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THE ROAD TO 5G NETWORKS

EXPERIENCE TO DATE AND FUTURE DEVELOPMENTS

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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.

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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.

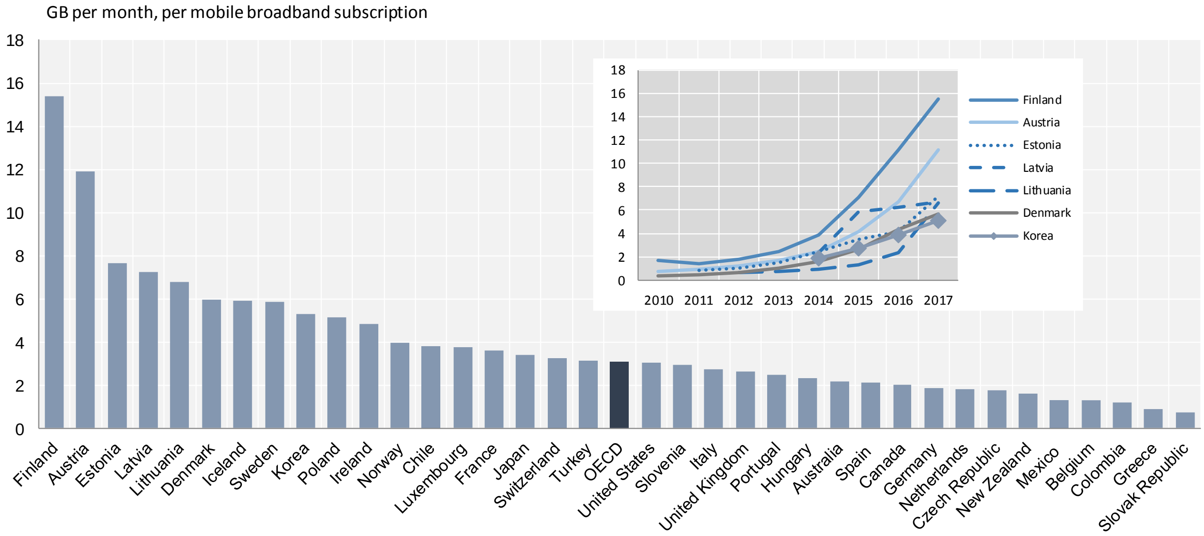
Some trials in mining have been underway. For instance, a cross-industry consortium (composed by Telia, Boliden, Ericsson, Volvo, ABB, RISE SICS and LTU) joined forces for the Industrial Mobile Communication in Mining (PIMM) project, with the aim of testing how mobile connectivity can make mines safer. 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

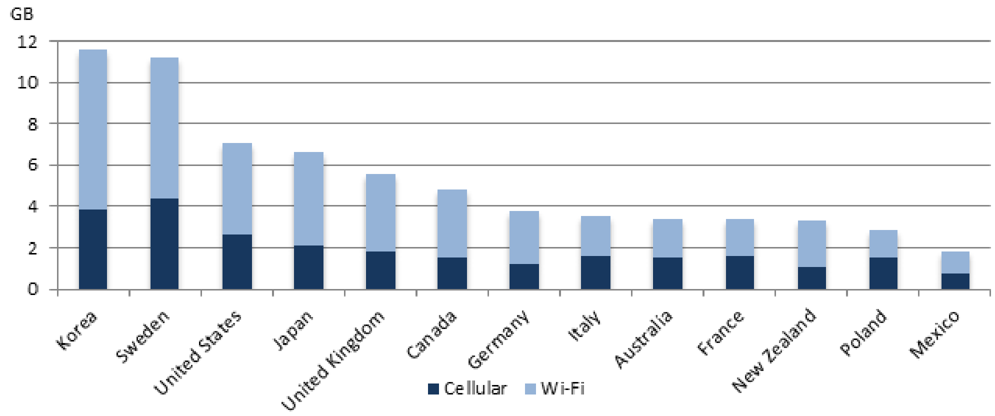


Note: The graph includes updated data for Mobile broadband subscriptions (2016 and 2017) and Mobile data volume/usage (2017) as well as the changes in the methodology (multiplier 1024 is used to convert TB into GB; the total amount of GB is divided by the yearly average number of Mobile broadband subscriptions).
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 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

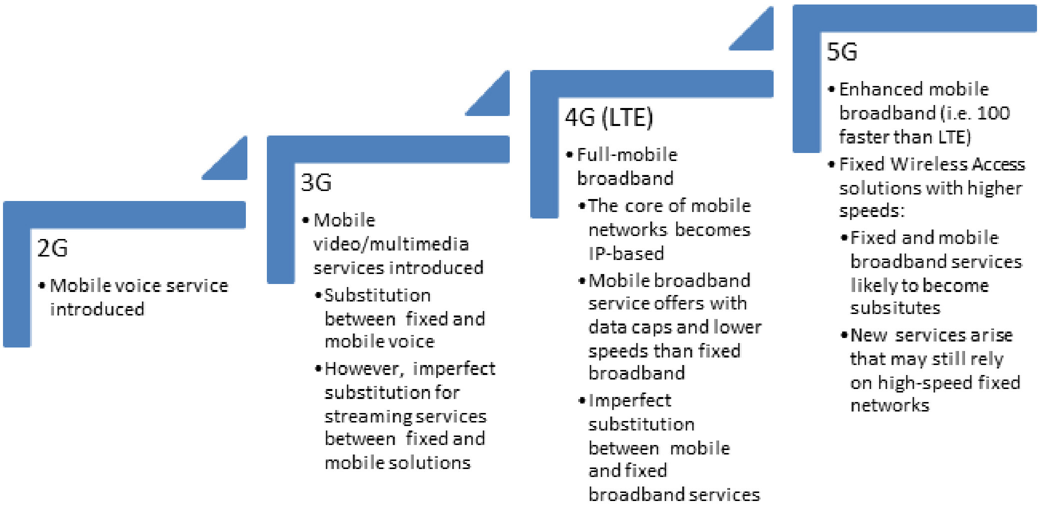
Mobile Traffic disaggregated by the Wi-Fi Offloaded traffic and Cellular network traffic



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.

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 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]).

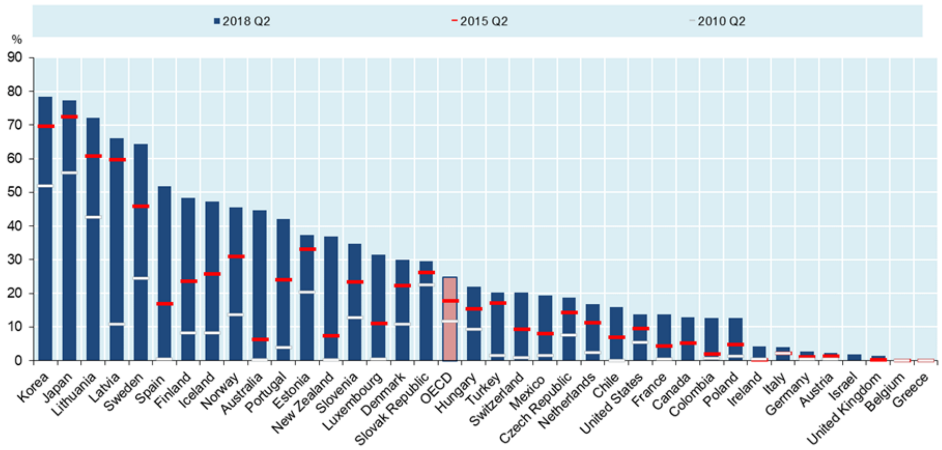
Given all these ecosystem (technological) developments, in conjunction with the regulatory developments, many observers note that more 5G trials will be undertaken in 2019, noting that most trials up to now have focused on the non-standalone standard and on interoperability.

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.

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]

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	

	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]).

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:

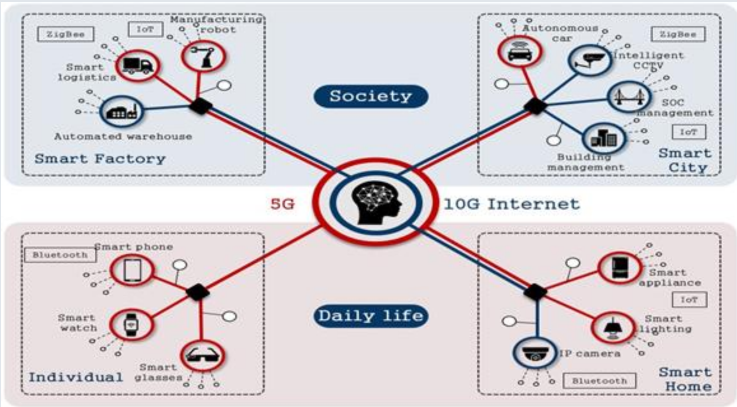
- One of the World's first commercialisation of 5G (first half of 2019), and a nationwide 5G network by 2022
- Increasing the number of IoT connected devices to 30 million by 2021 (from the currently 11.6 million)
- Building smart, safe networks based on software and Artificial Intelligence
- Guarantying 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).

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

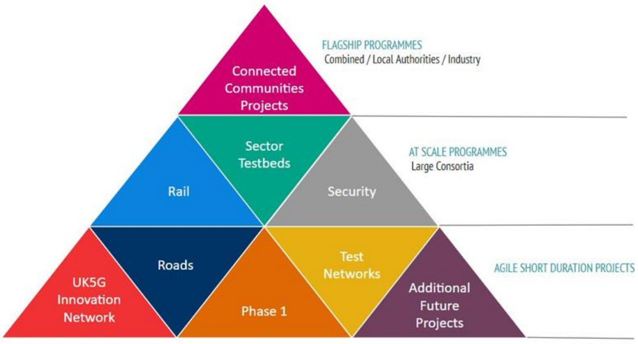
The "5G Testbeds and Trials Programme" (5GTT), launched in late 2017, is set to run until 2020-21. The aim is launch a series of projects across the United Kingdom to deploy new wireless infrastructure and test 5G technology in a number of sectors to create new applications and services. The programme 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).

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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