., pulsed) EMFs result in different biological effects (Kowalczuk et al. 2010; Juutilainen et al. 2011), no theoretical distinction has been made between these types of exposure (all exposures have been considered empirically in terms of whether they adversely affect health).

Thresholds for Radiofrequency EMF-Induced Health Effects

Nerve stimulation. Exposure to EMFs can induce electric fields within the body, which for frequencies up to 10 MHz can stimulate nerves (Saunders and Jeffreys 2007). The effect of this stimulation varies as a function of frequency, and it is typically reported as a "tingling" sensation for frequencies around 100 kHz. As frequency increases, heating effects predominate and the likelihood of nerve stimulation decreases; at 10 MHz the effect of the electric field is typically described as "warmth." Nerve stimulation by induced electric fields is detailed in the ICNIRP low frequency guidelines (2010).

Changes to permeability of cell membranes. When (low frequency) EMFs are pulsed, the power is distributed across a range of frequencies, which can include radiofrequency EMFs (Joshi and Schoenbach 2010). If the pulse is sufficiently intense and brief, exposure to the resultant EMFs may cause cell membranes to become permeable, which in turn can lead to other cellular changes. However, there is no evidence that the radiofrequency spectral component from an EMF pulse (without the low-frequency component) is sufficient to cause changes in the permeability of cell membranes. The restrictions on nerve stimulation in the ICNIRP (2010) guidelines (and used here) are sufficient to ensure that permeability changes do not occur, so additional protection from the resultant radiofrequency EMFs is not necessary. Membrane permeability changes have also been shown to occur with 18 GHz continuous wave exposure (e.g., Nguyen et al. 2015). This has only been demonstrated in vitro, and the effect requires very high exposure levels (circa 5 kW kg^{-1}, over many minutes) that far exceed those required to cause thermally-induced harm (see "Temperature rise" section). Therefore, there is also no need to specifically set restrictions to protect against this effect, as the restrictions designed to protect against smaller temperature rises described in the "Temperature Rise" section will also provide protection against this.

Temperature rise. Radiofrequency EMFs can generate heat in the body and it is important that this heat is kept to a safe level. However, as can be seen from Appendix B, there is a dearth of radiofrequency exposure research using sufficient power to cause heat-induced health effects. Of particular note is that although exposures (and resultant temperature rises) have occasionally been shown to cause severe harm, the literature lacks concomitant evidence of the lowest exposures required to cause harm. For very low exposure levels (such as within the ICNIRP (1998) basic restrictions) there is extensive evidence that the amount of heat generated is not sufficient to cause harm, but for exposure levels above those of the ICNIRP (1998) basic restriction levels, there is limited research. Where there is good reason to expect health impairment at temperatures lower than those shown to impair health via radiofrequency EMF exposure, ICNIRP uses those lower temperatures as a basis for its restrictions (see "Radiofrequency EMF health research" section).

It is important to note that these guidelines restrict radiofrequency EMF exposure to limit temperature rise rather than absolute temperature, whereas health effects are primarily related to absolute temperature. This strategy is used because it is not feasible to limit absolute temperature, which is dependent on many factors that are outside the scope of these guidelines, such as environmental temperature, clothing and work rate. This means that if exposure caused a given temperature rise, this could improve, not affect, or impair health depending on a person's initial temperature. For example, mild heating can be pleasant if a person is cold, but unpleasant if they are already very hot. The restrictions are therefore set to avoid significant increase in temperature, where "significant" is considered in light of both potential harm and normal physiological temperature variation. These guidelines differentiate between steady-state temperature rises (where temperature increases slowly, allowing time for heat to dissipate over a larger tissue mass and for thermoregulatory processes to counter temperature rise), and brief temperature rises (where there may not be sufficient time for heat to dissipate, which can result in larger temperature rises in small regions given the same absorbed radiofrequency energy). This distinction suggests the need to account for steady-state and brief exposure durations separately.

Steady-state temperature rise

Body core temperature. Body core temperature refers to the temperature deep within the body, such as in the abdomen and brain, and varies substantially as a function of such factors as sex, age, time of day, work rate, environmental conditions and thermoregulation. For example, although the mean body core temperature is approximately 37°C (and within the "normothermic" range[4]), this typically varies over a 24-h period to meet physiological needs, with the magnitude of the variation as large as 1°C (Reilly et al. 2007). As thermal load increases, thermoregulatory functions such as vasodilation and sweating can be engaged to restrict body core temperature rise. This is important because a variety of health effects can occur once body core temperature has increased by more than approximately 1°C (termed "hyperthermia"). For example, risk of accident increases with hyperthermia (Ramsey et al. 1983), and at body core temperatures >40°C it can lead to heat stroke, which can be fatal (Cheshire 2016).

Detailed guidelines are available for minimizing adverse health risk associated with hyperthermia within the occupational setting (ACGIH 2017). These aim to modify work environments in order to keep body core temperature within +1°C of normothermia, and require substantial knowledge of each particular situation due to the range of variables that can affect it. As described in Appendix B, body core temperature rise due to radiofrequency EMFs that results in harm is only seen where temperature increases more than +1°C, with no clear evidence of a specific threshold for adverse health effects. Due to the limited literature available, ICNIRP has adopted a conservative temperature rise value as the operational adverse health effect threshold (the 1°C rise of ACGIH 2017). It is important to note that significant physiological changes can occur when body core temperature increases by 1°C. Such changes are part of the body's normal thermoregulatory response (e.g., Van den Heuvel et al. 2017), and thus do not *in themselves* represent an adverse health effect.

Recent theoretical modeling and generalization from experimental research across a range of species predicts that exposures resulting in a whole-body average SAR of approximately 6 W kg^{-1}, within the 100 kHz to 6 GHz range, over at least a 1-hour interval under thermoneutral conditions[5] (28°C, naked, at rest), is required to induce a 1°C body core temperature rise in human adults. A higher SAR is required to reach this temperature rise in children due to their more-efficient heat dissipation (Hirata et al. 2013). However, given the limited measurement data available, ICNIRP has adopted a conservative position and uses 4 W kg^{-1} averaged over 30 min as the radiofrequency EMF exposure level corresponding to a body core temperature rise of 1°C. An averaging time of 30 min is used to take into account the time it takes to reach a steady-state temperature (for more details, see Appendix A, "Temporal averaging considerations" section). As a comparison, a human adult generates a total of approximately 1 W kg^{-1} at rest (Weyand et al. 2009), nearly 2 W kg^{-1} standing, and 12 W kg^{-1} running (Teunissen et al. 2007).

As EMF frequency increases, exposure of the body and the resultant heating becomes more superficial, and above about 6 GHz this heating occurs predominantly within the skin. For example, 86% of the power at 6 and 300 GHz is absorbed within 8 and 0.2 mm of the surface respectively (Sasaki et al. 2017). Compared to heat in deep tissues, heat in superficial tissues is more easily removed from the body because it is easier for the thermal energy to transfer to the environment. This is why basic restrictions to protect against body core temperature rise have traditionally been limited to frequencies below 10 GHz (e.g., ICNIRP 1998). However, research has shown that EMF frequencies above 300 GHz (e.g., infrared radiation) can increase body core temperature beyond the 1°C operational adverse health effect threshold described above (Brockow et al. 2007). This is because infrared radiation, as well as lower frequencies within the scope of the present guidelines, cause heating within the dermis, and the extensive vascular network within the dermis can transport this heat deep within the body. It is therefore appropriate to also protect against body core temperature rise above 6 GHz.

ICNIRP is not aware of research that has assessed the effect of 6 to 300 GHz EMFs on body core temperature, nor of research that has demonstrated that it is harmful. However, as a conservative measure, ICNIRP uses the 4 W kg^{-1} corresponding to the operational adverse health effect threshold for frequencies up to 6 GHz, for the >6 to 300 GHz range also. In support of this being a conservative value, it has been shown that 1260 W m^{-2} (incident power density) infrared radiation exposure to one side of the body results in a 1°C body core temperature rise (Brockow et al., 2007). If we related this to the exposure of a 70 kg adult with an exposed surface area of 1 m^2 and no skin reflectance, this would result in a whole-body exposure of approximately 18 W kg^{-1}; this is far higher than the 4 W kg^{-1} exposure level for EMFs below 6 GHz that is taken to represent a 1°C body

[4]Normothermia refers to the thermal state within the body whereby active thermoregulatory processes are not engaged to either increase or decrease body core temperature.

[5]Thermoneutral refers to environmental conditions that allow body core temperature to be maintained solely by altering skin blood flow.

core temperature rise. This is viewed as additionally conservative given that the Brockow et al. study reduced heat dissipation using a thermal blanket, which would underestimate the exposure required to increase body core temperature under typical conditions.

Local temperature. In addition to body core temperature, excessive localized heating can cause pain and thermal damage. There is an extensive literature showing that skin contact with temperatures below 42°C for extended periods will not cause pain or damage cells (e.g., Defrin et al. 2006). As described in Appendix B, this is consistent with the limited data available for radiofrequency EMF heating of the skin [e.g., Walters et al. (2000) reported a pain threshold of 43°C using 94 GHz exposure], but fewer data are available for heat sources that penetrate beyond the protective epidermis and to the heat-sensitive epidermis/dermis interface. However, there is also a substantial body of literature assessing thresholds for tissue damage which shows that damage can occur at tissue temperatures >41–43°C, with damage likelihood and severity increasing as a function of time at such temperatures (e.g., Dewhirst et al. 2003; Yarmolenko et al. 2011; Van Rhoon et al. 2013).

The present guidelines treat radiofrequency EMF exposure that results in local temperatures of 41°C or greater as potentially harmful. As body temperature varies as a function of body region, ICNIRP treats exposure to different regions separately. Corresponding to these regions, the present guidelines define two tissue types which, based on their temperature under normothermal conditions, are assigned different operational adverse health effect thresholds; "Type-1" tissue (all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue), and "Type-2" tissue (all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue). The normothermal temperature of Type 1 tissue is typically <33–36 °C, and that of Type-2 tissue <38.5 °C (DuBois 1941; Aschoff and Wever 1958; Arens and Zhang 2006; Shafahi and Vafai 2011). These values were used to define operational thresholds for local heat-induced health effects; adopting 41 °C as potentially harmful, the present guidelines take a conservative approach and treat radiofrequency EMF-induced temperature rises of 5°C and 2°C, within Type-1 and Type-2 tissue, respectively, as operational adverse health effect thresholds for local exposure.

It is difficult to set exposure restrictions as a function of the above tissue-type classification. ICNIRP thus defines two regions and sets separate exposure restrictions, where relevant, for these regions: "Head and Torso," comprising the head, eye, pinna, abdomen, back, thorax and pelvis, which includes both Type-1 and Type-2 tissue, and the "Limbs," comprising the upper arm, forearm, hand, thigh, leg and foot, which only includes Type-1 tissue. Exposure levels have been determined for each of these regions such that they do not result in temperature rises of more than 5°C and 2°C, in Type-1 and Type-2 tissue, respectively. As the Limbs, by definition, do not contain any Type-2 tissue, the operational adverse health effect threshold for the Limbs is always 5°C.

The testes can be viewed as representing a special case, whereby reversible, graded, functional change can occur within normal physiological temperature variation if maintained over extended periods, with no apparent threshold. For example, spermatogenesis is reversibly reduced as a result of the up to 2°C increase caused by normal activities such as sitting (relative to standing; Mieusset and Bujan 1995). Thus, it is possible that the operational adverse health effect threshold for Type-2 tissue may result in reversible changes to sperm function. However, there is currently no evidence that such effects are sufficient to impair health. Accordingly, ICNIRP views the operational adverse health effect threshold of 2°C for Type-2 tissue, which is within the normal physiological range for the testes, as appropriate for them also. Note that the operational adverse health effect threshold for Type-2 tissue, which includes the abdomen and thus potentially the fetus, is also consistent with protecting against the fetal temperature rise threshold of 2°C for teratogenic effects in animals (Edwards et al. 2003; Ziskin and Morrissey 2011).

Within the 100 kHz to 6 GHz EMF range, average SAR over 10 g provides an appropriate measure of the radiofrequency EMF-induced steady-state temperature rise within tissue. A 10-g mass is used because, although there can initially be EMF-induced temperature heterogeneity within that mass, heat diffusion rapidly distributes the thermal energy to a much larger volume that is well-represented by a 10-g cubic mass (Hirata and Fujiwara 2009). In specifying exposures that correspond to the operational adverse health effect thresholds, ICNIRP thus specifies an average exposure over a 10-g cubic mass, such that the exposure will keep the Type-1 and Type-2 tissue temperature rises to below 5 and 2°C respectively. Further, ICNIRP assumes realistic exposures (exposure scenarios that people may encounter in daily life, including occupationally), such as from EMFs from radio-communications sources. This method provides for higher exposures in the Limbs than in the Head and Torso. A SAR_{10g} of at least 20 W kg^{-1} is required to exceed the operational adverse health effect thresholds in the Head and Torso, and 40 W kg^{-1} in the Limbs, over an interval sufficient to produce a steady-state temperature (from a few minutes to 30 min). This time interval is operationalized as a 6-min average as it closely matches the thermal time constant for local exposure.

Within the >6 to 300 GHz range, EMF energy is deposited predominantly in superficial tissues; this makes SAR_{10g}, which includes deeper tissues, less relevant to this frequency range. Conversely, absorbed power density (S_{ab}) provides a measure of the power absorbed in tissue that closely approximates the superficial temperature rise (Funahashi et al. 2018). From 6 to 10 GHz there may still be significant absorption in the subcutaneous tissue. However, the maximum and thus worst-case temperature rise from 6 to 300 GHz is close to the skin surface, and exposure that will restrict temperature rise to below the operational adverse health effect threshold for Type-1 tissue (5°C) will also restrict temperature rise to below the operational adverse health effect threshold for Type-2 tissue (2°C). Note that there is uncertainty with regard to the precise frequency for the change from SAR to absorbed power density. Six GHz was chosen because at that frequency, most of the absorbed power is within the cutaneous tissue, which is within the upper half of a 10-g SAR cubic volume (that is, it can be represented by the 2.15 cm × 2.15 cm surface of the cube). Recent thermal modeling and analytical solutions suggest that for EMF frequencies between 6 and 30 GHz, the exposure over a square averaging area of 4 cm^2 provides a good estimate of local maximum temperature rise (Hashimoto et al. 2017; Foster et al. 2017). As frequency increases further, the averaging area needs to be reduced to account for the possibility of smaller beam diameters, such that it is 1 cm^2 from approximately 30 GHz to 300 GHz. Although the averaging area that best corresponds to temperature rise would therefore gradually change from 4 cm^2 to 1 cm^2 as frequency increases from 6 to 300 GHz, ICNIRP uses a square averaging area of 4 cm^2 for >6 to 300 GHz as a practical protection specification. Moreover, from >30 to 300 GHz (where focal beam exposure can occur), an additional spatial average of 1 cm^2 is used to ensure that the operational adverse health effect thresholds are not exceeded over smaller regions.

As 6 minutes is an appropriate averaging interval (Morimoto et al. 2017), and as an absorbed power density of approximately 200 W m^{-2} is required to produce the Type-1 tissue operational adverse health effect threshold of a 5°C local temperature rise for frequencies of >6 to 300 GHz (Sasaki et al. 2017), ICNIRP has set the absorbed power density value for local heating, averaged over 6 min and a square 4-cm^2 region, at 200 W m^{-2}; this will also restrict temperature rise in Type-2 tissue to below the operational adverse health effect threshold of 2°C. An additional specification of 400 W m^{-2} has been set for spatial averages of square 1-cm^2 regions, for frequencies >30 GHz.

Rapid temperature rise

For some types of exposure, rapid temperature rise can result in "hot spots," heterogeneous temperature distribution over tissue mass (Foster et al. 2016; Morimoto et al. 2017; Laakso et al. 2017; Kodera et al. 2018). This suggests the need to consider averaging over smaller time-intervals for certain types of exposure. Hot spots can occur for short duration exposures because there is not sufficient time for heat to dissipate (or average out) over tissue. This effect is more pronounced as frequency increases due to the smaller penetration depth.

To account for such heterogeneous temperature distributions, an adjustment to the steady-state exposure level is required. This can be achieved by specifying the maximum exposure level allowed, as a function of time, in order to restrict temperature rise to below the operational adverse health effect thresholds.

From 400 MHz to 6 GHz, ICNIRP specifies the restriction in terms of specific energy absorption (SA) of any 10-g cubic mass, where SA is restricted to $7.2[0.05+0.95(t/360)^{0.5}]$ kJ kg^{-1} for Head and Torso, and $14.4[0.025+0.975(t/360)^{0.5}]$ kJ kg^{-1} for Limb exposure, where t is exposure interval in seconds (Kodera et al. 2018). Note that for this specification, exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the total (sum) of exposures (including non-pulsed EMF), delivered in t seconds, must not exceed the below formulae (in order to ensure that the temperature thresholds are not exceeded).

There is no brief-interval exposure level specified below 400 MHz because, due to the large penetration depth, the total SA resulting from the 6-minute local SAR average cannot increase temperature by more than the operational adverse health effect threshold (regardless of the particular pattern of pulses or brief exposures).

Above 6 GHz, ICNIRP specifies the exposure level for both Head and Torso, and Limbs, in terms of absorbed energy density (U_{ab}) over any square averaging area of 4 cm^2, such that U_{ab} is specified as $72[0.05+0.95(t/360)^{0.5}]$ kJ m^{-2}, where t is the exposure interval in seconds (extension of Kodera et al. 2018).

An additional exposure level for square 1-cm^2 averaging areas is applicable for EMFs with frequencies of >30 to 300 GHz to account for focused beam exposure and is given by $144[0.025+0.975(t/360)^{0.5}]$ kJ m^{-2}.

The SA and U_{ab} values are conservative in that they are not sufficient to raise Type 1 or Type 2 tissue temperatures by 5 or 2°C, respectively.

GUIDELINES FOR LIMITING RADIOFREQUENCY EMF EXPOSURE

As described in the "Scientific Basis for Limiting Radiofrequency Exposure" section, radiofrequency EMF levels corresponding to operational adverse health effects were identified. Basic restrictions have been derived from these and are described in the "Basic Restrictions" section below. The basic restrictions related to nerve stimulation

Table 2. Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥6 min.[a]

Exposure scenario	Frequency range	Whole-body average SAR (W kg^{-1})	Local Head/Torso SAR (W kg^{-1})	Local Limb SAR (W kg^{-1})	Local S_{ab} (W m^{-2})
Occupational	100 kHz to 6 GHz	0.4	10	20	NA
	>6 to 300 GHz	0.4	NA	NA	100
General public	100 kHz to 6 GHz	0.08	2	4	NA
	>6 to 300 GHz	0.08	NA	NA	20

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. Whole-body average SAR is to be averaged over 30 min.
3. Local SAR and S_{ab} exposures are to be averaged over 6 min.
4. Local SAR is to be averaged over a 10-g cubic mass.
5. Local S_{ab} is to be averaged over a square 4-cm^2 surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a square 1-cm^2 surface area of the body is restricted to two times that of the 4-cm^2 restriction.

for EMF frequencies 100 kHz to 10 MHz, from ICNIRP (2010), were then added to the present set of basic restrictions, with the final set of basic restrictions given in Tables 2–4. Reference levels were derived from those final basic restrictions and are described in the "Reference Levels" section, with details of how to treat multiple frequency fields in terms of the restrictions in the "Simultaneous Exposure to Multiple Frequency Fields" section. Contact current guidance is provided in the "Guidance for Contact Currents", and health considerations for occupational exposure are described in the "Risk Mitigations Considerations for Occupational Exposure" section. To be compliant with the present guidelines, for each exposure quantity (e.g., E-field, H-field, SAR), and temporal and spatial averaging condition, either the basic restriction or corresponding reference level must be adhered to; compliance with both is not required. Note that where restrictions specify particular averaging intervals, 'all' such averaging intervals must comply with the restrictions.

Basic Restrictions

Basic restriction values are provided in Tables 2–4 with an overview of their derivation described below. As described above, the basic restrictions from ICNIRP (2010) for the frequency range 100 kHz to 10 MHz have not been re-evaluated here; these are described in Table 4. A more detailed description of issues pertinent to the basic restrictions is provided in Appendix A, in the "Relevant Biophysical Mechanisms" section. Note that for the basic restrictions described below, a pregnant woman is treated as a member of the general public. This is because recent modeling suggests that for both whole-body and local exposure scenarios, exposure of the mother at the occupational basic restrictions can lead to fetal exposures that exceed the general public basic restrictions.

Whole-body average SAR (100 kHz to 300 GHz). As described in the "Body core temperature" section, the guidelines take a whole-body average SAR of 4 W kg^{-1},

Table 3. Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for integrating intervals >0 to <6 min.[a]

Exposure scenario	Frequency range	Local Head/Torso SA (kJ kg^{-1})	Local Limb SA (kJ kg^{-1})	Local U_{ab} (kJ m^{-2})
Occupational	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$3.6[0.05+0.95(t/360)^{0.5}]$	$7.2[0.025+0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$36[0.05+0.95(t/360)^{0.5}]$
General public	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$0.72[0.05+0.95(t/360)^{0.5}]$	$1.44[0.025+0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$7.2[0.05+0.95(t/360)^{0.5}]$

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. t is time in seconds, and restrictions must be satisfied for all values of t between >0 and <360 s, regardless of the temporal characteristics of the exposure itself.
3. Local SA is to be averaged over a 10-g cubic mass.
4. Local U_{ab} is to be averaged over a square 4-cm^2 surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a square 1-cm^2 surface area of the body is restricted to $72[0.025+0.975(t/360)^{0.5}]$ for occupational and $14.4[0.025+0.975(t/360)^{0.5}]$ for general public exposure.
5. Exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t s, must not exceed these levels.

Table 4. Basic restrictions for electromagnetic field exposure from 100 kHz to 10 MHz, for peak spatial values.[a]

Exposure scenario	Frequency range	Induced electric field; E_{ind} (V m^{-1})
Occupational	100 kHz to 10 MHz	$2.70 \times 10^{-4} f$
General public	100 kHz to 10 MHz	$1.35 \times 10^{-4} f$

[a]Note:

1. f is frequency in Hz.

2. Restriction values relate to any region of the body, and are to be averaged as root mean square (rms) values over 2 mm × 2 mm × 2 mm contiguous tissue (as specified in ICNIRP 2010).

averaged over the entire body mass and a 30-minute interval, as the exposure level corresponding to the operational adverse health effect threshold for an increase in body core temperature of 1°C. A reduction factor of 10 was applied to this threshold for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. Variability in an individual's ability to regulate their body core temperature is particularly important as it is dependent on a range of factors that the guidelines cannot control. These include central and peripherally-mediated changes to blood perfusion and sweat rate (which are in turn affected by a range of other factors, including age and certain medical conditions), as well as behavior and environmental conditions.

Thus the basic restriction for occupational exposure becomes a whole-body average SAR of 0.4 W kg^{-1}, averaged over 30 min. Although this means that SAR can be larger for smaller time intervals, this will not affect body core temperature rise appreciably because the temperature will be "averaged-out" within the body over the 30-min interval, and it is this time-averaged temperature rise that is relevant here. Further, as both whole-body and local restrictions must be met simultaneously, exposures sufficiently high to be hazardous locally will be protected against by the local restrictions described below.

As the general public cannot be expected to be aware of exposures and thus to mitigate risk, a reduction factor of 50 was applied for the general public, making the whole-body average SAR restriction for the general public 0.08 W kg^{-1}, averaged over 30 min.

It is noteworthy that the scientific uncertainty pertaining to both dosimetry and potential health consequences of whole-body radiofrequency exposure have reduced substantially since the ICNIRP (1998) guidelines. This would justify less conservative reduction factors, but as ICNIRP considers that the benefits of maintaining stable basic restrictions outweighs any benefits that subtle changes to them would provide, ICNIRP has retained the same reduction factors as before for the whole-body average basic restrictions. Similarly, although temperature rise is more superficial as frequency increases (and thus it is easier for the resultant heat to be lost to the environment), the whole-body average SAR restrictions above 6 GHz have been conservatively set the same as those ≤6 GHz.

Local SAR (100 kHz to 6 GHz)

Head and Torso

As described in the "Local temperature" section within the 100 kHz to 6 GHz range, the guidelines take a SAR of 20 W kg^{-1}, averaged over a 10-g cubic mass and 6-min interval, as the local exposure level corresponding to the operational adverse health effect threshold for the Head and Torso (5°C in Type-1 tissue and 2°C in Type-2 tissue). A reduction factor of 2 was applied to this for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. Reduction factors for local exposure are smaller than for whole-body exposure because the associated health effect threshold is less dependent on environmental conditions and the highly variable centrally-mediated thermoregulatory processes, and because the associated health effect is less serious medically. Thus, the basic restriction for occupational exposure becomes a SAR_{10g} of 10 W kg^{-1}, averaged over a 6-min interval. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and also recognizing greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public, reducing the general public basic restriction to a SAR_{10g} of 2 W kg^{-1} averaged over a 6-min interval.

Limbs

As described in the "Local temperature" section, within the 100 kHz to 6 GHz range, the guidelines take a SAR of 40 W kg^{-1}, averaged over a 10-g cubic mass and 6-min interval, as the local exposure level corresponding to the operational adverse health effect threshold for the Limbs of a 5°C rise in local temperature. As with the Head and Torso restrictions, a reduction factor of 2 was applied to this threshold for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for occupational exposure of a SAR_{10g} of 20 W kg^{-1}. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and also to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public, reducing the general public restriction to 4 W kg^{-1} averaged over a 6-min interval.

Local SA (400 MHz to 6 GHz). As described in the "Rapid temperature rise" section, within the >400 MHz to 6 GHz range, an additional constraint is required to ensure that the cumulative energy permitted by the 6-minute

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average SAR_{10g} basic restriction is not absorbed by tissues too rapidly. Accordingly, ICNIRP sets an SA level for exposure intervals of less than 6 min, as a function of time, to limit temperature rise to below the operational adverse health effect thresholds. This SA level, averaged over a 10-g cubic mass, is given by $7.2[0.05+0.95(t/360)^{0.5}]$ kJ kg^{-1} for the Head and Torso, and $14.4[0.025+0.975(t/360)^{0.5}]$ kJ kg^{-1} for the Limbs, where t is exposure duration in seconds.

As with the SAR_{10g} basic restrictions, a reduction factor of 2 was applied to these exposure levels for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for the Head and Torso of $3.6[0.05+0.95(t/360)^{0.5}]$ kJ kg^{-1}, and for the Limbs of $7.2[0.025+0.975(t/360)^{0.5}]$ kJ kg^{-1}. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public. This makes the general public restriction $0.72[0.05+0.95(t/360)^{0.5}]$ kJ kg^{-1} for the Head and Torso, and $1.44[0.025+0.975(t/360)^{0.5}]$ kJ kg^{-1} for the Limbs.

Note that for these brief exposure basic restrictions, the exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t seconds, must not exceed these local SA values.

Local absorbed power density (>6 GHz to 300 GHz). As described in the "Local temperature" section, within the >6 to 300 GHz range, the guidelines take an absorbed power density of 200 W m^{-2}, averaged over 6 min and a square 4-cm^2 surface area of the body, as the local exposure corresponding to the operational adverse health effect threshold for both the Head and Torso, and Limb regions (5 and 2°C local temperature rise in Type-1 and Type-2 tissue, respectively). As with the local SAR restrictions, a reduction factor of 2 was applied to this exposure level for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for occupational exposure of 100 W m^{-2}, averaged over 6 min and a square 4-cm^2 surface area of the body.

As the general public cannot be expected to be aware of these exposures and thus to mitigate risk, and to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied, which reduces the general public basic restriction to 20 W m^{-2}, averaged over 6 min and a square 4-cm^2 surface area of the body.

Further, to account for focal beam exposure from >30 to 300 GHz, absorbed power density averaged over a square 1-cm^2 surface area of the body must not exceed 2 times that of the 4-cm^2 basic restrictions for workers or the general public.

Local absorbed energy density (>6 GHz to 300 GHz). As described in the "Rapid temperature rise" section, within the >6 to 300 GHz range, an additional constraint is required to ensure that the cumulative energy permitted by the 6-min average absorbed power density basic restriction is not absorbed by tissue too rapidly. Accordingly, for both the Head and Torso, and Limbs, ICNIRP set a maximum absorbed energy density level for exposure intervals of less than 6 minutes, as a function of time, to limit temperature rise to below the operational adverse health effect thresholds for both Type-1 and Type-2 tissues. This absorbed energy density level, averaged over any square 4-cm^2 surface area of the body, is given by $72[0.05+0.95(t/360)^{0.5}]$ kJ m^{-2}, where t is exposure duration in seconds. To account for focal beam exposure from >30 to 300 GHz, the absorbed energy density level corresponding to the operational adverse health effect threshold, averaged over a square 1-cm^2 surface area of the body, is given by $144[0.025+0.975(t/360)^{0.5}]$ kJ m^{-2}. Note that for these basic restrictions for brief exposures, the exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t seconds, must be used to satisfy this formula.

As with the absorbed power density basic restrictions, a reduction factor of 2 was applied to this exposure level for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for occupational exposure of $36[0.05+0.95(t/360)^{0.5}]$ kJ m^{-2}, over any square 4-cm^2 surface area of the body. From >30 to 300 GHz, an additional basic restriction for occupational exposure is $72[0.025+0.975(t/360)^{0.5}]$ kJ m^{-2}, averaged over any square 1-cm^2 surface area of the body. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public, reducing the general public restriction to $7.2[0.05+0.95(t/360)^{0.5}]$ kJ m^{-2}, averaged over any square 4-cm^2 surface area of the body. From >30 to 300 GHz, an additional basic restriction for the general public is $14.4[0.025+0.975(t/360)^{0.5}]$ kJ m^{-2}, averaged over any square 1-cm^2 surface area of the body.

Basic restriction tables. To be compliant with the basic restrictions, radiofrequency EMF exposure must not exceed the restrictions specified for that EMF frequency in Table 2, 3 or 4. That is, for any given radiofrequency EMF frequency, relevant whole-body SAR, local

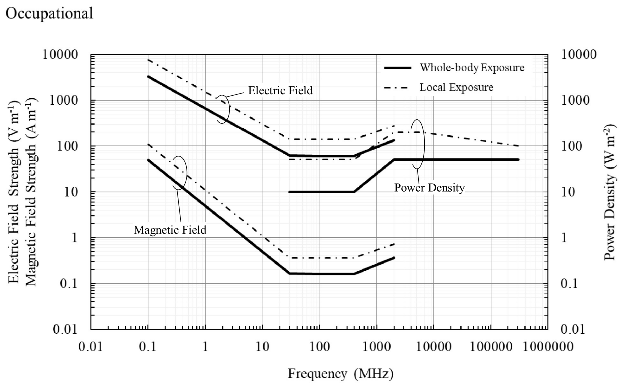

FIGURE 1. Reference levels for time averaged occupational exposures of ≥6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values; see Tables 5 and 6 for full specifications).

SAR, S_{ab}, SA, U_{ab} and induced E-field[6] restrictions must be met simultaneously.

Reference Levels

Reference levels have been derived from a combination of computational and measurement studies to provide a means of demonstrating compliance using quantities that are more-easily assessed than basic restrictions, but that provide an equivalent level of protection to the basic restrictions for worst-case exposure scenarios. However, as the derivations rely on conservative assumptions, in most exposure scenarios the reference levels will be more conservative than the corresponding basic restrictions. Further details regarding the reference levels are provided in Appendix A, the "Derivation of Reference Levels" section.

Reference levels are provided in Tables 5–9. Figures 1 and 2 provide graphical representations of the occupational and general public reference level values for extended durations of exposure (≥6 min). Table 5 reference levels are averaged over a 30-min interval, and correspond to the whole-body average basic restrictions. Table 6 (averaged over a 6-min interval), Table 7 (integrated over intervals between >0 and <6 min), and Table 8 (peak instantaneous field strength measures) each relate to basic restrictions that are averaged over smaller body regions. Additional limb current reference levels have been set to account for effects of grounding near human body resonance frequencies (Dimbylow 2001) that might otherwise lead to reference levels underestimating exposures within tissue at certain EMF frequencies (averaged over 6 min; Table 9). Limb current reference levels are only relevant in exposure scenarios where a person is not electrically isolated.

Tables 5–9 specify averaging and integrating times of the relevant exposure quantities to determine whether personal exposure level is compliant with the guidelines. These averaging times are not necessarily the same as the measurement times needed to estimate field strengths or other exposure quantities. Depending on input from technical standards bodies, actual measurement times used to provide an appropriate estimate of exposure quantities may be shorter than the intervals specified in these tables.

An important consideration for the application of reference levels is to what degree the quantities used to assess compliance with the reference levels (i.e., E_{inc}, H_{inc}, S_{inc}, U_{inc}, S_{eq}, U_{eq}, I) adequately predict the quantities used to assess compliance with the basic restrictions. In situations where reference level quantities are associated with greater uncertainty, reference levels must be applied more conservatively. For the purposes of the guidelines, the degree of adequacy strongly depends on whether external EMFs can be considered to be within the far-field, radiative near-field or reactive near-field zone. Accordingly, in most cases, different reference level assessment rules have been set for EMFs as a function of whether they are within the far-field, radiative or reactive near-field zone.

A difficulty with this approach is that other factors may also affect the adequacy of estimating basic restriction quantities from reference level quantities. These include the EMF frequency, physical dimensions of the EMF source and its distance from the resultant external EMFs assessed, as well as the degree to which the EMFs vary over the space to be occupied by a person. Taking into account such sources of uncertainty, the guidelines have more conservative rules for exposure in the reactive and radiative near-field than far-field zone. It is noted that there is no simple delineation of the far-field, radiative and reactive near-field zones that is sufficient for ensuring that reference levels will adequately correspond to the basic restrictions. Accordingly, although a definition of these zones is provided in

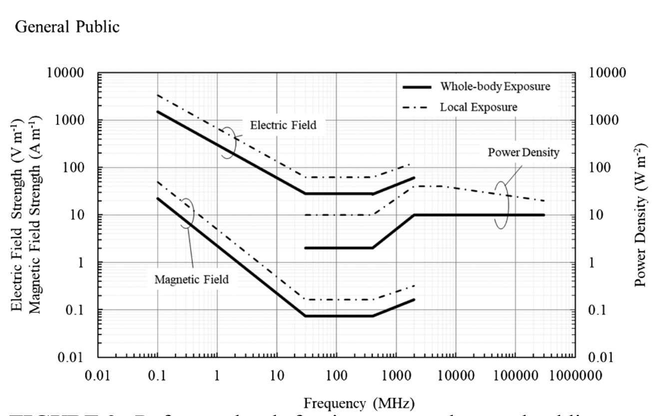

FIGURE 2. Reference levels for time averaged general public exposures of ≥6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values; see Tables 5 and 6 for full specifications).

[6]Note that although the term internal is used in place of induced in ICNIRP (2010), induced is used here for consistency within the present document.

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Table 5. Reference levels for exposure, averaged over 30 min and the whole body, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$660/f_M^{0.7}$	$4.9/f_M$	NA
	>30 – 400 MHz	61	0.16	10
	>400 – 2000 MHz	$3f_M^{0.5}$	$0.008f_M^{0.5}$	$f_M/40$
	>2 – 300 GHz	NA	NA	50
General public	0.1 – 30 MHz	$300/f_M^{0.7}$	$2.2/f_M$	NA
	>30 – 400 MHz	27.7	0.073	2
	>400 – 2000 MHz	$1.375f_M^{0.5}$	$0.0037f_M^{0.5}$	$f_M/200$
	>2 – 300 GHz	NA	NA	10

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. f_M is frequency in MHz.
3. S_{inc}, E_{inc}, and H_{inc} are to be averaged over 30 min, over the whole-body space. Temporal and spatial averaging of each of E_{inc} and H_{inc} must be conducted by averaging over the relevant square values (see eqn 8 in Appendix A for details).
4. For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither E_{inc} or H_{inc} exceeds the above reference level values.
5. For frequencies of >30 MHz to 2 GHz: (a) within the far-field zone: compliance is demonstrated if either S_{inc}, E_{inc} or H_{inc}, does not exceed the above reference level values (only one is required); S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if either S_{inc}, or both E_{inc} and H_{inc}, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both E_{inc} and H_{inc} do not exceed the above reference level values; S_{inc} cannot be used to demonstrate compliance, and so basic restrictions must be assessed.
6. For frequencies of >2 GHz to 300 GHz: (a) within the far-field zone: compliance is demonstrated if S_{inc} does not exceed the above reference level values; S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if S_{inc} does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

Appendix A in the "General Considerations for Reference Levels" section this is only intended as a guide, and information from a technical standards body, designed to specify external exposures for each EMF source type to more adequately match the basic restrictions, should be utilized to improve reference level assessment procedures.

Related to the near- and far-field zone distinctions, for some exposure conditions the less onerous plane wave equivalent incident power density (S_{eq}) and plane wave equivalent incident energy density (U_{eq}) quantities can be used in place of S_{inc} and U_{inc}, respectively; where this is permitted, it is specified below. In such cases, the *plane wave equivalent incident energy densities* are to be averaged in the same way as described in Tables 5–7 for the corresponding *incident power densities*.

In terms of electromagnetic fields in the far-field zone, the following rules apply. For EMF frequencies from >30 MHz to 2 GHz, ICNIRP requires compliance to be demonstrated for only one of the E-field, H-field or S_{inc} quantities in order to be compliant with that particular reference level. Further, S_{eq} can be substituted for S_{inc}. Similarly, for EMF frequencies >400 MHz where the restrictions are specified in terms of U_{inc}, these can be substituted for by U_{eq}. EMF frequencies from 100 kHz to 30 MHz are treated as always being within the near-field zone; see next paragraph.

In terms of electromagnetic fields in the near-field zones, the following rules apply. From 100 kHz to 30 MHz, relevant personal exposures from present radiofrequency EMF sources are typically within the near-field zone. The present guidelines treat *all* exposures within this frequency range as near-field, and requires compliance with both the E-field and H-field reference level values in order to be compliant with the reference levels. For EMF frequencies from >30 MHz to 2 GHz, personal exposure within either the radiative or reactive near-field zones is treated as compliant if both the E-field and H-field strengths are below the reference level values described in the tables. For frequencies >30 MHz to 300 GHz, personal exposure within the radiative near-field zone is treated as compliant if S_{inc} (or, where relevant U_{inc}) is below the reference level value. However, for exposure within the >2 to 300 GHz range, within the reactive near-field the quantities applied for the reference level values are treated as inadequate to ensure compliance with the basic restrictions. In such cases, compliance with the basic restrictions must be assessed.

ICNIRP is aware that for some exposure scenarios, radiofrequency EMFs at the reference levels specified below could potentially result in exposure that exceeds basic restrictions. Where such scenarios were identified, ICNIRP determined whether the reference levels needed to be reduced by considering the magnitude of the difference between the resultant tissue exposure and corresponding basic restriction (including comparison with the associated dosimetric uncertainty), and whether the violation was likely to adversely affect health (including consideration of the degree of conservativeness in the associated basic

Table 6. Reference levels for local exposure, averaged over 6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$1504/f_M^{0.7}$	$10.8/f_M$	NA
	>30 – 400 MHz	139	0.36	50
	>400 – 2000 MHz	$10.58 f_M^{0.43}$	$0.0274 f_M^{0.43}$	$0.29 f_M^{0.86}$
	>2 – 6 GHz	NA	NA	200
	>6 – <300 GHz	NA	NA	$275/f_G^{0.177}$
	300 GHz	NA	NA	100
General public	0.1 – 30 MHz	$671/f_M^{0.7}$	$4.9/f_M$	NA
	>30 – 400 MHz	62	0.163	10
	>400 – 2000 MHz	$4.72 f_M^{0.43}$	$0.0123 f_M^{0.43}$	$0.058 f_M^{0.86}$
	>2 – 6 GHz	NA	NA	40
	>6 – 300 GHz	NA	NA	$55/f_G^{0.177}$
	300 GHz	NA	NA	20

[a] Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.

2. f_M is frequency in MHz; f_G is frequency in GHz.

3. S_{inc}, E_{inc}, and H_{inc} are to be averaged over 6 min, and where spatial averaging is specified in Notes 6–7, over the relevant projected body space. Temporal and spatial averaging of each of E_{inc} and H_{inc} must be conducted by averaging over the relevant square values (see eqn 8 in Appendix A for details).

4. For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither peak spatial E_{inc} or peak spatial H_{inc}, over the projected whole-body space, exceeds the above reference level values.

5. For frequencies of >30 MHz to 6 GHz: (a) within the far-field zone, compliance is demonstrated if one of peak spatial S_{inc}, E_{inc} or H_{inc}, over the projected whole-body space, does not exceed the above reference level values (only one is required); S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if either peak spatial S_{inc}, or both peak spatial E_{inc} and H_{inc}, over the projected whole-body space, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both E_{inc} and H_{inc} do not exceed the above reference level values; S_{inc} cannot be used to demonstrate compliance; for frequencies >2 GHz, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

6. For frequencies of >6 GHz to 300 GHz: (a) within the far-field zone, compliance is demonstrated if S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the above reference level values; S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the above reference level values; and (c) within the reactive near-field zone reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

7. For frequencies of >30 GHz to 300 GHz, exposure averaged over a square 1-cm^2 projected body surface space must not exceed twice that of the square 4-cm^2 restrictions.

restriction). Where the difference was small, and where it would not adversely affect health, reference levels were retained that can potentially result in exposures that exceed the basic restrictions.

This situation has been shown to occur in terms of the reference levels corresponding to whole-body average SAR basic restrictions, which, in the frequency range of body resonance (up to 100 MHz) and from 1 to 4 GHz, can potentially lead to whole-body average SARs that exceed the basic restrictions (ICNIRP 2009). The exposure scenario where this can potentially occur is very specific, requiring a small stature person (such as a 3-years-old child) to be extended (e.g., standing still and straight with arms above the head) for at least 30 min, while being subject to a plane wave exposure within the above frequency ranges, incident to the child from front to back. The resultant SAR elevation is small relative to the basic restriction (15–40%), which is similar to or smaller than the whole-body average SAR measurement uncertainty (Flintoft et al. 2014; Nagaoka and Watanabe 2019), there are many levels of conservativeness built into the basic restriction derivation itself, and importantly, this will not impact on health. This latter point is important because the basic restriction that this relates to was set to protect against body core temperature rises of greater than 1°C, and being of small stature, the individual in this hypothetical exposure scenario would more easily dissipate heat to the environment than a larger person due to their increased body "surface area-to-mass ratio" (Hirata et al. 2013). Within a small stature person the net effect of this "increased whole-body average SAR" and "increased heat loss" would be a smaller temperature rise than would occur in a person of larger stature who did not exceed the basic restriction, and in both cases would be substantially smaller than 1°C. ICNIRP has thus not altered the reference levels to account for this situation.

Simultaneous Exposure to Multiple Frequency Fields

It is important to determine whether, in situations of simultaneous exposure to fields of different frequencies, these

Table 7. Reference levels for local exposure, integrated over intervals of between >0 and <6 minutes, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

Exposure scenario	Frequency range	Incident energy density; U_{inc} (kJ m^{-2})
Occupational	100 kHz – 400 MHz	NA
	>400 – 2000 MHz	$0.29 f_M^{0.86} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>2 – 6 GHz	$200 \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>6 – <300 GHz	$275/f_G^{0.177} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	300 GHz	$100 \times 0.36[0.05+0.95(t/360)^{0.5}]$
General public	100 kHz – 400 MHz	NA
	>400 – 2000 MHz	$0.058 f_M^{0.86} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>2 – 6 GHz	$40 \times 0.36[0.05+0.95(t/360)^{0.5}]$
	>6 – <300 GHz	$55/f_G^{0.177} \times 0.36[0.05+0.95(t/360)^{0.5}]$
	300 GHz	$20 \times 0.36[0.05+0.95(t/360)^{0.5}]$

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. f_M is frequency in MHz; f_G is frequency in GHz; t is time interval in seconds, such that exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t seconds, must not exceed these reference level values.
3. U_{inc} is to be calculated over time t, and where spatial averaging is specified in Notes 5–7, over the relevant projected body space.
4. For frequencies of 100 kHz to 400 MHz, >0 to <6-min restrictions are not required and so reference levels have not been set.
5. For frequencies of >400 MHz to 6 GHz: (a) within the far-field zone: compliance is demonstrated if peak spatial U_{inc}, over the projected whole-body space, does not exceed the above reference level values; U_{eq} may be substituted for U_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if peak spatial U_{inc}, over the projected whole-body space, does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
6. For frequencies of >6 GHz to 300 GHz: (a) within the far-field or radiative near-field zone, compliance is demonstrated if U_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the above reference level values; (b) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
7. For frequencies of >30 GHz to 300 GHz: exposure averaged over a square 1-cm^2 projected body surface space must not exceed $275/f_G^{0.177} \times 0.72[0.025+0.975(t/360)^{0.5}]$ kJ m^{-2} for occupational and $55/f_G^{0.177} \times 0.72[0.025+0.975(t/360)^{0.5}]$ kJ m^{-2} for general public exposure.

exposures are additive in their effects. Additivity should be examined separately for the effects of thermal and electrical stimulation, and restrictions met after accounting for such additivity. The formulae below apply to relevant frequencies under practical exposure situations. As the below reference level summation formulae assume worst-case conditions among the fields from multiple sources, typical exposure situations may in practice result in lower exposure levels than indicated by the formulae for the reference levels.

The following issues are noted. In terms of the reference levels, the largest ratio of the E-field strength, H-field strength or power density, relative to the corresponding reference level values, should be evaluated to demonstrate compliance. Reference levels are defined in terms of external physical quantities and have transitions, in terms of quantities, at specific frequencies. For example, field strengths are used below 30 MHz, whereas both field strength and incident power density are applicable from 30 MHz to 2 GHz. Where the exposure includes frequency components below and above the transition, additivity should be used to account for this. The same principle applies for basic restrictions. Field values entering the below equations must be derived using the same spatial and temporal constraints referred to in the basic restriction and reference level tables. The summation equations for basic restrictions and reference levels are presented separately below. However, for practical compliance purposes,

Table 8. Reference levels for local exposure to electromagnetic fields from 100 kHz to 10 MHz (unperturbed rms values), for peak values.[a]

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})
Occupational	100 kHz – 10 MHz	170	80
General public	100 kHz – 10 MHz	83	21

[a]Note:

1. Regardless of the far-field/near-field zone distinction, compliance is demonstrated if neither peak spatial E_{inc} or peak spatial H_{inc}, over the projected whole-body space, exceeds the above reference level values.

Table 9. Reference levels for current induced in any limb, averaged over 6 min, at frequencies from 100 kHz to 110 MHz. [a]

Exposure scenario	Frequency range	Electric current; I (mA)
Occupational	100 kHz – 110 MHz	100
General public	100 kHz – 110 MHz	45

[a]Note

1. Current intensity values must be determined by averaging over the relevant square values (see eqn 8 in Appendix A for details).
2. Limb current intensity must be evaluated separately for each limb.
3. Limb current reference levels are not provided for any other frequency range.
4. Limb current reference levels are only required for cases where the human body is not electrically isolated from a ground plane.

the evaluation by basic restriction and reference level can be combined. For example, the second term in eqn (2) can be replaced by the fourth term in eqn (4) for frequency components above 6 GHz. To be compliant with the guidelines, the summed values in each of Eqn (1) to (7) must be less than 1.

Basic restrictions for intervals ≥6 min. For practical application of the whole-body average basic restrictions, SAR should be added according to

$$\sum_{i=100\text{ kHz}}^{300\text{ GHz}} \frac{SAR_i}{SAR_{BR}} \leq 1, \tag{1}$$

where SAR_i and SAR_{BR} are the whole-body average SAR levels at frequency i and the whole-body average SAR basic restrictions given in Table 2, respectively.

For practical application of the local SAR and local absorbed power density basic restrictions, values should be added according to

$$\sum_{i=100\text{ kHz}}^{6\text{ GHz}} \frac{SAR_i}{SAR_{BR}} + \sum_{i>6\text{ GHz}}^{30\text{ GHz}} \frac{S_{ab,4cm,i}}{S_{ab,4cm,BR}} + \sum_{i>30\text{ GHz}}^{300\text{ GHz}} \text{MAX}\left\{\left(\frac{S_{ab,4cm,i}}{S_{ab,4cm,BR}}\right), \left(\frac{S_{ab,1cm,i}}{S_{ab,1cm,BR}}\right)\right\} \leq 1, \tag{2}$$

where, SAR_i and SAR_{BR} are the local SAR level at frequency i and the local SAR basic restriction given in Table 2, respectively; $S_{ab,4cm,i}$ and $S_{ab,4cm,BR}$ are the 4-cm^2 absorbed power density level at frequency i and the 4-cm^2 absorbed power density basic restriction given in Table 2, respectively; $S_{ab,1cm,i}$ and $S_{ab,1cm,BR}$ are the 1-cm^2 absorbed power density level at frequency i and the 1-cm^2 absorbed power density basic restriction given in Table 2, respectively; inside the body, S_{ab} terms are to be treated as zero; when evaluating the summation of SAR and S_{ab} over the body surface, the center of the SAR averaging space is taken to be x,y,z, such that the x,y plane is parallel to the body surface (z = 0) and z = −1.08 cm (approximately half the length of a 10-g cube), and the center of the S_{ab} averaging area is defined as x,y,0; eqn (2) must be satisfied for every position in the human body.

Reference levels for intervals ≥6 min. For practical application of the whole-body average reference levels, incident electric field strength, incident magnetic field strength and incident power density values should be added according to;

$$\sum_{i=100\text{ kHz}}^{30\text{ MHz}} \left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2 + \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2\right\} + \sum_{i>30\text{ MHz}}^{2\text{ GHz}} \text{MAX}\left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2, \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2, \left(\frac{S_{inc,i}}{S_{inc,RL,i}}\right)\right\} + \sum_{i>2\text{ GHz}}^{300\text{ GHz}} \left(\frac{S_{inc,i}}{S_{inc,RL}}\right) \leq 1, \tag{3}$$

where, $E_{inc,i}$ and $E_{inc,RL,i}$ are the whole-body average incident electric field strength and whole-body average incident electric field strength reference level given in Table 5, at frequency i, respectively; $H_{inc,i}$ and $H_{inc,RL,i}$ are the whole-body average incident magnetic field strength and whole-body average incident magnetic field strength reference level given in Table 5, at frequency i, respectively; $S_{inc,i}$ and $S_{inc,RL,i}$ are the whole-body average incident power density and whole-body average incident power density reference level given in Table 5, at frequency i, respectively. Note that the second term is not appropriate for the reactive near-field zone, and so cannot be used in eqn (3).

For practical application of the local reference levels, incident electric field strength, incident magnetic field strength and incident power density values should be added according to

$$\sum_{i=100\text{ kHz}}^{30\text{ MHz}} \text{MAX}\left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2, \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2\right\} + \sum_{i>30\text{ MHz}}^{2\text{ GHz}} \text{MAX}\left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2, \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2, \left(\frac{S_{inc,i}}{S_{inc,RL,i}}\right)\right\} + \sum_{i>2\text{ GHz}}^{6\text{ GHz}} \left(\frac{S_{inc,i}}{S_{inc,RL,i}}\right) + \sum_{i>6\text{ GHz}}^{30\text{ GHz}} \left(\frac{S_{inc,4cm,i}}{S_{inc,4cm,RL,i}}\right) + \sum_{i>30\text{ GHz}}^{300\text{ GHz}} \text{MAX}\left\{\left(\frac{S_{inc,4cm,i}}{S_{inc,4cm,RL,i}}\right), \left(\frac{S_{inc,1cm,i}}{S_{inc,1cm,RL,i}}\right)\right\} \leq 1, \tag{4}$$

where, $E_{inc,i}$ and $E_{inc,RL,i}$ are the local incident electric field strength and local incident electric field strength reference level given in Table 6, at frequency i, respectively; $H_{inc,i}$ and $H_{inc,RL,i}$ are the local incident magnetic field strength and local incident magnetic field strength reference level given in Table 6, at frequency i, respectively; $S_{inc,i}$ and $S_{inc,RL,i}$ are the local incident power density and local incident power density reference level given in Table 6, at frequency i, respectively; inside the body above 6 GHz, S_{inc} terms are to be treated as zero; eqn (4) must be satisfied for every position in the human body.

For practical application of the limb current reference levels, limb current values should be added according to

$$\sum_{i=100\text{ kHz}}^{110\text{ MHz}} \left(\frac{I_i}{I_{RL}}\right)^2 \leq 1, \tag{5}$$

where I_i is the limb current component at frequency i; and I_{RL} is the limb current reference level value from Table 9. If there are non-negligible contributions to the local SAR around limbs over 110 MHz, these need to be considered by combining corresponding terms in eqns (2) or (4).

Basic restrictions for intervals <6 min. For practical application of the local basic restrictions for time intervals (t)<6 min, SAR, SA and absorbed energy density values should be added according to:

$$\sum_{i=100\text{ kHz}}^{400\text{ MHz}} \int_t \frac{SAR_i(t)}{360 \times SAR_{BR}} dt$$

$$+ \sum_{i>400\text{ MHz}}^{6\text{ GHz}} \frac{SA_i(t)}{SA_{BR}(t)}$$

$$+ \sum_{i>6\text{ GHz}}^{30\text{ GHz}} \frac{U_{ab,4cm,i}(t)}{U_{ab,4cm,BR}(t)}$$

$$+ \sum_{i>30\text{ GHz}}^{300\text{ GHz}} \text{MAX}\left\{\left(\frac{U_{ab,4cm,i}(t)}{U_{ab,4cm,BR}(t)}\right), \left(\frac{U_{ab,1cm,i}(t)}{U_{ab,1cm,BR}(t)}\right)\right\} \leq 1, \tag{6}$$

where, $SAR_i(t)$ and $SAR_{BR}(t)$ are the local SAR level at frequency i and the local SAR basic restriction given in Table 2, over time t, respectively; $SA_i(t)$ and $SA_{BR}(t)$ are the local SA level at frequency i and the local SA basic restriction given in Table 3, over time t, respectively; $U_{ab,4cm,i}(t)$ and $U_{ab,4cm,BR}(t)$ are the 4-cm^2 absorbed power density level at frequency i and the 4-cm^2 absorbed power density basic restriction given in Table 3, over time t, respectively; $U_{ab,1cm,i}(t)$ and $U_{ab,1cm,BR}(t)$ are the 1-cm^2 absorbed power density level at frequency i and the 1-cm^2 absorbed power density basic restriction given in Table 3, over time t, respectively; inside the body, U_{ab} terms are to be treated as zero; when evaluating the summation of SAR and/or SA, and U_{ab}, over the body surface, the center of the SAR and/or SA averaging space is taken to be x,y,z, such that the x,y plane is parallel to the body surface (z = 0) and z = −1.08 cm (approximately half the length of a 10-g cube), and the center of the U_{ab} averaging area is defined as x,y,0; eqn (6) must be satisfied for every position in the human body; for simultaneous exposure of brief and extended exposures, SAR, SA and U_{ab} must all be accounted for in this equation.

Reference levels for intervals <6 min. For practical application of the local reference levels for time intervals (t) <6 min, incident electric field strength, incident magnetic field strength, incident power density and incident energy density values should be added according to:

$$\sum_{i>100\text{ kHz}}^{30\text{ MHz}} \text{MAX}\left\{\left(\int_t \frac{E^2_{inc,i}(t)}{360^*E^2_{inc,RL,i}} dt\right), \left(\int_t \frac{H^2_{inc,i}(t)}{360^*H^2_{inc,RL,i}} dt\right)\right\}$$

$$+ \sum_{i>30\text{ MHz}}^{400\text{ MHz}} \text{MAX}\left\{\left(\int_t \frac{E^2_{inc,i}(t)}{360^*E^2_{inc,RL,i}} dt\right), \left(\int_t \frac{H^2_{inc,i}(t)}{360^*H^2_{inc,RL,i}} dt\right), \left(\int_t \frac{S_{inc,i}(t)}{360^*S_{inc,RL,i}} dt\right)\right\}$$

$$+ \sum_{i>400\text{ MHz}}^{6\text{ GHz}} \frac{U_{inc,i}(t)}{U_{inc,RL,i}(t)} + \sum_{i=6\text{ GHz}}^{30\text{ GHz}} \frac{U_{inc,4cm,i}(t)}{U_{inc,4cm,RL,i}(t)}$$

$$+ \sum_{i>30\text{ GHz}}^{300\text{ GHz}} \text{MAX}\left\{\left(\frac{U_{inc,4cm,i}(t)}{U_{inc,4cm,RL,i}(t)}\right), \left(\frac{U_{inc,1cm,i}(t)}{U_{inc,1cm,RL,i}(t)}\right)\right\} \leq 1, \tag{7}$$

where $E_{inc,i}(t)$ and $E_{inc,RL,i}$ are the local E_{inc} level over time t and the local E_{inc} reference level given in Table 6, at frequency i, respectively; $H_{inc,i}(t)$ and $H_{inc,RL,i}$ are the local H_{inc} level over time t and the local H_{inc} reference level given in Table 6, at frequency i, respectively; $S_{inc,i}(t)$ and $S_{inc,RL,i}$ are the local S_{inc} level over time t and the local S_{inc} reference level given in Table 6, at frequency i, respectively; $U_{inc,i}(t)$ and $U_{inc,RL}(t)$ are the incident energy density level and the incident energy density reference level, over time t, at frequency i, given in Table 7, respectively; $U_{inc,4cm,i}(t)$ and $U_{inc,4cm,RL}(t)$ are the 4-cm^2 incident energy density level and the 4-cm^2 incident energy density reference level, over time t, at frequency i, given in Table 7, respectively; $U_{inc,1cm,i}(t)$ and $U_{inc,1cm,RL}(t)$ are the 1-cm^2 incident energy density level and the 1-cm^2 incident energy density reference level, over time t, at frequency i, given in Table 7, respectively; inside the body, U_{inc} terms are to be treated as zero; eqn (7) must be satisfied for every position in the human body.

Guidance for Contact Currents

Within approximately the 100 kHz to 110 MHz range, contact currents can occur when a person touches a conducting object that is within an electric or magnetic field, causing current flow between object and person. At high levels these can result in nerve stimulation or pain (and potentially tissue damage), depending on EMF frequency (Kavet et al. 2014; Tell and Tell 2018). This can be a particular concern around large radiofrequency transmitters, such as those that are found near high power antennas used for broadcasting below 30 MHz and at 87.5–108 MHz, where there have been sporadic reports of pain and burn-related accidents. Contact currents occur at the region of contact, with smaller contact regions producing larger biological effects (given the same current). This is due to the larger current density (A m^{-2}), and consequently the higher localized SAR in the body.

Exposure due to contact currents is indirect, in that it requires an intermediate conducting object to transduce the field. This makes contact current exposure unpredictable, due to both behavioral factors (e.g., grasping versus touch contact) and environmental conditions (e.g., configuration of conductive objects), and it reduces ICNIRP's ability to protect against them. Of particular importance is the heterogeneity of the current density passing to and being absorbed by the person, which is due not only to the contact area, but also to the conductivity, density and heat capacity of the tissue through which the current passes, and most importantly the resistance between conducting object and contacting tissue (Tell and Tell 2018).

Accordingly, these guidelines do not provide restrictions for contact currents, and instead provide "guidance" to assist those responsible for transmitting high-power radiofrequency fields to understand contact currents, the potential hazards, and how to mitigate such hazards. For the purpose of specification, ICNIRP here defines high-power radiofrequency EMFs as those emitting greater than 100 V m^{-1} within the frequency range 100 kHz to 100 MHz at their source.

There is limited research available on the relation between contact currents and health. In terms of pain, the health effect arising from the lowest contact current level, the main data comes from Chatterjee et al. (1986). In that study sensation and pain were assessed in a large adult cohort as a function of contact current frequency and contact type (grasping versus touch contact). Reversible, painful heat sensations were reported to occur with average (touch contact) induced current thresholds of 46 mA within the 100 kHz to 10 MHz range tested, which required at least 10 s of exposure to be reported as pain. Thresholds were frequency-independent within that range, and thresholds for grasping contact were substantially higher than those for touch contact.

However, given that the threshold value reported was an average across the participants, and given the standard deviation of the thresholds reported, ICNIRP considers that the lowest threshold across the cohort would have been approximately 20 mA. Further, modeling from that data suggests that children would have lower thresholds; extrapolating from Chatterjee et al. (1986) and Chan et al. (2013), the lowest threshold in children would be expected to be within the range of 10 mA. The upper frequency of contact current capable of causing harm is also not known. Although the ICNIRP (1998) guidelines specified reference levels to account for contact currents from 100 kHz to 110 MHz, Chatterjee et al. (1986) only tested up to 10 MHz, and Tell and Tell (2018) reported strong reductions in contact current sensitivities from about 1 MHz to 28 MHz (and did not assess higher frequencies). Thus, it is not clear that contact currents will remain a health hazard across the entire 100 kHz to 110 MHz range.

In determining the likelihood and nature of hazard due to potential contact current scenarios, ICNIRP views the above information as important for the responsible person in managing risk associated with contact currents within the frequency range 100 kHz to 110 MHz. This may also assist in conducting a risk-benefit analysis associated with allowing a person into a radiofrequency EMF environment that may result in contact currents. The above information suggests that risk of contact current hazards can be minimized by training workers to avoid contact with conducting objects, but that where contact is required, the following factors are important. Large metallic objects should be connected to ground (grounding); workers should make contact via insulating materials (e.g., radiofrequency protective gloves); and workers should be made aware of the risks, including the possibility of "surprise," which may impact on safety in ways other than the direct impact of the current on tissue (for example, by causing accidents).

Risk Mitigation Considerations for Occupational Exposure

To justify radiofrequency EMF exposure at the occupational level, an appropriate health and safety program is required. Part of such a program requires an understanding of the potential effects of radiofrequency EMF exposure, including consideration of whether biological effects resulting from the exposure may add to other biological effects that are unrelated to radiofrequency EMF. For example, where body core temperature is already elevated due to factors unrelated to EMF, such as through strenuous activity, radiofrequency EMF-induced temperature rise needs to be considered in conjunction with the other sources of heating. Similarly, it is also important to consider whether a person has an illness or condition that might affect their capacity to thermoregulate, or whether environmental impediments to heat dissipation might be present.

The relevant health effects that the whole-body SAR restrictions protect against are increased cardiovascular load (due to the work that the cardiovascular system must perform in order to restrict body core temperature rise), and where temperature rise is not restricted to a safe level, a cascade of functional changes that may lead to both reversible and irreversible effects on tissues (including brain, heart, and kidney). These effects typically require body core temperatures greater than 40°C (or an increase of approximately 3°C relative to normothermia). Large reduction factors have thus been used to make it extremely unlikely that radiofrequency-induced temperature rise would exceed 1°C (occupational restrictions have been set that would, under normothermic conditions, lead to body core temperature rises of <0.1°C), but care must be exercised when other factors are present that may affect body core temperature. These include high environmental temperatures, high physical activity, and impediments to normal thermoregulation (such as the use of thermally insulating clothing or certain medical conditions). Where significant heat is expected from other sources, it is advised that workers have a suitable means of verifying their body core temperature (see ACGIH 2017 for further guidance).

The relevant health effects that the localized basic restrictions protect against are pain and thermally-mediated tissue damage. Within Type-1 tissue, such as in the skin and limbs, pain (due to stimulation of nociceptors) and tissue damage (due to denaturation of proteins) typically require temperatures above approximately 41°C. Occupational exposure of the Limbs is unlikely to increase local temperature by more than 2.5°C, and given that Limb temperatures are normally below 31–36°C, it is unlikely that radiofrequency EMF exposure of Limb tissue, in itself, would result in either pain or tissue damage. Within Type-2 tissue, such as within regions of the Head and Torso (excluding superficial tissue), harm is also unlikely to occur at temperatures below 41°C. As occupational exposure of the Head and Torso tissue is unlikely to increase temperature by more than 1°C, and given that body core temperature is normally around 37–38°C, it is unlikely that radiofrequency EMF exposure would lead to temperature rises sufficient to harm Type-2 tissue or tissue function.

However, care must be exercised when a worker is subject to other heat sources that may add to that of the radiofrequency EMF exposure, such as those described above in relation to body core temperature. For superficial exposure scenarios, local thermal discomfort and pain can be important indicators of potential thermal tissue damage. It is thus important, particularly in situations where other thermal stressors are present, that the worker understands that radiofrequency EMF exposure can contribute to their thermal load and is in a position to take appropriate action to mitigate potential harm.

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APPENDIX A: BACKGROUND DOSIMETRY

Introduction

This appendix provides additional dosimetry information that is directly relevant to the derivation of the radiofrequency exposure restrictions that form the basis of the present guidelines. As described in the main document, the operational adverse health effects resulting from the lowest radiofrequency exposure levels are due to heating (nerve stimulation is discussed within the low frequency guidelines; ICNIRP 2010). Accordingly, this appendix details the choice of quantities used to restrict temperature rise to the operational adverse health effect thresholds described in the main document, the methods used to derive these restrictions (including, where relevant, the associated uncertainty), the spatial and temporal averaging methods used to represent temperature rise, and the derivation of the basic restrictions and reference levels themselves (including, where relevant, the associated uncertainty). The operational adverse health effect thresholds considered are 1°C body core temperature rise for exposures averaged over the whole body, and 5°C and 2°C local temperature rise over more-localized regions for "Type-1" and "Type-2" body tissue, respectively.[7]

QUANTITIES AND UNITS

Detailed explanations for the basic quantities, e.g., **E**, **H**, I, T, and *t* are found elsewhere (see ICNIRP 1985, 2009a, 2009, 2010). In this section, the other quantities used in the guidelines are detailed (i.e., SAR, SA, S_{inc}, S_{ab}, S_{eq}, U_{inc}, U_{ab}, and U_{eq}). Vector quantities are presented in **bold** font.

It is noted that radiofrequency basic restrictions and reference levels are based on the lowest radiofrequency exposure levels that may cause an adverse health effect. Since the health effects are related to the temperature rises caused by the exposure, it is determined by energy or power of the radiofrequency exposure. Therefore, squared values of **E**, **H**, and I are considered for time or spatial integration, or where summation of multiple frequencies is applied. The following equation is an example of the spatial average of **E** over a volume *V*:

$$E_{spatial\_average} = \sqrt{\frac{1}{V}\int_v |\mathbf{E}|^2 dv}, \qquad (8)$$

where V is the volume of the integration ($V = \int_v dv$).

Specific Energy Absorption Rate (SAR) and Specific Energy Absorption (SA)

SAR is defined as the time derivative of the incremental energy consumption by heat, δW, absorbed by or dissipated in an incremental mass, δm, contained in a volume element, δV, of a given mass density of the tissue (kg m^{-3}), ρ, and is expressed in watt per kilogram (W kg^{-1}):

$$\text{SAR} = \frac{\delta}{\delta t}\left(\frac{\delta W}{\delta m}\right) = \frac{\delta}{\delta t}\left(\frac{\delta W}{\rho \delta V}\right). \qquad (9)$$

Dielectric properties of biological tissues or organs are generally considered as dielectric lossy material and magnetically transparent because the relative magnetic permeability (μ_r) is 1. Therefore, the SAR is usually derived from the following equation:

$$\text{SAR} = \frac{\sigma |\mathbf{E}|^2}{\rho}, \qquad (10)$$

where σ is the conductivity (S m^{-1}) and **E** is the internal electric-field (root mean square (rms) value).

Temperature rise is strongly correlated with SAR. Under conditions where heat loss due to processes such as conduction is not significant, SAR and temperature rise are directly related as follows;

$$\text{SAR} = C\frac{dT}{dt}, \qquad (11)$$

where C is specific heat capacity (J kg^{-1} °C^{-1}) of the tissue, T is temperature (°C) and t is the duration of exposure (s). For most realistic cases, a large amount of heat energy rapidly diffuses during the exposure. Therefore, eqn (11) cannot be routinely applied to human exposure scenarios. However, eqn (11) is useful for brief exposure scenarios where heat loss is not significant.

SAR is used as a basic restriction in the present guidelines. The SAR basic restrictions are defined as spatially averaged values; that is, whole-body average SAR and SAR_{10g}. The whole-body average SAR is the total power absorbed in the whole body divided by the body mass:

$$\text{Whole-body average SAR} = \frac{(Total\ power)_{WB}}{(Total\ mass)_{WB}} = \frac{\left[\int_{WB}\sigma|\mathbf{E}|^2 dv\right]_{WB}}{\int_{WB}\rho dv}. \qquad (12)$$

SAR_{10g} is defined as the total power absorbed in a 10-g cubic volume divided by 10 g (see the "Spatial averaging considerations" section):

$$\text{SAR}_{10g} = \frac{(Total\ power)_{V_{10g}}}{(Total\ mass)_{V_{10g}}} = \frac{\left[\int_{V_{10g}}\sigma|\mathbf{E}|^2 dv\right]_{V_{10g}}}{\int_{V_{10g}}\rho dv}. \qquad (13)$$

A 10-g volume (V_{10g}) is approximately computed as a 2.15 cm × 2.15 cm × 2.15 cm cube, based on the assumption that the tissue has the same mass density as water, or 1,000 kg m^{-3}.

SA (J m^{-3}) is derived as the time integral of SAR during the time from t_1 to t_2:

[7]Type-1 tissue refers to all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue. Type-2 tissue refers to all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue.

$$SA = \int_{t_1}^{t_2} SAR(t)dt. \quad (14)$$

Absorbed Power Density (S_{ab}) and Absorbed Energy Density (U_{ab})

SAR_{10g} is no longer an appropriate surrogate for local temperature rise at frequencies above 6 GHz. Therefore, the absorbed power and energy densities are introduced in the guidelines for basic restrictions at such frequencies, where the radiofrequency power or energy absorption is largely confined within very superficial regions of the body. For example, the penetration depths are approximately 8.1 mm and 0.23 mm at 6 GHz and 300 GHz, respectively (see also Table 10). The absorbed power density (W m^{-2}) is defined at the body surface:

$$S_{ab} = \iint_A dxdy \int_0^{Z_{max}} \rho(x,y,z) \cdot SAR(x,y,z)\, dz/A, \quad (15)$$

where the body surface is at $z = 0$, A is the averaging area (in m^2), and Z_{max} is depth of the body at the corresponding region; where Z_{max} is much larger than the penetration depth, infinity can be substituted for Z_{max}. Considering heat diffusion, a square 2 cm × 2 cm region (from 6 to 300 GHz) is used for the averaging area of the absorbed power and energy density basic restrictions.

A more rigorous formula for absorbed power density is based on the Poynting vector (**S**):

$$S_{ab} = \iint_A Re[\mathbf{S}] \cdot \boldsymbol{ds}/A = \iint_A Re[\mathbf{E} \times \mathbf{H}^*] \cdot \boldsymbol{ds}/A, \quad (16)$$

where Re[X] and X* are the real part and the complex conjugate of a complex value "X," respectively, and ***ds*** is the integral variable vector with its direction normal to the integral area A on the body surface.

Similar to the relationship between SAR and SA, the absorbed energy density is derived as the temporal integration of the absorbed power density (J m^{-2}):

$$U_{ab} = \int_{t_1}^{t_2} S_{ab}(t)dt. \quad (17)$$

Incident Power Density (S_{inc}) and Incident Energy Density (U_{inc})

The incident power and energy densities are used as reference levels in the guidelines. The incident power density is defined as the modulus of the complex Poynting vector:

$$S_{inc} = |\mathbf{E} \times \mathbf{H}^*|. \quad (18)$$

In the case of the far-field or transverse electromagnetic (TEM) plane wave, the incident power density is derived as:

$$S_{inc} = \frac{|\mathbf{E}|^2}{Z_0} = Z_0|\mathbf{H}|^2, \quad (19)$$

where Z_0 is the characteristic impedance of free space, i.e., 377 Ω. The above equation is also used for the evaluation of the plane wave equivalent incident power density (S_{eq}).

S_{inc} is also related to S_{ab} using the reflection coefficient Γ:

$$S_{ab} = \left(1 - |\Gamma|^2\right) S_{inc}. \quad (20)$$

The reflection coefficient (Γ) is derived from the dielectric properties of the tissues, shape of the body surface, incident angle, and polarization.

Similar to the relationship between SAR and SA, the incident energy density is derived as the temporal integration of the incident power density during the time from t_1 to t_2:

$$U_{inc} = \int_{t_1}^{t_2} S_{inc}(t)\, dt. \quad (21)$$

In near-field exposure scenarios, the components of the Poynting vector are not real values but complex ones. In such cases a detailed investigation of the Poynting vector components may be necessary to calculate the incident power density relevant to radiofrequency safety.

RELEVANT BIOPHYSICAL MECHANISMS

Whole-Body Average Exposure Specifications

Relevant quantity. Health effects due to whole-body exposure are related to body core temperature rise. It is, however, difficult to predict body core temperature rise based on exposure of the human body to radiofrequency EMFs.

Body core temperature depends on the whole-body thermal energy balance. Radiofrequency energy absorbed by the body is transferred to the body core via blood flow, which can activate thermoregulatory responses to maintain the body core temperature (Adair and Black 2003). This means that the time rate of the energy balance is essential for the body core temperature dynamics. Accordingly, whole-body average SAR is used as the physical quantity relating to body core temperature rise.

The relationship between the total energy absorption and the body core temperature is in general independent of frequency. However, at frequencies higher than a few GHz, core temperature does not generally elevate as much as with the same level of whole-body average SAR at lower frequencies because of larger heat transfer from the body surface to air via convection or radiative emission, which

Table 10. Penetration depth of human skin tissue (dermis), for frequencies 6 to 300 GHz.

Frequency (GHz)	Relative permittivity	Conductivity (S/m)	Penetration depth (mm)
6	36	4.0	8.1
10	33	7.9	3.9
30	18	27	0.92
60	10	40	0.49
100	7.3	46	0.35
300	5.0	55	0.23

includes the effect of vasodilation in the skin (Hirata et al. 2013). The power absorption is confined primarily within skin surface tissues where localized temperature rise is more significant than the body core temperature rise (Laakso and Hirata 2011). However, it has also been reported that infrared radiation (IR) exposure can cause significant body core temperature rise (Brockow et al. 2007). Infrared radiation refers to electromagnetic waves with frequencies between those of radiofrequency EMF and visible light. This means that despite the penetration depth of infrared radiation being very small or comparable to the high GHz radiofrequency EMFs (or millimeter waves) it is still possible for infrared radiation exposure to raise body core temperature significantly. For conservative reasons, therefore, ICNIRP set equal whole-body average limits for frequencies both above and below 6 GHz. This is especially important for cases of multiple-frequency exposure of both higher and lower frequencies. Thus, the applicable frequency is defined as the entire frequency range considered in the guidelines.

Temporal averaging considerations. The definition of the time constant for body core temperature is not clear. However, under simplified conditions that produce a reasonable estimate of the time constant (e.g., assuming a first order lag), temperature dynamics can be described as follows:

$$T(t) = T_0 + (T_\infty - T_0)\left(1 - e^{\frac{-t}{\tau}}\right), \quad (22)$$

where T is the temperature as a function of time t, T_0 and T_∞ are the initial and steady-state temperatures, respectively, and τ is the time constant. In this case, the time constant corresponds to the time taken for 63% of the temperature rise, from initial temperature to steady state temperature, to be reached. In the present guidelines, the time to reach a steady-state of 80–90% of the equilibrium temperature, from the initial temperature, is considered for guideline setting; this is almost two times the time constant in eqn (22).

Further, the time needed to reach the steady-state body core temperature depends on the level of heat load, which in this case relates to the whole-body average SAR. Hirata et al. (2007) numerically simulated the body core temperature rise of a naked body exposed to a plane wave at 65 MHz and 2 GHz, and reported that in both cases it takes at least 60 min to reach a 1°C body core temperature rise for whole-body average SARs of 6 to 8 W kg^{-1}. This time is also dependent on the sweating rate, with strong sweating increasing this time by 40–100 min (Hirata et al. 2008; Nelson et al. 2013). Consequently, the time to reach the steady state temperature rise due to whole-body exposure to radiofrequency EMFs below 6 GHz is 30 min or longer.

As described above, power absorption is mainly confined within the surface tissues at frequencies above 6 GHz (see Table 10). Thermoregulatory responses are thus initiated by the skin temperature rise rather than body core temperature rise. However, the time needed for the steady state temperature rise is not significantly affected by this, and so is not taken into account. It is thus reasonable to keep the averaging time above 6 GHz the same as that below 6 GHz, because there is no quantitative investigation on the time constant of body core temperature rise above 6 GHz.

Whole-body average SAR needed to raise body core temperature by 1°C. Thermoregulatory functions are activated if a human body is exposed to significant heating load, which often results in non-linear relations between whole-body average SAR and body core temperature rise.

Adair and colleagues have experimentally investigated body core temperature (via esophageal temperature measurement) during whole-body exposure. They have reported no or minor increases of the esophageal temperature (<0.1°C) during the whole-body exposure at 100 MHz, 220 MHz, and 2450 MHz, with whole-body average SAR ranging from 0.54 to 1 W kg^{-1} in normal ambient temperature conditions, from 24°C to 28°C (Adair et al. 2001, 2003, 2005).

They also reported a relatively high body core temperature rise (0.35°C) for whole-body average SAR at 220 MHz of 0.675 W kg^{-1} in a hot ambient temperature (31°C) condition, although this was found in only one person and the mean of the body core temperature rises (6 persons) was not appreciable. There is no data on body core temperature rise for whole-body exposure to radiofrequency EMFs above 6 GHz. The only available data are on infrared radiation (Brockow et al. 2007). The conservativeness for whole-body exposure at higher frequencies is discussed in the main text.

There are two main factors affecting body core temperature rise due to radiofrequency exposure: sweating and mass-to-body surface ratio.

Evaporative heat loss due to sweating reduces body core temperature efficiently and needs to be accounted for when estimating body core temperature rise due to EMF. For example, Hirata et al. (2007) reported that 4.5 W kg^{-1} is required to increase the body core temperature by 1°C for a person with a lower sweat rate, such as an elderly person, while 6 W kg^{-1} is required for a person with a normal sweat rate. The decline of sweat rate in elderly people is primarily due to degradation of thermal sensation (Dufour and Candas, 2007).

Similarly, heat exchange between the body surface and external air is also very important. Hirata et al. (2009) found that the steady-state body core temperature rise due to whole-body radiofrequency EMF exposure is proportional to the ratio of the (whole-body) power absorption to the surface area of the body. The ratio of the mass to the surface area is smaller for smaller-dimension bodies such as children, and so greater whole-body average SAR is required to elevate their body core temperature.

This coincides with the finding that smaller persons have a lower body core temperature rise for the same whole-body average SAR. For example, Hirata et al. (2008) numerically evaluated the body core temperature rise in 8-months-old and 3-years-old child models and found that their body core temperature rises were 35% smaller than that of an adult female model for the same whole-body average SAR. They concluded that the higher ratio of a child's surface area to body mass is the reason for more effective cooling resulting from heat loss to the environment. Consequently, the body core temperature rise in the child is smaller than that of the adult at the same whole-body average SAR.

Addressing the issue more broadly, theoretical modeling and generalization from experimental research across a range of species has shown that within the 100 kHz to 6 GHz range, whole-body average SARs of at least 6 W kg^{-1}, for exposures of at least 1 h at moderately high ambient temperature (28°C), are necessary to increase body core temperature by 1°C for healthy adults and children (Hirata et al. 2013), and at least 4.5 W for those with lower sweat rates, such as the elderly (Hirata et al. 2007).

Considerations for fetal exposure. The primary thermoregulatory mechanism for a fetus is body core heat exchange with the mother via blood flow through the umbilical cord. The fetal temperature is therefore tightly controlled by maternal temperature, and it takes longer to reach thermal equilibrium than in adults (Gowland and De Wilde 2008). The body core temperature of the fetus is typically 0.5°C higher than that of the mother (Asakura 2004). This relationship is not changed significantly by radiofrequency EMF exposure of the mother at 26 weeks gestation, as reported by Hirata et al. (2014). In the frequency range from 40 MHz to 500 MHz, they computed steady-state fetal temperature, taking the thermal exchange between mother and fetus into account, and reported that the fetal temperature rise was only 30% higher than that of the mother, even when the power absorption was focused around the fetus. At lower frequencies, the SAR distribution becomes more homogeneous because of the longer wavelength and penetration depth, which results in more homogeneous temperature rise over the whole-body of the mother and fetus. At higher frequencies, the SAR distribution becomes more superficial because of the shorter penetration depth. This results in a smaller SAR of the young fetus or embryo, as it is generally located in the deep region of the abdomen of the mother, as well as resulting in a smaller whole-body SAR of the older fetus because the size of the fetus is larger than the penetration depth. This suggests that EMF whole-body exposure to the mother will result in a similar body core temperature rise in the fetus relative to that of the mother, even at frequencies outside those investigated in that study.

It follows that an EMF-induced body core temperature rise within the mother will result in a similar rise within the fetus, and thus an exposure at the occupational whole-body average SAR basic restriction would result in a similar body core temperature rise in mother and fetus. Therefore, to maintain fetal temperature to the level required by the general public, a pregnant woman is considered a member of the general public in terms of the whole-body average SAR basic restriction.

ICNIRP's decision on the occupational whole-body average SAR for pregnant women is significantly conservative compared with the established teratogenic fetal temperature threshold (2°C: Edwards et al. 2003; Ziskin and Morrissey 2011). ICNIRP also recognizes that the body core temperature of the fetus, especially during early stage one or embryonic development, is not clearly defined, and that there is no direct evidence that occupational whole-body exposure of the pregnant worker will harm the fetus. It is thus acknowledged that the decision to treat a pregnant worker as a member of the general public is conservative. ICNIRP also notes that there are some mitigating techniques that can be considered in order to allow pregnant workers to enter areas where radiofrequency EMFs are at occupational exposure levels, without exceeding the general public restrictions. For example, within a 30-min averaging interval, a pregnant worker could be within an area at the occupational exposure restriction level for 6 min, providing that the SAR averaged over 30 min (which includes this 6-min interval) does not exceed the general public restrictions. In considering such mitigating techniques, local region exposure restrictions for the pregnant worker are also important, and are described in the "Considerations for fetal exposure" in "Exposure Specifications for Local Regions (100 kHz to 6 GHz)" and in "Exposure Specifications for Local Regions (>6 GHz to 300 GHz)" sections.

Exposure Specifications for Local Regions (100 kHz to 6 GHz)

Relevant quantity. For cases of exposure to radiofrequency EMF over localized body regions, temperature can rise in part of the body without altering body core temperature. Local temperature rise must therefore also be restricted. The maximum local temperature rise generally appears on the surface of the body, and local SAR is a useful surrogate for local temperature rise due to localized radiofrequency EMF exposure. However, other factors, such as clothing, environmental conditions, and physiological states can have more impact on local temperature than SAR itself.

The transition frequency between local SAR and area-averaged absorbed power density is chosen as 6 GHz (Funahashi et al. 2018). This was done as a practical compromise suitable for the conditions relevant to the spatial and temporal averaging described in the following subsections, because no optimal single frequency exists for this transition. For frequencies lower than the transition frequency, the SAR is a metric for simultaneously protecting both the internal tissues (e.g., brain) and the skin, as explained in the "Spatial averaging considerations" section. At higher frequencies (especially above 10 GHz), the absorbed power density is a surrogate for maximum skin temperature rise.

Spatial averaging considerations. Different averaging schemes (e.g., cubic, spherical, contiguous single tissue) and masses have been assessed in terms of their ability to predict local temperature rise (Hirata and Fujiwara 2009; McIntosh and Anderson 2011). These suggest that the effect of the size of the averaging mass is more crucial than the shape of the averaging volume, and that SAR varies with different averaging schemes by a factor of approximately 2 (Hirata et al. 2006). It has also been shown that SAR averaged over a single tissue provides somewhat worse correlation with local temperature than that for multiple tissues, because the heat generated in biological tissue can diffuse up to a few centimeters (i.e., across multiple tissue types). Consequently, a cubic averaging mass of 10 g, including all tissues, is used as an appropriate spatial averaging regime for frequencies up to 6 GHz. This metric has been shown to be applicable even for plane wave exposures, in that local temperature rise in the Head and Torso, and Limbs, is correlated with SAR when this averaging mass is used (Razmadze et al. 2009; Bakker et al. 2011; Hirata et al. 2013).

Temporal averaging considerations. Time to reach steady-state temperature, given the balance between rate of radiofrequency power deposition on one hand, and heat diffusion and conduction on the other, is characterized by the time constant of temperature rise. The time constant primarily depends on heat convection due to blood flow and thermal conduction. Van Leeuwen et al. (1999), Wang and Fujiwara (1999), and Bernardi et al. (2000) report that the time needed for 80–90% of the steady-state temperature rise, at 800 MHz to 1.9 GHz, is 12–16 min. These guidelines take 6 min as a suitable, conservative averaging time for steady-state temperature rise up to 6 GHz for local exposures.

Local SAR required to increase local Type-1 and Type-2 tissue temperature by 5 and 2°C, respectively. Although early research provided useful rabbit eye data concerning the relation between 2.45 GHz exposure and local temperature rise (e.g., Guy et al. 1975; Emery et al. 1975), research with more accurate techniques has demonstrated that the rabbit is an inappropriate model for the human eye (Oizumi et al. 2013). However, given the concern about potential radiofrequency harm to the eye, there are now several studies that provide more-accurate information about radiofrequency-induced heating of the human eye. Expressed as heating factors for the SAR averaged over 10 g of tissue (the °C rise per unit mass, per W of absorbed power), the computed heating factors of a human eye have been relatively consistent [0.11–0.16°C kg W^{-1}: Hirata (2005); Buccella et al. (2007); Flyckt et al. (2007); Hirata et al. (2007); Wainwright (2007); Laakso (2009); Diao et al. (2016)]. In most studies, the heating factor was derived for the SAR averaged over the eyeball (contiguous tissue). The SAR averaged over the cubic volume (which includes other tissues) is higher than that value (Diao et al. 2016), resulting in lower heating factors.

There is also a considerable number of studies on the temperature rise in the head exposed to mobile phone handset antennas (Van Leeuwen et al. 1999; Wang and Fujiwara 1999; Bernardi et al. 2000; Gandhi et al. 2001; Hirata and Shiozawa 2003; Ibrahim et al. 2005; Samaras et al. 2007). Hirata and Shiozawa (2003) reported that heating factors are 0.24 or 0.14°C kg W^{-1} for the local SAR averaged over a 10-g contiguous volume, with and without the pinna, respectively. Other studies considering the local SAR averaged over a 10-g cubic volume including the pinna reported heating factors of the head in the range of 0.11–0.27°C kg W^{-1} (Van Leeuwen et al. 1999; Bernardi et al. 2000; Gandhi et al. 2001). Fujimoto et al. (2006) studied the temperature rise in a child head exposed to a dipole antenna and found that it is comparable to that in the adult when the same thermal parameters were used. The heating factor in the brain (the ratio of the temperature rise in the brain to peak SAR in the head) is 0.1°C kg W^{-1} or smaller (Morimoto et al. 2016). Only one study reported the temperature rise in the trunk for body-worn antennas (Hirata et al. 2006). This study showed that the heating factor in the skin is in the range of 0.18–0.26 °C kg W^{-1}. Uncertainty factors associated with the heating factors are attributable to the energy absorbed in the pinna (for mobile phones) and other surrounding structures (for example, see Foster et al. 2018) as well as the method for spatial averaging of SAR.

Those studies are consistent with research showing that, within the 100 kHz–6 GHz range, numerical estimations converge to show that the maximum heating factor is lower than 0.25°C kg W^{-1} in the skin and 0.1°C kg W^{-1} in the brain for exposures of at least approximately 30 min. Based on these heating factors, the operational adverse health effect thresholds for the eye and brain (Type 1) and for the skin (Type 2) will not be exceeded for local SARs of up to 20 W kg^{-1}.

Considerations for fetal exposure. Local SAR heating factors for the fetus, as a function of gestation stage and fetal posture and position, have been determined that take heat exchange between mother and fetus into account (Akimoto et al. 2010; Tateno et al. 2014; Takei et al. 2018). This research used numerical models of 13-week, 18-week, and 26-week pregnant women. The heating factors of the fetus were several times lower than those of the mother in most cases. However, the largest heating factor was observed when the fetal body position is very close to the surface of the abdomen (i.e., middle and later stages of gestation). These provide 0.1°C kg W^{-1} as a conservative heating factor for the fetus.

Based on these findings, exposure of the mother at the occupational basic restriction of 10 W kg^{-1} will result in a temperature rise in the fetus of approximately 1°C, which is lower than the operational adverse health effect threshold for the Head and Torso, but results in a smaller reduction factor (i.e., 2) than that considered appropriate for the general public (i.e., 10). It follows that a localized occupational radiofrequency EMF exposure of the mother would cause the temperature to rise in the fetus to a level higher than that deemed acceptable for the general public. Therefore, to maintain fetal temperature to the level required by the general public local SAR restrictions, a pregnant woman is considered a member of the general public in terms of the local SAR restriction.

It is noted that the above-mentioned case appears only in the middle and late pregnancy stages (18 to 26-week gestation), while the heating factor of the fetus in the early pregnancy stage (12-week gestation) is at most 0.02°C kg W^{-1} (Tateno et al. 2014; Takei et al. 2018). This 12-week gestation fetal temperature rise is 100 times lower than the threshold (2°C) for teratogenic effects in animals (Edwards et al. 2003; Ziskin and Morrissey 2011).

Exposure Specifications for Local Regions (>6 GHz to 300 GHz)

Relevant quantity. In a human body exposed to radiofrequency EMF, an electromagnetic wave exponentially decays from the surface to deeper regions. This phenomenon is characterized according to penetration depth, as described below:

$$S_{ab} = PD_0 \int_0^{Z_{max}} e^{-\frac{2z}{\delta}}\, dz, \qquad (23)$$

where S_{ab} is the absorbed power density, the body surface is at $z = 0$, δ is the penetration depth from the body surface in the z direction (defined as the distance from the surface where 86% of the radiofrequency power is absorbed), and Z_{max} is depth of the body at the corresponding region; where Z_{max} is much larger than the penetration depth, infinity can be substituted for Z_{max}. PD_0 is the specific absorbed power averaged over the area A at $z = 0$, as described below:

$$PD_0 = \iint_A \rho(x, y, 0) \cdot SAR(x, y, 0)\, dxdy/A. \qquad (24)$$

The penetration depth depends on the dielectric properties of the medium, as well as frequency. As frequency increases, the penetration depth decreases, and is predominantly within the surface tissues at frequencies higher than about 6 GHz. Table 10 lists the penetration depths based on the dielectric properties of skin tissue (dermis) measured by Sasaki et al. (2017) and Sasaki et al. (2014).

As a result, the local SAR averaged over a 10-g cubical mass with side lengths of 2.15 cm is no longer a good proxy for local temperature rise; that is, the power deposition is limited to within a few millimeters of the surface tissues. Conversely, the power density absorbed in the skin provides a better approximation of the superficial temperature rise from 6 GHz to 300 GHz (Foster et al. 2016; Funahashi et al. 2018).

Spatial averaging considerations. Thermal modeling (Hashimoto et al. 2017) and analytical solutions (Foster et al. 2016) suggest that a square averaging area of 4 cm^2 or smaller provides a close approximation to local maximum temperature rise due to radiofrequency heating at frequencies greater than 6 GHz. This is supported by computations for realistic exposure scenarios (He et al. 2018). An important advantage of the 4-cm^2 averaging area is the consistency at 6 GHz between local SAR and absorbed power density; the face of an averaging 10-g cube of SAR is approximately 4 cm^2.

Because the beam area can usually only be focused to the size of the wavelength, the averaging area of the absorbed power density relevant to the temperature rise depends on frequency; smaller averaging areas are necessary as frequency increases. Therefore, a smaller averaging area is sometimes necessary for extremely focused beams at higher frequencies. An additional criterion is therefore imposed for frequencies above 30 GHz for the spatial peak (maximum) absorbed power density averaged over 1 cm^2, such that it must not exceed 2 times the value for the averaging area of 4 cm^2 (Foster et al. 2016).

Temporal averaging considerations. As well as the cases of localized exposure at frequencies lower than 6 GHz, the temperature rise due to localized exposure to radiofrequency EMF over 6 GHz also achieves an equilibrium state with a particular time constant. Morimoto et al. (2017) demonstrated that the same averaging time as the local SAR (6 min) is appropriate for localized exposure from 6 GHz to 300 GHz. The time needed for steady-state local temperature rise decreases gradually as frequency increases, but no notable change is observed at frequencies higher than 15 GHz (Morimoto et al. 2017). The time needed to reach 80–90% of the maximum temperature rise is approximately 5–10 min at 6 GHz and 3–6 min at 30 GHz. However, it is noted that the time constant becomes shorter if brief or irregular exposure is considered, which is discussed in the "Brief Exposure Specifications for Local Regions (>6 GHz to 300 GHz)" section. In the present guidelines, 6 min is chosen as the averaging time, with additional restrictions for briefer or irregular exposures subjected to additional constraints as a conservative measure.

Absorbed power density required to increase local Type-1 tissue temperature by 5°C. Above 6 GHz, power absorption is primarily restricted to superficial tissue and cannot result in tissue temperatures that exceed operational adverse health effect thresholds for Type-2 tissues without also exceeding those for the more superficial Type-1 tissues (e.g., Morimoto et al. 2016). Therefore, exposure level must be chosen to ensure that temperature rise in the more superficial Type-1 tissue does not exceed the operational threshold of 5°C.

Tissue heating, as a function of absorbed power density over 6 GHz, is dependent on a variety of factors, as it is for lower frequencies. A comprehensive investigation of the heating factors for absorbed power density [in terms of the temperature rise (°C) over a unit area (m^2), per W of absorbed power] has been conducted in the case of a plane wave incident to a multi-layered slab model as an extreme uniform exposure condition (Sasaki et al. 2017). In that study, Monte Carlo statistical estimation of the heating factor was conducted where it was shown that the maximum heating factor for absorbed power density is 0.025°C m^2 W^{-1}. This value is more conservative (larger) than results from other studies on the temperature rise in the skin (Alekseev et al. 2005; Foster et al. 2016; Hashimoto et al. 2017) and the eye (Bernardi et al. 1998; Karampatzakis and Samaras 2013). Thus, to increase temperature by 5°C requires an absorbed power density of 200 W m^{-2}.

Considerations for fetal exposure. As discussed in the "Considerations for fetal exposure" of the "Exposure Specifications for Local Regions (100 kHz to 6 GHz)" section in relation to the frequency characteristics of the SAR distribution, the contribution of surface heating due to radiofrequency EMF exposure above 6 GHz to fetal temperature rise is likely very small (and smaller than that from below 6 GHz). This suggests that the fetus will not receive appreciable heating from localized exposure above 6 GHz. However, there is currently no study that has assessed this. ICNIRP thus takes a conservative approach for exposures above 6 GHz and requires that the pregnant worker is treated as a member of the general public in order to ensure that the fetus will not be exposed above the general public basic restrictions.

Brief exposure specifications for local regions (100 kHz to 6 GHz)

The 6-min averaging scheme for localized exposure allows greater strength of the local SAR if the exposure duration is shorter than the averaging time. However, if the exposure duration is significantly shorter, heat diffusion mechanisms are inadequate to restrict temperature rise. This means that the 6-min averaged basic restriction can temporarily cause higher temperature rise than the operational adverse health effect thresholds if the exposure period is shorter than 6 min.

A numerical modeling investigation for brief exposure to radiofrequency EMF from 100 MHz to 6 GHz, using a multi-layer model and an anatomical head model, found that the SA corresponding to the allowable temperature rise is greatly variable depending on a range of factors (Kodera et al. 2018). Based on that study and empirical equations of the SA corresponding to the operational adverse health effect threshold for the skin (5°C), the exposure corresponding to this temperature rise is derived from the following equations for Head and Torso:

$$\mathrm{SA}(t) = 7.2\left(0.05 + 0.95\sqrt{t/360}\right)\ \left(\mathrm{kJ\ kg^{-1}}\right), \quad (25)$$

where t is time in seconds and applicable for t<360, and SA (t) is spatially averaged over any 10-g cubic tissue, considering the continuity of the SAR at 6 min. The averaging procedure of SA is in the same manner as SAR in eqn (13). For Limbs, the following equation should be satisfied:

$$\mathrm{SA}(t) = 14.4\left(0.025 + 0.975\sqrt{t/360}\right)\ \left(\mathrm{kJ\ kg^{-1}}\right). \quad (26)$$

It is noted that the above logic results in slightly different time functions for brief exposure below and above 6 GHz; the resultant time functions below 6 GHz are more conservative than for above 6 GHz (i.e., eqns 27 and 28).

The numerical modeling study by Kodera et al. (2018) also shows that the temperature rise in Type-2 tissue (e.g., brain) is also kept below 1°C by the SA restriction defined in eqn (25). They furthermore reported that the SA corresponding to the allowable temperature rise increases as frequency decreases. At 400 MHz or lower, the SA derived from the local 6-min SAR basic restriction [10 (W kg^{-1}) × 360 (s) = 3.6 (kJ kg^{-1})] does not cause the temperature rise corresponding to the operational adverse health effect threshold for the Head and Torso to be exceeded. Accordingly, this SA limit is only required for exposures above 400 MHz.

It should be noted that eqns (25) and (26) must be met for all intervals up to 6 min, regardless of the particular pulse or non-pulsed continuous wave patterns. That is, exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t seconds, must not exceed that specified in eqns (25) to (26), as exposure to a part of the exposure pattern can be more critical than exposure to a single pulse or the exposure averaged over t. For example, if two 1-s pulses are separated by 1 s, the levels provided by eqns (25) and (26) must be satisfied for each of the 1-s pulses as well as for the total 3-s interval.

The above discussion on brain temperature rise suggests that the temperature rise in the fetus will also be lower than that assumed for the steady-state (6-min) exposure. That is, as the Type-2 tissue temperature rise will be kept below the operational adverse health effect threshold by applying eqn (25), this will presumably also be the case for temperature rises for the fetus due to brief exposures. However, there is no study available that has considered the effect of brief exposure of pregnant women up to the occupational limit on the fetus. ICNIRP thus maintains the same conservative policy for <6-min exposure as for >6-min exposure (see "Considerations for fetal exposure of Exposure Specifications for Local Regions (100 kHz to 6 GHz)" section), and requires the pregnant worker to be subject to the general public restrictions.

Brief Exposure Specifications for Local Regions (>6 GHz to 300 GHz)

Similar to the situation for frequencies up to 6 GHz, temperature rise can be enhanced for intense short pulses or discontinuous exposures above 6 GHz, relative to a continuous exposure with the same absorbed power density averaged over a 6-min interval. This becomes significant at frequencies higher than 30 GHz (Foster et al. 2016). Considering the robustness and consistency of simple multi-layer models, the basic restrictions for the brief exposures are derived based on investigations using simple models (Foster et al. 2016; Morimoto et al. 2017). Unlike continuous wave exposure, the effect of diffraction, or interference of waves reflected from protruding parts of the body back to the skin, may be apparent for brief pulses. Although the effect of diffraction to the absorbed power density is yet to be fully determined, the resultant temperature rise is estimated to be up to 3 times higher if pulsed than that due to the same absorbed power density spread evenly over a 6-min interval (Laakso et al. 2017).

Considering these factors, absorbed energy density basic restrictions (U_{ab}) have been set as a function of the square root of the time interval, to account for heterogeneity of temperature rise (Foster et al. 2016). These have been set to match the operational adverse health effect threshold for Type 1 tissue, as well as to match the absorbed energy density derived from the absorbed power density basic restriction for 360 s. As per the brief interval exposure limits for frequencies up to 6 GHz, the superficial nature of the resultant temperature rise will not result in temperatures that exceed Type-2 tissue operational adverse health effect thresholds, and so only the Type-1 tissue threshold of 5°C needs to be considered here.

Consequently, an extension of the formula from Kodera et al. (2018) for frequencies up to 6 GHz, specifies the maximum absorbed energy density level for brief exposures corresponding to the 5°C temperature rise as follows:

$$U_{ab}(t) = 72\left(0.05 + 0.95\sqrt{t/360}\right)\ \left(\text{kJ m}^{-2}\right) \quad \text{averaged over } 2\text{ cm} \times 2\text{ cm}, \tag{27}$$

where t is the time interval in seconds and is applicable for t<360s. Above 30 GHz, an additional criterion is given for 1 cm × 1 cm averaging areas, such that absorbed energy density must not exceed the value specified in eqn (28):

$$U_{ab}(t) = 144\left(0.025 + 0.975\sqrt{t/360}\right)\ \left(\text{kJ m}^{-2}\right) \quad \text{averaged over } 1\text{ cm} \times 1\text{ cm}. \tag{28}$$

It should be noted that eqns (27) and (28) must both be met for all intervals up to 6 min, regardless of the particular pulse or non-pulsed continuous wave patterns. That is, exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in t seconds, must not exceed that specified in eqns (27) and (28), as exposure to a part of the exposure pattern can be more critical than exposure to a single pulse or the exposure averaged over t. For example, if two 1-s pulses are separated by 1 s, the levels provided by eqns (27) and (28) must be satisfied for each of the 1-s pulses, as well as for the total 3-s interval.

As discussed above, in relation to the frequency characteristics of the SAR distribution, the contribution of the surface heating due to radiofrequency EMF above 6 GHz to fetal temperature rise is likely smaller than that below 6 GHz. This is the same for cases of brief exposure. However, as there is no study on the fetus relating to exposure of a pregnant woman to radiofrequency EMF above 6 GHz, ICNIRP adopts a conservative approach and treats a pregnant worker as a member of the general public to ensure that the fetal exposure will not exceed that of the general public.

DERIVATION OF REFERENCE LEVELS

General Considerations for Reference Levels

As described in the main guidelines document, the reference levels have been derived as a practical means of assessing compliance with the present guidelines. The reference levels for **E**-field strength, **H**-field strength and incident power density have been derived from dosimetric studies assuming whole-body exposure to a uniform field distribution, which is generally the worst-case scenario. Due to the strongly conservative nature of the reference levels in most exposure scenarios, reference levels may often be exceeded without exceeding the corresponding basic restrictions, but this should always be verified to determine compliance.

Different reference level application rules have been set for exposure in the far-field, radiative near-field and reactive near-field zones. The intention of ICNIRP's distinction between these zones is to provide assurance that the reference levels are generally more conservative than the basic restrictions. In so far as the distinction between the zones is concerned, the principle (but not only) determinant of this is the degree to which a field approximates plane wave conditions. A difficulty with this approach is that other factors may also affect the adequacy of estimating reference level quantities from basic restriction quantities. These include the EMF frequency, physical dimensions of the EMF source and its distance from the resultant external EMFs assessed, as well as the degree to which the EMFs vary over the space to be occupied by a person. Taking into account such sources of uncertainty, the guidelines have more conservative rules for exposure in the reactive and radiative near-field than far-field zone. This makes it difficult to specify whether, for the purpose of compliance, an exposure should be considered reactive near-field, radiative near-field or far-field without consideration of a range of factors that cannot be easily specified in advance. As a rough guide, distances $> 2D^2/\lambda$ (m), between $\lambda/(2\pi)$ and $2D^2/\lambda$ (m), and $< \lambda/(2\pi)$ (m) from an antenna correspond approximately to the far-field, radiative near-field and reactive near-field, respectively, where D and λ refer to the longest dimension of the antenna and wavelength, respectively, in meters. However, it is anticipated that input from technical standards bodies should be utilized to better determine which of the far-field/near-field zone reference level rules should be applied so as to provide appropriate concordance between reference levels and basic restrictions.

E-Field and H-Field Reference Levels up to 30 MHz

In the ICNIRP (1998) guidelines, the reference levels in this frequency region were derived from the whole-body average SAR for whole-body exposure to plane waves. However, Taguchi et al. (2018) demonstrated that whole-body exposure to the decoupled **H**-field results in a whole-body average SAR significantly lower than that calculated for the whole-body exposure to plane-waves with the same **H**-field strength. The whole-body exposure to the decoupled **E**-field was also calculated and it was found that the whole-body average SARs are almost the same as those for the plane wave with the same direction and strength as the **E**-field. The reference levels relevant to the whole-body average SAR basic restrictions below 30 MHz in these guidelines are therefore based on the numerical calculations of the whole-body average SAR for the whole-body exposure to the decoupled uniform **E**-field and **H**-field, separately. Taguchi et al. (2018) also concluded that local SAR basic restrictions, including in the ankle, will also be satisfied when the whole-body SAR basic restrictions are satisfied. This means that compliance with the whole-body average reference levels in this frequency region will result in exposures that do not exceed the whole-body average and local SAR basic restrictions.

In the low frequency guidelines (ICNIRP 2010) where reference levels for frequencies up to 10 MHz are set to protect against nerve cell stimulations, a reduction factor of 3 was applied to account for uncertainty associated with the numerical modeling of the relation between the external fields and the induced (internal) electric fields. The reason for this is that 2-mm cube-averaged values (within a specific tissue) were evaluated in the low frequency guidelines, which are significantly affected by computational artifact.

In the present guidelines, however, the uncertainty of the numerical simulation is not significant because the spatial averaging procedure applied in evaluating the whole-body average and local SAR significantly decreases the uncertainty of the computational artifact. Therefore, additional reduction factors due to computational uncertainty do not need to be considered in deriving the reference levels relevant to the local and whole-body average SAR basic restrictions below 30 MHz in these guidelines.

E-Field, H-Field and Power Density Reference Levels From >30 MHz to 6 GHz

The ICNIRP (1998) whole-body average SAR for exposure to a field strength equal to the reference level becomes close to the basic restrictions around the whole-body resonant frequency (30–200 MHz) and post resonant frequency region (1,500–4,000 MHz).

The resonance frequency appears at a frequency where half of the wavelength in free space is close to the height (vertical dimension of a person standing) of the human body in free space, or where a quarter of the wavelength in free space is close to the height of a human body standing on the ground plane (Durney et al. 1986), resulting in higher whole-body average SARs. Whole-body resonance appears only for the case of vertically polarized plane wave incidence. If different polarizations are assumed, the resultant whole-body average SAR is significantly (a few orders of magnitude) lower than that of the case of the vertical polarization around the whole-body resonant frequency (Durney et al. 1986). Whole-body resonance has been confirmed by numerical computations (Dimbylow 1997; Nagaoka et al. 2004; Dimbylow 2005; Conil et al. 2008; Kühn et al. 2009; Hirata et al. 2010).

Above the whole-body resonant frequency, especially above a few GHz, the differences in the whole-body average SARs due to polarization are not significant compared with those at the whole-body resonant frequency. Hirata et al. (2009) reported that the whole-body average SAR in child models from 9 months to 7 years old, exposed to horizontally polarized plane wave incidence, is only slightly higher (up to 20%) than the vertically polarized plane wave at frequencies from 2 GHz to 6 GHz. A similar tendency has been reported in other studies (Vermeeren et al. 2008; Kühn et al. 2009).

ICNIRP had concluded that, given the same external field, the child whole-body average SAR can be 40% higher than those of adults (ICNIRP 2009). After that ICNIRP statement, Bakker et al. (2010) reported similar (but slightly higher) enhancements (45%) of the child whole-body average SAR. The effects of age dependence of dielectric properties of the tissues and organs have also been investigated, but no significant effect relevant to whole-body average SAR has been found (Lee and Choi 2012). It is noted that the increased whole-body average SARs have been reported from calculations using very thin child models, which were scaled from adult, and very young (infant) models. Those studies assumed that the child or infant maintains their posture for a substantial time interval so as to match an extreme case condition, in order for their whole-body SAR to exceed the basic restriction. Further, a more recent study using child models that have used the standard dimensions specified by the International Commission on Radiological Protection (ICRP), rather than scaled versions of adults, showed that the increases of the whole-body average SARs in the standard child models are not significant (at most 16%; Nagaoka et al. 2019). Similarly, the relation between whole-body average SAR and whole-body mass has been investigated and it has been found that the whole-body average SAR in low body mass index (BMI) adults can increase in a similar manner to the case of the child (Hirata et al. 2010, 2012; Lee and Choi 2012).

As discussed in the "Considerations for fetal exposure" of the "Whole-body Average Exposure Specifications" section, the temperature of the fetus is similar to the body core temperature of the mother. The whole-body average SAR, which is used to restrict body core temperature rise, is defined as the power absorption in the whole body divided by the whole-body mass. Therefore, the whole-body average SAR of a pregnant woman, whose mass is larger, is generally the same as, or lower than, that of a non-pregnant woman in this frequency region. Nagaoka et al. (2007) reported that the whole-body average SAR of a 26-week pregnant woman model exposed to the vertically polarized plane wave from 10 MHz to 2 GHz was almost the same as, or lower than, the non-pregnant woman model for the same exposure condition.

Dimbylow (2007) reported that, using a simplified pregnant woman model, the whole-body average SAR in both the fetus and mother is highest for ungrounded conditions, at approximately 70 MHz. A similar tendency was found for anatomical fetus models of second and third trimester conditions, with the whole-body average SARs in a fetus of 20, 26, and 29 week gestation periods approximately 80%, 70%, and 60% of those in the mother, respectively (Nagaoka et al. 2014). The whole-body average SARs of the fetus, while still embryonic, are comparable to or lower than the whole-body average SARs in the mother, because the embryo is located deep within the abdomen of the mother (Kawai et al. 2009). The pregnant woman is therefore not considered independently from the fetus in terms of reference levels and is subject to the general public restrictions.

As described above, there are numerous databases relevant to whole-body average SAR for whole-body exposure in this frequency region. These include a considerable number reported since the ICNIRP (1998) guidelines, which are generally consistent with the database used as the basis for the ICNIRP (1998) guidelines. ICNIRP uses a combination of the older and newer databases to derive the reference levels, taking into account some incongruences discussed below.

Since publishing the ICNIRP (1998) guidelines it has been shown that the whole-body average SAR basic restrictions can be exceeded for exposure levels at the reference level for children or small stature people. As reviewed above, the whole-body average SAR is exceeded by no more than 45%, and only for very specific child models, and more recent modeling using realistic, international standardized child models shows only a modest increase of 16% at most (Nagaoka et al. 2019). This deviation is comparable with the uncertainty expected in the numerical calculations. For example, Dimbylow et al. (2008) reported that differences in the procedure or algorithm used for the whole-body averaging results in 15% variation of the whole-body average SARs at 3 GHz, and that the assignment of the dielectric properties of the skin conditions (dry or wet) reported also results in 10% variation in the whole-body average SARs at 1.8 GHz (Gabriel et al. 1996).

As reviewed in the "Considerations for fetal exposure" of the "Whole-body Average Exposure Specifications" section, the heating factor of children is generally lower than that of adults. It follows that the increased SAR will not result in a larger temperature rise than is allowed for adults, and so will not affect health. Given the magnitude of uncertainty and the lack of health benefit in reducing the reference levels to account for small stature people, this has not resulted in ICNIRP altering the reference levels in the frequency range >30 MHz to 6 GHz.

It is also noted that there are other conditions where the whole-body average reference levels can result in whole-body average SARs that exceed the basic restrictions by up to 35%. This occurs in human models with unusual postures that would be difficult to maintain for a sufficient duration in order to cause the elevated SAR (Findlay and

Dimbylow 2005; Findlay et al. 2009). However, the elevated SAR is small compared with the associated uncertainties and the conservative nature of the basic restrictions themselves, the postures are not likely to be routinely encountered, and there is no evidence that this will result in any adverse health effects.

Reference Levels From >6 GHz to 300 GHz for Whole-Body Exposure

Above 6 GHz, radiofrequency EMFs generally follow the characteristics of plane wave or far-field exposure conditions; incident power density or equivalent incident power density is used as the reference level in this frequency region. The reactive near-field exists very close to a radiofrequency source in this frequency region. The typical boundary of the reactive near-field and the radiative near-field is defined as $\lambda/(2\pi)$ (e.g., 8 mm at 6 GHz). Because the incident power density used for the reference levels above 6 GHz does not appropriately correlate with the absorbed power density used for the basic restrictions in the reactive near-field region, reference levels cannot be used to determine compliance in the reactive near field; basic restrictions need to be assessed for such cases.

The radiofrequency power absorbed in the body exponentially decays in the direction from the surface to deeper regions (see eqn 23). Therefore, the power absorption is primarily confined within the body surface above 6 GHz, where the total power absorption or the whole-body average SAR is approximately proportional to the exposed area of the body surface (Hirata et al. 2007; Gosselin et al. 2009; Kühn et al. 2009; Uusitupa et al. 2010). For example, an experimental study using a reverberation chamber found a strong correlation between the whole-body average SAR and the surface area of a human body from 1 GHz to 12 GHz (Flintoft et al. 2014).

Because the whole-body average SAR is approximately proportional to the incident power density and body surface area (and is not dependent on EMF frequency), ICNIRP has extended the whole-body reference levels from below 6 GHz, up to 300 GHz. ICNIRP (1998) set whole-body reference levels within this range (up to 10 GHz) at 50 W m^{-2} and 10 W m^{-2} (for occupational and general public exposure, respectively). As there is no evidence that these levels will result in exposures that exceed the whole-body basic restrictions above 6 GHz, or that they will cause harm, these guidelines retain the ICNIRP (1998) reference levels for whole-body exposure conditions.

The same time and spatial average for the whole-body average SAR basic restrictions are applied to these corresponding reference levels. Therefore, the incident power density is to be temporally averaged over 30 min and spatially averaged over the space to be occupied by a human body (whole-body space).

Reference Levels From >6 GHz to 300 GHz for Local Exposure

The incident power density (S_{inc}) reference levels above 6 GHz for local exposure can be derived from the basic restrictions (i.e., from absorbed power density, S_{ab}):

$$S_{inc} = S_{ab} T^{-1} \left(\mathrm{W\ m^{-2}}\right), \tag{29}$$

where T is Transmittance, defined as follows:

$$\text{Transmittance} = 1 - |\Gamma|^2. \tag{30}$$

The reflection coefficient Γ is derived from the dielectric properties of the tissues, shape of the body surface, incident angle and polarization. For transverse electric (TE)-wave incidence, the angle corresponding to the maximum transmittance is the angle normal to the body surface, whereas for transverse magnetic (TM)-wave incidence this occurs at the Brewster angle (the angle of incidence at which there is no reflection of the TM wave). Furthermore, for cases of oblique incidence of the radiofrequency EMF wave, Li et al. (2019) have shown that the incident power and energy densities of TE waves, averaged over the body or boundary surface, overestimate the absorbed power and energy densities, while the absorbed power and energy densities of TM-waves around the Brewster angle approach the incident power and energy densities. They also found that normal incidence is always the worst case scenario regarding temperature rise (Li et al. 2019).

In the present guidelines, the basic restrictions and reference levels are derived from investigations assuming normal incidence to the multi-layered human model. As this represents worst-case modeling for most cases, the results obtained and used in these guidelines will generally be conservative.

The variation and uncertainty of the transmittance for the normal-angle incident condition have been investigated (Sasaki et al. 2017). The transmittance asymptotically increases from 0.4 to 0.8 as the frequency increases from 10 GHz to 300 GHz. Similar tendencies have also been reported elsewhere (Kanezaki et al. 2009; Foster et al. 2016; Hashimoto et al. 2017).

Considering the frequency characteristics of the transmittance, the reference levels for local exposure have been derived as exponential functions of the frequency linking 200 W m^{-2} at 6 GHz to 100 W m^{-2} at 300 GHz (for occupational exposure). The same method is applied for the derivation of reference levels for the general public. For the same reasons given in the "Reference Levels from >6 GHz to 300 GHz for Whole-body Exposure" section, reference levels cannot be used to determine compliance in the reactive near field; basic restrictions need to be assessed for such cases.

The temporal and spatial characteristics are almost the same for incident power density and absorbed power density at the body surface for the scale considered in the basic restrictions, i.e., 6 min, and either 4 cm^2 or 1 cm^2 (an additional criteria above 30 GHz). Therefore, the same averaging conditions are applied to the incident power density reference levels, as for the absorbed power density basic restrictions.

Limb Current Reference Levels

Limb current is defined as the current flowing through the limbs, such as through an ankle or wrist. High local SAR can appear in these parts of the body because of their anatomical composition. The volume ratio of the high conductivity tissues to the low conductivity tissues is small in the ankle and wrist, resulting in the current concentrating into high conductivity tissues such as muscle, and thus greater SAR. This phenomenon is particularly pronounced for cases of a human body standing on the ground plane in a whole-body resonant condition.

The local SAR in limbs (ankle and wrist) is strongly correlated with the current flowing through the limbs. Although the local SAR is generally difficult to measure directly, the limb SAR can be derived from the limb current (I), which can be relatively easily measured, as follows:

$$\mathrm{SAR} = \frac{\sigma \mathrm{E}^2}{\rho} = \frac{\mathrm{J}^2}{\sigma\rho} = \frac{\mathrm{I}^2}{\sigma\rho A^2}, \qquad (31)$$

where J and A are the current density and effective section area, respectively.

The limb current reference levels are therefore set in order to evaluate the local SAR in the ankle and wrist, especially around the ankle in a grounded human body for the whole-body resonant condition. As the frequency increases above the whole-body resonant frequency for the grounded condition, the efficiency of the localization within the limbs gradually decreases. Thus, at higher frequencies, the maximum local SAR does not generally appear around limbs, and is thus not relevant.

Dimbylow (2002) showed that a limb current of 1 A at 10 MHz to 80 MHz causes 530 W kg^{-1} to 970 W kg^{-1} of local SAR averaged over 10 g in the ankles of an adult male model standing on a grounded plane. It is noted that the shape of the averaging region of the 10-g tissue was not cubic, but contiguous, which results in higher SAR values than those of a cube. Based on that study, ICNIRP sets the limb current reference levels at 100 mA and 45 mA for occupational and general public exposures, respectively, to conservatively ensure compliance with the local SAR basic restrictions in the limbs (e.g., the maximum local SAR in the limbs for a 100 mA current would only be 10 W kg^{-1}). Taguchi et al. (2018) confirmed this relation between SAR and ankle current from 10 MHz to 100 MHz in different anatomical models.

Similarly, Dimbylow (2001) computed the 10-g local SAR (with contiguous tissue) for a 100-mA wrist current, which resulted in 27 W kg^{-1} at 100 kHz, decreasing to 13 W kg^{-1} at 10 MHz. Considering the reduction of SAR for the cubic compared to contiguous shape, the 100-mA limb current at the wrist will also conservatively ensure compliance with the local SAR basic restrictions in the wrist. Based on this, ICNIRP has revised the lower frequency range to 100 kHz, from 10 MHz in ICNIRP (1998).

As shown in eqn (31), the local SAR is proportional to the squared value of the limb current. In eqn (31), however, the effective area is a constant to relate the limb current to the 10-g averaged local SAR and depends on not only the actual section area but also tissue distribution/ratio and conductivity. Because the conductivity asymptotically increases as the frequency increases from 100 kHz to 110 MHz, the relationship between local SAR and limb current is not constant across this frequency range. For example, Dimbylow (2002) demonstrated that the local SAR due to a constant limb current halved as frequency increased from 10 MHz to 80 MHz. This suggests that the upper frequency limit for limb current reference levels could potentially be lowered, relative to the upper limit of the 10 MHz to 110 MHz range of ICNIRP (1998). However, due to the lack of research addressing this issue, ICNIRP has kept the same upper frequency range as in ICNIRP (1998).

Because the limb current reference levels are relevant to the local SAR basic restrictions, the same temporal averaging is applied (i.e., 6 min). Further, as the squared value of the limb current is proportional to the local SAR, the squared value of the limb current must be used for time averaging (as described in the "Quantities and Units" section). Note that temperature rise for exposures of less than 6 min is only of concern for frequencies above 400 MHz, which is higher than the upper frequency limit for limb currents. Limb current reference levels are therefore not required for exposures of less than 6 min.

Reference Levels for Brief Exposure (<6 min)

The reference levels for brief exposure are derived to match the brief exposure basic restrictions, which have been set in terms of SA and absorbed energy density, up to and above 6 GHz, respectively.

The reference levels have been derived from numerical computations with the multi-layered human model exposed to a plane wave, or to typical sources used close to the body, such as a dipole antenna.

The reference levels vary as a function of time interval to match the absorbed energy density basic restrictions (above 6 GHz), with a similar function used below 6 GHz to match the SA basic restrictions. It is noted that the time function of the absorbed energy density basic restrictions and corresponding incident energy density reference levels are more conservative than those for the SA basic restrictions and corresponding incident energy density reference levels. This means that the reference levels are more conservative above than below 6 GHz.

Because the reference levels are based on the multilayered model, the uncertainty included in the dosimetry is not significant. Conversely, this simple modeling is likely overly conservative for a realistic human body shape and structure. This overestimation decreases as the frequency increases because the penetration depth is short relative to the body-part dimensions. Morphological variations are also not significant.

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APPENDIX B: HEALTH RISK ASSESSMENT LITERATURE

Introduction

The World Health Organization (WHO) has undertaken an in-depth review of the literature on radiofrequency electromagnetic fields (EMFs) and health, which was released as a Public Consultation Environmental Health Criteria Document in 2014. This independent review is the most comprehensive and thorough appraisal of the adverse effects of radiofrequency EMFs on health. Further, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), a European Commission initiative, also produced a report on potential health effects of exposure to electromagnetic fields (SCENIHR 2015), and the Swedish Radiation Safety Authority (SSM) have produced several international reports regarding this issue (SSM 2015, 2016, 2018). Accordingly, the present guidelines have used these literature reviews as the basis for the health risk assessment associated with exposure to radiofrequency EMFs rather than providing another review of the individual studies. However, for completeness, ICNIRP considered more recent research published after the reviews from WHO, SCENIHR and SSM in the development of the current guidelines (cut-off date September 1st, 2019). The discussion of ICNIRP's appraisal of the radiofrequency health literature below provides a brief overview of the literature, a limited number of examples to help explain the overview, and the conclusions reached by ICNIRP.

The summary of the research on biological and health effects of radiofrequency EMFs presented below considers effects on body systems, processes or specific diseases. This research feeds into the determination of thresholds for adverse human health effects. Research domains considered are experimental tests on cells, animals and humans, and human observational studies assessing relationships between radiofrequency EMFs and a range of potentially health-related outcomes. The experimental studies have the advantages of being able to control a large number of potential confounders and to manipulate radiofrequency EMF exposure. However, they are also limited in terms of making comparisons to realistic exposure environments, employing exposure durations sufficient to assess many disease processes, and, in the case of in vitro and animal research, relating the results to humans can also be difficult. Epidemiological research more closely relates to actual health within the community, but it is mostly observational and, thus, depending on the type of studies, various types of error and bias are of concern. These include confounding, selection bias, information bias, reverse causality, and exposure misclassification; in general, prospective cohort studies are least affected by bias but large sample sizes are needed for rare diseases. Therefore, it is important to consider research across a range of study types in order to arrive at useful conclusions concerning the relation between radiofrequency EMF exposure and adverse health effects.

It is important to note that ICNIRP bases its guidelines on substantiated[8] adverse health effects. This makes the difference between a biological and an adverse health effect an important distinction, where only adverse health effects require restrictions for the protection of humans. Research on the health effects of radiofrequency EMFs has tended to concentrate on a few areas of particular interest and concern, with some other areas receiving little or no attention. There is not sufficient research addressing potential relations between radiofrequency EMFs and the skeletal, muscular, respiratory, digestive, and excretory systems, and so these are not considered further. This review considers the potential for different types of radiofrequency EMF exposure to adversely affect health, including sinusoidal (e.g., continuous wave) and non-sinusoidal (e.g., pulsed) EMFs, and both acute and chronic exposures.

BRAIN PHYSIOLOGY AND FUNCTION

Brain Electrical Activity and Cognitive Performance

Human research addressing higher cognitive function has primarily been conducted within the ICNIRP (1998) basic restriction values. This has mainly been assessed via performance measures and derivations of the electroencephalogram (EEG) and cerebral blood flow (CBF) measures (sensitive measures of brain electrical activity and blood flow/metabolism, respectively). Most double-blind human experimental studies on cognitive performance, CBF or event-related potential (a derivative of the EEG) measures of cognitive function, did not report an association with radiofrequency EMF exposure. A number of sporadic findings have been reported, but these do not show a consistent or meaningful pattern. This may be a result of the large number of statistical comparisons and occasional chance findings. There are therefore no substantiated reports of radiofrequency EMFs adversely affecting performance, CBF, or event-related potential measures of cognitive function. Studies analyzing frequency components of the EEG have reliably shown that the 8–13 Hz alpha band in waking EEG and the 10–14 Hz "sleep spindle" frequency range in sleep EEG, are affected by radiofrequency EMF exposure with specific energy absorption rates (SAR) <2 W kg^{-1}, but there is no evidence that these relate to adverse health effects (e.g., Loughran et al. 2012).

Both rodents and non-human primates have shown a decrease in food-reinforced memory performance with exposures to radiofrequency EMFs at a whole-body average SAR >5 W kg^{-1} for rats, and a whole-body average SAR >4 W kg^{-1} for non-human primates, exposures which correspond to increases in body core temperatures of approximately 1°C. However, there is no indication that these changes were due to reduced cognitive ability, rather than the normal temperature-induced reduction of motivation (hunger). Such changes in motivation are considered normal and reversible thermoregulatory responses, and do not in themselves represent adverse health effects. Similarly, although not considered an adverse health effect, behavioral changes to reduce body temperature have also been observed in non-human primates at whole-body average SARs of 1 W kg^{-1}, with the threshold the same for acute, repeated exposures and for long-term exposures.

There is limited epidemiological research on higher cognitive function. There have been reports of subtle changes to performance measures with radiofrequency EMFs, but findings have been contradictory, as there is no evidence that the reported changes are related to radiofrequency EMF exposure and alternative explanations for observed effects are plausible.

In summary, there is no substantiated experimental or epidemiological evidence that exposure to radiofrequency EMFs affects higher cognitive functions relevant to health.

Symptoms and Wellbeing

There is research addressing the potential for radiofrequency EMFs to influence mood, behavior characteristics, and symptoms.

A number of human experimental studies testing for acute changes to wellbeing or symptoms are available, and these have failed to identify any substantiated effects of exposure. A small portion of the population attributes non-specific symptoms to various types of radiofrequency EMF exposure; this is referred to as Idiopathic Environmental Intolerance attributed to EMF (IEI-EMF). Double-blind experimental

[8]Further details concerning the term substantiated can be found in the main guidelines document.

studies have consistently failed to identify a relation between radiofrequency EMF exposure and such symptoms in the IEI-EMF population, as well as in healthy population samples. These experimental studies provide evidence that "belief about exposure" (e.g., the so-called "nocebo" effect), and not exposure itself, is the relevant symptom determinant (e.g., Eltiti et al. 2018; Verrender et al. 2018).

Epidemiological research has addressed potential long-term effects of radiofrequency EMF exposure from fixed-site transmitters and devices used close to the body on both symptoms and well-being, but with a few exceptions these are cross-sectional studies with self-reported information about symptoms and exposure. Selection bias, reporting bias, poor exposure assessment, and nocebo effects are of concern in these studies. In studies on transmitters, no consistent associations between exposure and symptoms or well-being have been observed when objective measurements of exposure were made or when exposure information was collected prospectively. In studies on mobile phone use, associations with symptoms and problematic behavior have been observed. However, these studies can generally not differentiate between potential effects from radiofrequency EMF exposure and other consequences of mobile phone use, such as sleep deprivation when using the mobile phone at night. Overall, the epidemiological research does not provide evidence of a causal effect of radiofrequency EMF exposure on symptoms or well-being.

However, there is evidence that radiofrequency EMFs, at sufficiently high levels, can cause pain. Walters et al. (2000) reported a pain threshold of 12.5 kW m^{-2} for 94 GHz, 3-s exposure to the back, which raised temperature from 34°C to 43.9°C (at a rate of 3.3°C per second). This absolute temperature threshold is consistent with Torbjork et al. (1984), who observed a median threshold for pain at 43°C, which was in compliance with simultaneously measured response thresholds of nociceptors (41°C and 43°C).

Another instance of pain induced by radiofrequency EMFs is due to *indirect* exposure via contact currents, where radiofrequency EMFs in the environment are redirected via a conducting object to a person, and the resultant current flow, dependent on frequency, can stimulate nerves, cause pain, and/or damage tissue. Induced current thresholds resulting from contact currents are very difficult to determine, with the best estimates of thresholds for health effects being for pain, which is approximately 10 and 20 mA for children and adults, respectively (extrapolated from Chatterjee et al. 1986).

In summary, no reports of adverse effects of radiofrequency EMF exposures on symptoms and wellbeing have been substantiated, except for pain, which is related to elevated temperature at high exposure levels (from both direct and indirect radiofrequency EMF exposure). Thresholds for direct effects on pain are in the vicinity of 12.5 kW m^{-2} for 94 GHz exposures to the back, which is consistent with thermal physiology knowledge. Thresholds for indirect effects (contact currents) are within the vicinity of 10 and 20 mA, for EMFs between 100 kHz and 110 MHz, for children and adults respectively.

Other Brain Physiology and Related Functions

A number of studies of potential adverse effects of radiofrequency EMFs on physiological functions that could adversely affect health have been conducted, primarily using in vitro techniques. These have included multiple cell lines and assessed functions such as intra- and intercellular signaling, membrane ion channel currents and input resistance, Ca^{2+} dynamics, signal transduction pathways, cytokine expression, biomarkers of neurodegeneration, heat shock proteins, and oxidative stress-related processes. There have been some reports of morphological changes to cells, but these have not been verified, and their relevance to health has also not been demonstrated. There have also been reports of radiofrequency EMFs inducing leakage of albumin across the blood-brain barrier in rats (e.g., Nittby et al., 2009), but due to methodological limitations of the studies and failed attempts to independently verify the results, there remains no evidence of an effect. Some studies also tested for effects of co-exposure of radiofrequency EMFs with known toxins, but there is currently no demonstration that this affects the above conclusions.

Intense pulsed low frequency electric fields (with radiofrequency components) can cause cell membranes to become permeable, allowing exchange of intra- and extra-cellular materials (Joshi and Schoenbach 2010); this is referred to as electroporation. Exposure to an unmodulated 18 GHz field has also been reported to cause a similar effect (Nguyen et al. 2017). Both exposures require very high field strengths [e.g., 10 kV m^{-1} (peak) in tissue in the case of low frequency electric fields, and 5 kW kg^{-1} at 18 GHz]. These levels have not been shown to adversely affect health in realistic exposure scenarios in humans and, given their very high thresholds, are protected against by restrictions based on effects with lower thresholds. Accordingly, electroporation is not discussed further.

In summary, there is no evidence of effects of radiofrequency EMFs on physiological processes that impair human health.

AUDITORY, VESTIBULAR, AND OCULAR FUNCTION

A number of animal and some human studies have tested for potential effects of radiofrequency EMFs on function and pathology of the auditory, vestibular, and ocular systems.

Sub-millisecond pulses of radiofrequency EMF can result in audible sound. Specifically, within the 200–3000

MHz EMF range, *microwave hearing* can result from brief (approximately 35–100 μs) radiofrequency pulses to the head, which cause thermoelastic expansion that is detected by sensory cells in the cochlea via the same processes involved in normal hearing. This phenomenon is perceived as a brief low-level noise, often described as a "click" or "buzzing." For example, Röschmann (1991) applied 10- and 20-μs pulses at 2.45 GHz that caused a specific energy absorption (SA) of 4.5 mJ kg^{-1} per pulse, and which was estimated to result in a temperature rise of approximately 0.00001°C per pulse. These pulses were barely audible, suggesting that this corresponded to a sound at the hearing threshold. Although higher intensity SA pulses may result in more pronounced effects, there is no evidence that microwave hearing in any realistic exposure scenarios can affect health, and so the present Guidelines do not provide a restriction to specifically account for microwave hearing.

Experimental and observational studies have also been conducted to test for adverse effects of EMF exposure from mobile phones. A few studies have investigated effects on auditory function and cellular structure in animal models. However, these results are inconsistent.

Beyond the behavioral and electrophysiological indices of sensory processing described above, a number of studies have tested for acute effects of radiofrequency EMF exposure on auditory, vestibular and ocular functioning in humans. These have largely been conducted using mobile phone-like signals at exposure levels below the ICNIRP (1998) basic restriction levels. Although there are some reports of effects, the results are highly variable with the larger and more methodologically rigorous studies failing to find such effects.

There is very little epidemiological research addressing sensory effects of devices that emit radiofrequency EMFs. The available research has focused on mobile phone use and does not provide evidence that this is associated with increased risk of tinnitus, hearing impairment, or vestibular or ocular function.

Animal studies have also reported that the heating that results from radiofrequency EMF exposure may lead to the formation of cataracts in rabbits. In order for this to occur, very high local SAR levels (100–140 W kg^{-1}) at low frequencies (< 6 GHz) are needed with temperature increases of several °C maintained for several hours. However, the rabbit model is more susceptible to cataract formation than in primates (with primates more relevant to human health), and cataracts have not been found in primates exposed to radiofrequency fields. No substantiated effects on other deep structures of the eye have been found (e.g., retina or iris). However, rabbits can be a good model for damage to superficial structures of the eye (e.g., the cornea) at higher frequencies (30–300 GHz). The baseline temperature of the cornea is relatively low compared with the posterior portion of the eye, and so very high exposure levels are required to cause harm superficially. For example, Kojima et al. (2018) reported that adverse health effects to the cornea can occur at incident power densities higher than 1.4 kW m^{-2} across frequencies from 40 to 95 GHz; no effects were found below 500 W m^{-2}. The authors concluded that the blink rates in humans (ranging from once every 3 to 10 s, as opposed to once every 5 to 20 min in rabbits) would preclude such effects in humans.

In summary, no reported effects on auditory, vestibular, or ocular function or pathology relevant to human health have been substantiated. Some evidence of superficial eye damage has been shown in rabbits at exposures of at least 1.4 kW m^{-2}, although the relevance of this to humans has not been demonstrated.

NEUROENDOCRINE SYSTEM

A small number of human studies have tested whether indices of endocrine system function are affected by radiofrequency EMF exposure. Several hormones, including melatonin, growth hormone, luteinizing hormone, cortisol, epinephrine, and norepinephrine have been assessed, but no consistent evidence of effects of exposure has been observed.

In animal studies, substantiated changes have only been reported from acute exposures with whole-body SARs in the order of 4 W kg^{-1}, which result in core temperature rises of 1°C or more. However, there is no evidence that this corresponds to an impact on health. Although there have been a few studies reporting field-dependent changes in some neuroendocrine measures, these have also not been substantiated. The literature, as a whole, reports that repeated, daily exposure to mobile phone signals does not impact on plasma levels of melatonin or on melatonin metabolism, oestrogen or testosterone, or on corticosterone or adrenocorticotropin in rodents under a variety of conditions.

Epidemiological studies on potential effects of exposure to radiofrequency EMFs on melatonin levels have reported conflicting results and suffer methodological limitations. For other hormonal endpoints, no epidemiological studies of sufficient scientific quality have been identified.

In summary, the lowest level at which an effect of radiofrequency EMFs on the neuroendocrine system has been observed is 4 W kg^{-1} (in rodents and primates), but there is no evidence that this translates to humans or is relevant to human health. No other reported effects have been substantiated.

NEURODEGENERATIVE DISEASES

No human experimental studies exist for adverse effects on neurodegenerative diseases.

Although it has been reported that exposure to pulsed radiofrequency EMFs increased neuronal death in rats, which could potentially contribute to an increased risk of neurodegenerative disease, other studies have failed to confirm these results. Some other effects have been reported (e.g., changes to neurotransmitter release in the cortex of the brain, protein expression in the hippocampus, and autophagy in the absence of apoptosis in neurons), but such changes have not been shown to lead to neurodegenerative disease. Other studies investigating effects on neurodegeneration are not informative due to methodological or other shortcomings.

A Danish epidemiological cohort study has investigated potential effects of mobile phone use on neurodegenerative disorders and reported reduced risk estimates for Alzheimer disease, vascular and other dementia, and Parkinson disease (Schüz et al. 2009). These findings are likely to be the result of reverse causation, as prodromal symptoms of the disease may prevent persons with early symptoms to start using a mobile phone. Results from studies on multiple sclerosis are inconsistent, with no effect observed among men, and a borderline increased risk in women, but with no consistent exposure-response pattern.

In summary, no adverse effects on neurodegenerative diseases have been substantiated.

CARDIOVASCULAR SYSTEM, AUTONOMIC NERVOUS SYSTEM, AND THERMOREGULATION

As described above, radiofrequency EMFs can induce heating in the body. Although humans have a very efficient thermoregulatory system, too much heating puts the cardiovascular system under stress and may lead to adverse health effects.

Numerous human studies have investigated indices of cardiovascular, autonomic nervous system, and thermoregulatory function, including measures of heart rate and heart rate variability, blood pressure, body, skin and finger temperatures, and skin conductance. Most studies indicate that there are no effects on endpoints regulated by the autonomic nervous system. The relatively few reported effects of exposure were small and would not have an impact on health. The reported changes were also inconsistent and may be due to methodological limitations or chance. With exposures at higher intensities, up to a whole-body SAR of about 1 W kg^{-1} (Adair et al. 2001), sweating and cardiovascular responses have been reported that are similar to that observed under increased heat load from other sources. The body core temperature increase was generally less than 0.2°C.

The situation is different for animal research, in that far higher exposure levels have been used, often to the point where thermoregulation is overwhelmed, and temperature increases to the point where death occurs. For example, Frei et al. (1995) exposed rats to 35 GHz fields at 13 W kg^{-1} whole-body exposure, which raised body core temperature by 8°C (to 45°C), resulting in death. Similarly, Jauchem and Frei (1997) exposed rats to 350 MHz fields at 13.2 W kg^{-1} whole-body exposure and reported that thermal breakdown (i.e., where the thermoregulatory system can no longer cope with the increased body core temperature) occurred at approximately 42°C. It is difficult to relate these animal findings directly to humans, as humans are more-efficient thermoregulators than rodents. Taberski et al. (2014) reported that in Djungarian hamsters no body core temperature elevation was seen after whole-body exposure to 900 MHz fields at 4 W kg^{-1} with the only detectable effect a reduction of food intake (which is consistent with reduced eating in humans when body core temperature is elevated).

Few epidemiological studies on cardiovascular, autonomic nervous system, or thermoregulation outcomes are available. Those that are have not demonstrated a link between radiofrequency EMF exposure and measures of cardiovascular health.

In summary, no effects on the cardiovascular system, autonomic nervous system, or thermoregulation that compromise human health have been substantiated for exposures with whole-body average SARs below approximately 4 W kg^{-1}, with harm only found in animals exposed to whole-body average SARs substantially higher than 4 W kg^{-1}.

IMMUNE SYSTEM AND HAEMATOLOGY

There have been inconsistent reports of transient changes in immune function and haematology following radiofrequency EMF exposures. These have primarily been from in vitro studies, although some animal studies have also been conducted. These reports have not been substantiated.

The few human studies that have been conducted have not provided any evidence that radiofrequency EMFs affect health in humans via the immune system or haematology.

FERTILITY, REPRODUCTION, AND CHILDHOOD DEVELOPMENT

There is very little human experimental research addressing possible effects of radiofrequency EMF exposure on reproduction and development. What is available has focused on hormones that are relevant to reproduction and development, and as described in the Neuroendocrine System section above, there is no evidence that they are affected by radiofrequency EMF exposure. Other research has addressed this issue by looking at different stages of development (for endpoints such as cognition and brain electrical activity), in order to determine whether there may be greater sensitivity to radiofrequency fields as a function of age. There is currently no evidence that developmental phase is relevant to this issue.

Numerous animal studies have shown that exposure to radiofrequency EMFs associated with a significant temperature increase can cause effects on reproduction and development. These include increased embryo and fetal losses, increased fetal malformations and anomalies, and reduced fetal weight at term. Such exposures can also cause a reduction in male fertility. However, extensive, well-performed studies have failed to identify developmental effects at whole-body average SAR levels up to 4 W kg^{-1}. In particular, a large four-generation study in mice on fertility and development using whole-body SAR levels up to 2.34 W kg^{-1} found no evidence of adverse effects (Sommer et al. 2009). Some studies have reported effects on male fertility at exposure levels below this value, but these studies have had methodological limitations and reported effects have not been substantiated.

Epidemiological studies have investigated various aspects of male and female infertility and pregnancy outcomes in relation to radiofrequency EMF exposure. Some epidemiological studies reported associations between radiofrequency EMFs and sperm quality or male infertility, but, taken together, the available studies do not provide evidence for an association with radiofrequency EMF exposure as they all suffer from limitations in study design or exposure assessment. A few epidemiological studies are available on maternal mobile phone use during pregnancy and potential effects on child neurodevelopment. There is no substantiated evidence that radiofrequency EMF exposure from maternal mobile phone use affects child cognitive or psychomotor development, or causes developmental milestone delays.

In summary, no adverse effects of radiofrequency EMF exposure on fertility, reproduction, or development relevant to human health have been substantiated.

CANCER

There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. This includes studies of cell proliferation, differentiation and apoptosis-related processes, proto-oncogene expression, genotoxicity, increased oxidative stress, and DNA strand breaks. Although there are reports of effects of radiofrequency EMFs on a number of these endpoints, there is no substantiated evidence of health-relevant effects (Vijayalaxmi and Prihoda 2019).

A few animal studies on the effect of radiofrequency EMF exposure on carcinogenesis have reported positive effects, but, in general, these studies either have shortcomings in methodology or dosimetry, or the results have not been verified in independent studies. Indeed, the great majority of studies have reported a lack of carcinogenic effects in a variety of animal models. A replication of a study in which exposure to radiofrequency EMFs increased the incidence of liver and lung tumors in an animal model with prenatal exposure to the carcinogen ENU (ethylnitrosourea) indicates a possible promoting effect (Lerchl et al. 2015; Tillmann et al. 2010). The lack of a dose-response relationship, as well as the use of an untested mouse model for liver and lung tumors whose relevance to humans is uncertain (Nesslany et al. 2015), makes interpretation of these results and their applicability to human health difficult, and, therefore, there is a need for further research to better understand these results.

Two recent animal studies investigating the carcinogenic potential of long-term exposure to radiofrequency EMFs associated with mobile phones and mobile phone base stations have also been released: one by the U.S. National Toxicology Program (NTP 2018a and b) and the other from the Ramazzini Institute (Falcioni et al. 2018). Although both studies used large numbers of animals, best laboratory practice, and exposed animals for the whole of their lives, they also have inconsistencies and important limitations that affect the usefulness of their results for setting exposure guidelines. Of particular importance is that the statistical methods employed were not sufficient to differentiate between radiofrequency-related and chance differences between treatment conditions; interpretation of the data is difficult due to the high body core temperature changes that resulted from the very high exposure levels used; and no consistency was seen across these two studies. Thus, when considered either in isolation (e.g., ICNIRP 2019) or within the context of other animal and human carcinogenicity research (HCN 2014, 2016), their findings do not provide evidence that radiofrequency EMFs are carcinogenic.

A large number of epidemiological studies of mobile phone use and cancer risk have also been performed. Most have focused on brain tumors, acoustic neuroma and parotid gland tumors, as these occur in close proximity to the typical exposure source from mobile phones (Röösli et al. 2019). However, some studies have also been conducted on other types of tumors, such as leukaemia, lymphoma, uveal melanoma, pituitary gland tumors, testicular cancer, and malignant melanoma. With a few exceptions, the studies have used a case-control design and have relied on retrospectively collected self-reported information about mobile phone use history. Only two cohort studies with prospective exposure information are available. Several studies have had follow-ups that were too short to allow assessment of a potential effect of long-term exposure, and results from case-control studies with longer follow-up are not consistent.

The large Interphone study, coordinated by the International Association for Research on Cancer, did not provide evidence of a raised risk of brain tumors, acoustic neuroma, or parotid gland tumors among regular mobile phone users, and the risk estimates did not increase with longer time since first mobile phone use (Interphone 2010, 2011). It should be noted that although somewhat elevated odds ratios were observed at the highest level of cumulative call time for acoustic neuroma and glioma, there were no trends observed for any of the lower cumulative call time groups, with among the lowest risk estimates in the penultimate exposure category. This, combined with the inherent recall bias of such studies, does not provide evidence of an increased risk. Similar results were observed in a Swedish case-control study of acoustic neuroma (Pettersson et al. 2014). Contrary to this, a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time. However, they are not consistent with trends in brain cancer incidence rates from a large number of countries or regions, which have not found any increase in the incidence since mobile phones were introduced.

Furthermore, no cohort studies (which unlike case-control studies are not affected by recall or selection bias) report a higher risk of glioma, meningioma, or acoustic neuroma among mobile phone subscribers or when estimating mobile phone use through prospectively collected questionnaires. Studies of other types of tumors have also not provided evidence of an increased tumor risk in relation to mobile phone use. Only one study is available on mobile phone use in children and brain tumor risk (Aydin et al. 2011). No increased risk of brain tumors was observed.

Studies of exposure to environmental radiofrequency EMFs, for example from radio and television transmitters, have not provided evidence of an increased cancer risk either in children or in adults. Studies of cancer in relation to occupational radiofrequency EMF exposure have suffered substantial methodological limitations and do not provide sufficient information for the assessment of carcinogenicity of radiofrequency EMFs. Taken together, the epidemiological studies do not provide evidence of a carcinogenic effect of radiofrequency EMF exposure at levels encountered in the general population.

In summary, no effects of radiofrequency EMFs on the induction or development of cancer have been substantiated.

SUMMARY

The only substantiated adverse health effects caused by exposure to radiofrequency EMFs are nerve stimulation, changes in the permeability of cell membranes, and effects due to temperature elevation. There is no evidence of adverse health effects at exposure levels below the restriction levels in the ICNIRP (1998) guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to radiofrequency EMF exposure below those restriction levels.

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■■

Subsecretaría de Telecomunicaciones

RESOLUCIÓN EXENTA N° 2312

REF.: ESTABLECE OBJETIVOS Y OTORGA NORMAS BÁSICAS DE FUNCIONAMIENTO PARA LA INSTANCIA DE COOPERACIÓN DENOMINADA OBSERVATORIO NACIONAL 5G./

Con esta fecha se ha resuelto lo siguiente

SANTIAGO, 09 DE DICIEMBRE DE 2020

VISTOS:

a) Los artículos 6 y 7 de la Constitución Política del Estado.
b) La ley N° 18.575, Orgánica Constitucional de Bases Generales de la Administración del Estado.
c) La ley N° 18.168 General de Telecomunicaciones.
d) La ley N° 19.799, sobre Documentos Electrónicos, firma electrónica y servicios de certificación de dicha firma.
e) El Decreto Ley N° 1.028 de 1975, que precisa las atribuciones y deberes de los Subsecretarios de Estado.
f) El Decreto Ley N°1.762 de 1977, que crea la Subsecretaría de Telecomunicaciones.
g) La resolución N° 7, de 2019, de la Contraloría General de la República, que fija normas sobre exención del trámite de toma de razón, y demás normativa aplicable.

CONSIDERANDO:

1. Que la quinta generación de redes inalámbricas de telecomunicaciones, conocidas como "redes 5G", constituyen un estándar tecnológico de avanzado diseño y desarrollo que introduce mejoras significativas al paradigma de las redes actualmente en uso, fundamentalmente debido a su gran capacidad, alta velocidad y baja latencia. Ello ha motivado a que diversos Estados se encuentren concursando o subastando frecuencias del espectro radioeléctrico para promover el despliegue oportuno de las redes 5G, con el fin de fomentar la innovación en los mercados, mejorar el rendimiento de la economía y profundizar la calidad de vida de las y los ciudadanos.

2. Que la implementación oportuna de la tecnología 5G en Chile ofrece la posibilidad de desarrollar aplicaciones y productos innovadores en diversos sectores de la industria y sociedad, así como también mejorar la experiencia del usuario que demanda servicios de conectividad digital de alta calidad.

3. Que el pasado 05 de diciembre de 2019, se instaló el Plan Social de Desarrollo Digital, liderado por la Subsecretaría de Telecomunicaciones -en colaboración con el Banco Interamericano Desarrollo en Chile quien participa como Secretario Técnico del mismo- en el cual participan diversas instituciones del sector público, privado, social, académico y del ámbito internacional, con el propósito de fortalecer la política de telecomunicaciones en materias de inclusión digital, innovación y adopción responsable de tecnologías emergentes como 5G.

4. Que para el cumplimiento de sus objetivos, el Plan Social de Desarrollo Digital cuenta con cuatro mesas técnicas, presididas cada una por una institución pública en colaboración con la Subsecretaría de Telecomunicaciones: (i) Inclusión digital, presidida por el Ministerio de Desarrollo Social y Familia; (ii) Innovación para la igualdad social y desarrollo productivo, presidida por la Corporación de Fomento de la Producción; (iii) Plan 5G, presidida por la Subsecretaría de Telecomunicaciones, y (iv) Ciberseguridad en 5G, presidida por el CSIRT Chile.

5. Que dada la relevancia sobre la innovación para el desarrollo social y productivo, y la adopción responsable de la tecnología 5G en Chile, se presentó a los integrantes del Plan Social de Desarrollo Digital el proyecto Observatorio Nacional 5G que sustituirá a la mesa (ii) de dicho Plan, con el objeto de identificar, desarrollar y documentar casos de usos basados en la tecnología 5G que permitan conocer y comunicar a la sociedad su impacto social, económico, técnico y regulatorio en Chile.

6. Que resulta relevante contar con un mecanismo de coordinación y cooperación entre instituciones públicas, sociales, privadas y académicas para generar sinergias en la investigación de la tecnología 5G, así como la identificación y desarrollo de casos de uso que nos permitan a nivel nacional identificar y comprender los retos y desafíos de esta tecnología;

7. Que, en atención a la necesidad de contar con capacidades de investigación, desarrollo e innovación, así como para los fines de vinculación con el medio, resulta de especial importancia la cooperación con entidades académicas para abordar el análisis de impacto productivo, económico y social de los casos de uso de la tecnología 5G.

8. Que con fecha 17 de agosto de 2020, se anunció la iniciativa denominada Campus 5G con el objetivo de que instituciones de investigación públicas y privadas realicen pruebas, estableciéndose como laboratorios de experimentación de procesos con la finalidad de que la información obtenida sirva para generar publicaciones técnicas sobre el alcance y oportunidades de la tecnología 5G a nivel nacional;

9. Que a través de la innovación en espacios controlados para el desarrollo de casos de uso es posible conocer y advertir los efectos positivos y negativos de la tecnología 5G, así como fomentar la cooperación entre instituciones públicas, privadas, sociales y académicas para generar investigación, conocimiento y desarrollo de la tecnología 5G en Chile.

RESUELVO:

Artículo Único.- Apruébese reglamento interno para la operación de la instancia de cooperación bajo la denominación Observatorio Nacional 5G.

Título I.
Disposiciones Generales

Artículo 1º. El presente reglamento interno de operación del Observatorio Nacional 5G del Ministerio de Transportes y Telecomunicaciones, a cargo de la Subsecretaría de Telecomunicaciones, tiene por objeto establecer los objetivos y las normas básicas de funcionamiento de dicha instancia.

Los objetivos principales del Observatorio Nacional 5G serán los siguientes:

a) Constituir una instancia de coordinación, cooperación e intercambio de conocimiento en materia de tecnologías 5G, que contemple: (i) el desarrollo de casos de uso en el sector público, privado, social y académico; (ii) el diseño de servicios digitales basados en la tecnología 5G a través de espacios controlados "*sandbox*" para identificar su impacto en la regulación y los servicios que se ofrecen a la población en general; (iii) contar con redes de innovación en 5G; (iv) facilitar a las instituciones la identificación de fondos nacionales e internacionales para el desarrollo e investigación de casos de uso, y (v) difundir los avances y conocimiento de Chile en torno a la tecnología 5G.

b) Identificar y desarrollar casos de uso basados en la tecnología 5G que nos permitan conocer su impacto social, económico, técnico y regulatorio en Chile.
c) Documentar casos de uso en materia de 5G con la finalidad de identificar y dar a conocer el impacto social, económico, industrial y tecnológico de esta tecnología en Chile.
d) Contribuir a la estandarización e innovación, así como para alinear estrategias y compartir el conocimiento existente en torno a la tecnología 5G.
e) Difundir publicaciones, investigaciones, capacitaciones y/o cualquier actividad de conocimiento sobre la tecnología 5G.

Artículo 2º. Para efectos del presente reglamento se entenderá por:

a) **Actividad de conocimiento:** cualquier actividad que realicen los integrantes del Observatorio Nacional 5G tales como, webinar, taller, diplomado, curso, evento, encuentro, entre otros.
b) **Casos de uso:** proyectos piloto desarrollados por los integrantes del Observatorio Nacional 5G para la investigación y conocimiento de la tecnología 5G en diversos sectores sociales, económicos e industriales, previa autorización para fines experimentales conforme a la legislación aplicable.
c) **Registro Nacional del Observatorio**: Base de datos de personas naturales y jurídicas adheridas al Observatorio Nacional 5G.
d) **Investigación:** cualquier proyecto y/o estudio que desarrollen los integrantes del Observatorio Nacional 5G en torno a la tecnología 5G.
e) **Asamblea de Gobierno**: equipo coordinador y facilitador de las actividades relacionadas con el Observatorio Nacional 5G.
f) **Observatorio Nacional 5G**: Instancia de cooperación y coordinación nacional entre instituciones públicas, privadas, sociales y académicas, interesadas en participar en diversas acciones en materia 5G.
g) **Publicaciones:** cualquier documento digital, generado por los integrantes del Observatorio Nacional 5G, tales como libro, revista, artículo, página web, informe, folleto, material de aprendizaje, entre otros.
h) **SENCE**: Servicio Nacional de Capacitación y Empleo.
i) **Sitio Virtual**: Portal de Internet del Observatorio Nacional 5G.
j) **Subtel**: Subsecretaría de Telecomunicaciones.

Artículo 3º. El Observatorio Nacional 5G constituye un espacio para el intercambio de conocimiento en torno a esta tecnología, así como para la identificación, fomento y desarrollo de casos de uso para conocer su impacto social y económico. En ningún caso, el Observatorio constituirá una plataforma de regulación en materia de telecomunicaciones, siendo esta una atribución exclusiva de la Subtel.

Título II
Actividades del Observatorio Nacional 5G

Artículo 4º. Las personas naturales y jurídicas que formen parte del Observatorio Nacional 5G, podrán realizar las siguientes actividades:

a) Difundir actividades de conocimiento, investigaciones y/o publicaciones sobre la tecnología 5G en el Sitio Virtual.
b) Participar en el desarrollo, ejecución, documentación y difusión de los casos de uso en 5G.
c) Difundir contenidos relacionados con los retos y desafíos de la tecnología 5G.
d) Visualizar información relacionada con la infraestructura pasiva 5G disponible en el país.

Artículo 5. Para facilitar la ejecución de las actividades se proporcionará a los integrantes del Observatorio Nacional 5G diversos formatos y/o estándares para compartir y difundir información.

Artículo 6. La ejecución de los casos de uso requerirá de autorización por parte de la Subtel, conforme a las disposiciones legales aplicables en la materia.

Artículo 7. Los interesados podrán participar en las actividades del Observatorio Nacional 5G de acuerdo con las herramientas disponibles en el Sitio Virtual. Todas las actividades que se realicen en el marco del Observatorio Nacional 5G serán sin fines de lucro y de libre acceso al público.

Artículo 8. La cooperación institucional y el desarrollo de las actividades que deriven del Observatorio Nacional 5G se basarán en los siguientes principios:

- Las necesidades del usuario primero: Centrarse en las necesidades de los usuarios.
- Reutilizar y construir sobre iniciativas actuales: las iniciativas que funcionan deben ser reutilizables para futuros proyectos de colaboración, crear marcos de políticas y herramientas que otros ecosistemas digitales puedan complementar e implementar.
- Diseñar con datos: dejamos que los datos impulsen la toma de decisiones.
- Hacemos el trabajo duro para hacer las cosas simples: hacer que algo se vea simple es fácil. Hacer que algo sea fácil de usar es mucho más difícil, especialmente cuando los sistemas subyacentes son complejos, pero es lo que tenemos que hacer.
- Iterar: la mejor manera de diseñar un conjunto de herramientas de políticas es comenzar de a poco, iterar y volver a iterar. Lanzar productos mínimos viables temprano, probarlos con usuarios reales, pasar de alfa a beta agregando funciones, eliminando cosas que no funcionan y haciendo mejoras basadas en los comentarios de los usuarios. La iteración reduce el riesgo. Hace improbables los grandes fracasos y convierte los pequeños fracasos en lecciones. Si un prototipo no funciona, hay que desecharlo y comenzar de nuevo.
- Diseñamos para todos: el diseño de políticas accesibles es un buen diseño. Todo lo que construimos debe ser lo más inclusivo, y asequible posible.
- Comprender el contexto: no estamos diseñando para una industria o sector en particular, estamos diseñando para personas.
- Diseñamos políticas digitales convergentes: un conjunto de herramientas de políticas es algo que ayuda a los ecosistemas digitales a adoptar mejor la tecnología. Nuestro trabajo es descubrir las necesidades de los usuarios y crear un conjunto integral de herramientas de políticas que satisfaga esas necesidades.
- Somos coherentes, no uniformes: debemos usar el mismo lenguaje y los mismos patrones de diseño siempre que sea posible. Esto ayuda a las personas a familiarizarse con el diseño de la política pública, pero cuando esto no sea posible, debemos asegurarnos de que nuestro enfoque sea coherente.
- Trabajamos de forma abierta y colaborativa: Compartimos lo que estamos haciendo siempre que podemos. Con colegas, con usuarios, con el mundo. Compartimos hallazgos, diseños, ideas, intenciones. Gran parte de lo que estamos haciendo solo es posible gracias a colaboraciones abiertas.

Título III
De la Integración del Observatorio Nacional 5G

Artículo 9. Cualquier persona natural o jurídica, nacional o extranjera, podrá participar y cooperar en los objetivos y actividades del Observatorio Nacional 5G, quienes formarán parte del Registro Nacional del Observatorio.

Artículo 10. Para formar parte del Observatorio Nacional 5G los interesados deberán remitir a la Subtel una carta de adhesión según el procedimiento que para tal efecto se publique en el Sitio Virtual del Observatorio Nacional 5G. En la carta de adhesión los interesados en ser parte del Observatorio Nacional 5G indicarán si desean participar en la Asamblea de Gobierno.

Título IV
De la gobernanza del Observatorio Nacional 5G

Artículo 11. El Observatorio Nacional 5G contará con una Asamblea de Gobierno integrada por un representante de las instituciones de los siguientes sectores: público, social, académico y privado en Chile.

Los integrantes de la Asamblea de Gobierno serán electos de manera anual mediante un método estadístico de selección aleatoria basado en los datos del Registro Nacional del Observatorio que hayan manifestado su interés en ser parte de la Asamblea de Gobierno a través de la Carta de Adhesión.

Artículo 12. La Asamblea de Gobierno tiene por objeto facilitar a los integrantes del Observatorio Nacional 5G la coordinación y el desarrollo de las actividades que deriven del mismo, así como su difusión en el Sitio Virtual. Para facilitar las actividades de coordinación de la Asamblea de Gobierno, esta se auxiliará del Secretario Técnico del Plan Social de Desarrollo Digital.

Artículo 13. La Asamblea de Gobierno sesionará al menos dos veces durante un año de forma presencial o virtual, y tendrá a su cargo las siguientes funciones:

- **a)** Designar a los integrantes de la Asamblea de Gobierno que presidirá anualmente el Observatorio Nacional 5G, conforme a un método estadístico de selección aleatoria.
- **b)** Elaborar el plan anual de trabajo en colaboración con los integrantes del Observatorio Nacional 5G.
- **c)** Coordinar las actividades y el plan anual de trabajo.
- **d)** Administrar el Sitio Virtual a través de la Subtel.
- **e)** Generar un informe anual de las actividades del Observatorio Nacional 5G.
- **f)** Preparar la agenda de los asuntos a tratar en las sesiones de la Asamblea de Gobierno.
- **g)** Convocar, organizar y presidir las sesiones de seguimiento del Observatorio Nacional 5G.

Artículo 14. Las actividades que resulten del Observatorio Nacional 5G se concentrarán en el Sitio Virtual sin perjuicio de que su difusión se realice por diversos medios.

Artículo 15. La documentación de los casos de uso 5G se realizará con base en un estándar de documentación que estará disponible en el Sitio Virtual.

Título V
De los casos de uso

Artículo 16. El desarrollo de casos de uso 5G requiere previa autorización de Subtel conforme a la legislación aplicable.

Para facilitar la difusión de los casos de uso 5G, los integrantes podrán registrarlos y difundirlos a través del Sitio Virtual del Observatorio Nacional 5G.

Al finalizar el caso de uso, los integrantes podrán compartir su experiencia a través del Sitio Virtual destacando los retos y desafíos relacionados con la adopción responsable de la tecnología 5G en cada uno de los sectores industriales en que se aplique.

Artículo 17. A través del Sitio Virtual se difundirán las convocatorias nacionales e internacionales para que cualquier persona pueda acceder a centros de innovación y/o fondos para el desarrollo de casos de uso 5G.

Título VI
Del registro de actividades de conocimiento, publicaciones y/o investigaciones

Artículo 18. Para impulsar ecosistemas de emprendimiento podrán llevarse a cabo diversas actividades tales como jornadas y eventos para debatir sobre las últimas tendencias en materia de 5G en el ecosistema nacional; realizar seminarios temáticos en materias específicas 5G con la participación de centros, universidades y empresas del sector; organizar sesiones dirigidas al ecosistema *startup* para el debate de futuras tendencias tecnológicas debidas al despliegue de 5G; organizar sesiones sobre transformación digital enfocada al impacto social y económico de la tecnología 5G, entre otras.

Artículo 19. Los integrantes del Observatorio Nacional 5G podrán registrar actividades de conocimiento, y compartir enlaces a publicaciones digitales, investigaciones y/o a cualquier actividad de conocimiento que serán difundidos a través del Sitio Virtual.

La información y enlaces que compartan los integrantes a través del Sitio Virtual del Observatorio Nacional 5G se realiza únicamente para efectos de su difusión a la población en general sin que su contenido sea responsabilidad de la Subtel o de la Asamblea de Gobierno.

Artículo 20. La Subtel podrá realizar convocatorias a la sociedad en general, personas naturales y jurídicas, nacionales e internacionales para participar y contribuir con su opinión, experiencia y comentarios en torno a la tecnología 5G, a través de mesas de trabajo que podrán ser virtuales o presenciales según la metodología que establezca la Subtel. Lo anterior, sin perjuicio de los mecanismos de participación ciudadana previstos en la Norma General de Participación Ciudadana del Ministerio de Transportes y Telecomunicaciones.

Artículo 21. Las actividades del Observatorio Nacional 5G se difundirán a través del Sitio Virtual, tales como aplicabilidad de 5G en diferentes sectores industriales; resultados de los casos de uso; eventos para la difusión del 5G orientado a su aplicabilidad práctica en sectores productivos; promoción y difusión de capacitaciones, publicaciones, investigaciones o cualquier actividad de conocimiento.

Artículo 22. En el marco del Observatorio Nacional 5G se organizarán seminarios y jornadas informativas de forma presencial o virtual a lo largo del territorio nacional. Para facilitar el conocimiento del 5G e impulsar la definición de iniciativas de colaboración público-privada para la formación en esta tecnología, la Subtel podrá colaborar con el SENCE y las Universidades interesadas para tales efectos.

Disposiciones transitorias

Primera. La presente norma entrará en vigor el primer día hábil siguiente a su publicación en el Diario Oficial de la República de Chile.

Segunda. La presente normativa no se contrapone con las disposiciones legales, normas y/o convenios vigentes por los que se rija Subtel.

Tercera. Las instituciones que cuenten con convenio suscrito con la Subtel para realizar actividades en torno a la tecnología 5G podrán formar parte del Registro Nacional del Observatorio.

Cuarta. En la gestión de las actividades que deriven del Observatorio Nacional 5G se fomentará el uso de medios digitales conforme a la Ley 21.180 sobre la Transformación Digital del Estado.

ANÓTESE Y PUBLÍQUESE EN EL DIARIO OFICIAL Y EN EL SITIO WEB INSTITUCIONAL DE LA SUBSECRETARÍA DE TELECOMUNICACIONES

PAMELA VICTORIA GIDI MASIAS
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PAMELA GIDI MASÍAS
Subsecretaria de Telecomunicaciones

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Lo que transcribo para su conocimiento
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JOZSEF ALEJANDRO MARKOVITS ALARCON
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