FINAL REPORT FOR CTIA

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GLOBAL RACE TO 5G – SPECTRUM AND INFRASTRUCTURE PLANS AND PRIORITIES

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1 Executive summary

This is the final report of a study conducted by Analysys Mason on behalf of CTIA, comparing 5G spectrum and infrastructure policies proposed in markets worldwide to advance 5G technology and facilitate successful network deployment.[1]

Analysys Mason's study has:

- Investigated actions that are taking place outside the US regarding the development and commercialization of 5G, and the extent to which governments and regulators in other markets view 5G as a race that they are intent on winning.
- Compared what is happening to 5G in the US with other markets, in terms of 'readiness' for 5G, with a focus on two key governmental areas:
    1. Spectrum availability, licensing and deployment plans for 5G.
    2. Proposals aimed at streamlining planning processes for 5G infrastructure, including favorable mobile siting and licensing policies.

This report compares the situation in the US to that in other leading markets, specifically: Canada, China, France, Germany, Japan, Russia, Singapore, South Korea, and the UK.

Our 5G readiness analysis is based on five metrics that we have defined for this study, based upon our prior experience in analyzing actions taken by policymakers to promote technological leadership:

1. **Amount and timeline for 5G spectrum release**. This includes: the total amount of spectrum being released for 5G, availability of spectrum across several bands (low, medium and high), and the timescale for spectrum being made available for commercial use.

2. **5G spectrum roadmap published**. This provides a comparison in relation to overall spectrum planning for 5G, guided by whether regulators have published detailed roadmaps with indication of bands that are to be made available for 5G use, and/or are under study.

3. **Government backing and infrastructure policy**. This includes policies aimed at easing 5G infrastructure deployment, as well as government backing for early 5G deployment. Specifically, this captures the extent to which national governments are proactively aiming for 5G deployment and are putting policies in place aimed at encouraging further technological development and early commercial launch of 5G services.

[1] CTIA is the leading trade association for the wireless industry in the US, representing companies reflecting all parts of the wireless ecosystem, including mobile network operators, equipment manufacturers, software providers, and other providers of products and services involved in the mobile wireless marketplace.

4. **Industry 'proof-of-concept' trials**. This compares the extent of 5G network and equipment trials being conducted by industry parties, ahead of commercial network deployment.

5. **Industry commitment to 5G launch**. This assesses the progress that is being made by network operators towards commercial 5G launch.

Key findings

Our analysis of 5G readiness at the start of 2018 can be considered in three tiers. Based on our assessment, the leading group of countries in the first tier of our scoring are China, South Korea, the US and Japan; within that tier, China ranks highest in our overall scoring for 5G readiness, with South Korea, the US, and Japan, not far behind. In the second tier are Germany, UK, and France. In the third tier are Canada, Singapore, and Russia. This is based on our view at the time that this report was prepared (between December 2017 and March 2018), based on the factors we have considered.

As shown in Figure 1.1 below, China is the highest scoring country in our leading group of countries, based on a strong push for early 5G launch combined with government commitment to achieving 5G success. This is followed by South Korea, the US, and Japan. Our research has found shifts in 5G readiness occurred during 2017 and early 2018, with the progress made in 2017 to define specifications for 5G new radio (NR) leading to accelerated plans for commercialization. This confirms the situation is fluid, and current leadership rankings are not fixed. Although several other countries are at a preliminary stage with 5G planning, here, too, plans could develop rapidly during 2018–2019.

Figure 1.1: Overall 5G readiness scores [Source: Analysys Mason, 2018]

This analysis represents a view of 5G readiness in different markets at a point in time; other factors – including supply-side developments, shifts in commercial strategy, and other developments – could influence how 5G markets will develop globally.

Based on our analysis,[2] we have drawn the following conclusions:

[2] Our analysis and conclusions are based on three main sources: publicly available information (especially documentation published by MNOs, vendors, and national regulatory authorities (NRAs); primary research (interviews conducted by Analysys Mason with leading MNOs, regulators, and vendors); and Analysys Mason's own expertise and knowledge on 5G, based on recent work in this area.

There has been a significant market shift in 5G readiness within the past 12 months	Our research points to a shift in 5G readiness having occurred during 2017 and in early 2018. Several 5G commercial launches are now likely to occur in the 2018–2019 timeframe. This confirms that the elements needed for 5G are now established (i.e. industry specifications are in place and operators are confirming large-scale procurements of 3GPP Release 15-compliant equipment).

We have developed five spectrum and infrastructure-related metrics in this report to compare 5G readiness across markets – of these five metrics, we have given spectrum availability the highest weighting	Our research has identified five spectrum and infrastructure-related metrics influencing how 5G networks might emerge in different markets – spectrum availability, widespread 5G trials, 5G roadmaps being established by the national regulator, government commitment (including favorable infrastructure policies), and industry commitment to early 5G launch. Of these metrics, we consider the first of these – spectrum availability for commercial launch – to be the most important, and have given this the highest weighting in our analysis. The reason for this is that operator commitment to large-scale 5G network launch is dependent on sufficient spectrum being available to support the network launch, and to incentivize network investment. The five metrics we have defined, and the importance of spectrum availability, align with industry experience of the factors that have had the most impact on development of previous generations of mobile technology (i.e. 3G, and 4G). Although in several of the countries under consideration in this study 5G test and development is underway, these trials will only progress to commercial services being launched once spectrum licensing is confirmed.

In our view, infrastructure for 5G is the other policy area that is important to 5G launch	Our view is that infrastructure for 5G is one of the two key policy areas that is important to 5G launch. Infrastructure policy to streamline the siting procedures for mobile networks has been an ongoing area of policy development in many markets and overcoming barriers for further infrastructure deployment will be relevant in the 5G market, especially with the introduction of smaller cells, at street level.

Globally the most referenced spectrum for initial 5G deployment is	Globally, the most referenced spectrum for initial 5G deployment is in the 3.4–3.8GHz band, followed by spectrum in 24.25–29.5GHz (this range might include the 26GHz band in some countries, or 28GHz in

in the 3.4–3.8GHz and 24.25–29.5GHz bands, although adjacent bands are of interest, e.g. 3.7-4.2GHz in the U.S.	others). Countries that have been given the highest scores in our 'spectrum availability' assessment in this report are those in which there is commitment to a timely release of sufficient spectrum for mobile use in both these frequency ranges i.e. 3.4–3.8GHz along with 26GHz and/or 28GHz.[3]

Market differences will affect the underlying demand for 5G services in several ways, impacting the spectrum and related policies being proposed, and the cross-industry trials that are taking place	5G will deliver a range of different services, and the characteristics of those services could differ between markets (e.g. embracing fixed as well as mobile broadband services and delivering wireless connectivity to multiple industries with different connectivity needs). These market differences will affect the underlying demand for 5G services in different markets, and the spectrum and related policies that are needed to progress initial 5G implementation. In several of the markets that we have studied, large-scale 5G test and development, and cross-industry trials (some backed by governments) have been announced, which are likely to be helpful to stimulate demand for 5G commercial services. In our view, it remains to be seen whether these pre-commercial 5G trials will result in those markets obtaining 5G leadership, or not (with other relevant factors potentially including the timely release of spectrum and confirmed operator investment plans for commercial 5G launch).

Operators will follow different approaches to deploy 5G based on market need and operator strategy	The industry's initial specifications for 5G (i.e. 3GPP Release 15, published in December 2017) allow for different paths to 5G launch, i.e. operators can opt to deploy 5G NR as a non-standalone solution (connected to a 4G core network), or as a standalone network (i.e. 5G NR frequency carriers with a 5G core network). Global timescales are such that it appears that non-standalone and standalone solutions might be launched commercially within similar timeframes. Our research indicates that some markets will opt for the non-standalone deployment to accelerate the time-to-market and leverage their 4G core networks (e.g. US, Asia), whereas others may go for the standalone route first. Choices will depend on technological preferences in different markets, the nature of 5G services being launched, and network investment cycles. Both options will allow for 5G mobile broadband services to be

[3] It is noted that detailed plans for mobile use of the millimeter-wave bands to enable sharing among the services using these bands (satellite and terrestrial) are not available at the time of producing this report. Spectrum in the 3.4-3.8GHz band is part of the C-band, also used for satellite services and hence the amount of spectrum available for terrestrial 5G use in the C-band in different markets depends on protections for C-band satellite services.

	offered that are differentiated from 4G in terms of superior speed and latency performance, provided sufficient spectrum is available. Deployments of 5G will allow for interoperability with existing 4G networks (and other radio access technologies), so that a customer may experience smooth transitions between areas of 5G deployment and existing 4G coverage.

We have identified the following recommendations from our work:

- Global equipment vendors have made significant commitments to 5G research and development over the past few years together with mobile operators. As a result, consensus has been reached over the frequency bands that are likely to be the most important for early 5G launch. These bands for initial global launch are the ones for which vendors expect to have commercial 5G network equipment, and devices, ready for use in the short term, broadly falling into two areas of spectrum – mid-band, around 3.5GHz, and mm-wave, between 24.25GHz and 29.5GHz (and several bands above this). Initial 5G services are likely to be mobile broadband-based (i.e. enhancements to today's 4G services, but with new 5G capabilities, such as very high throughput, and very low latency), but will expand into several verticals, and to provide a wide variety of use cases, over time.

Achieving these wide-ranging, dynamically changing 5G capabilities depends on operators having sufficient spectrum available to them within the bands that vendors are promoting for 5G use. This underlines the importance of governments and regulators planning for sufficient spectrum release, during 2018–2019, in these globally harmonized frequency ranges. Compared to several other markets, it is possible that further focus in the US should be directed towards release of spectrum in the mid-range for 5G.

- Mobile networks are already being densified to support the substantial increase in data traffic that networks are now carrying; it is widely expected that 5G will result in a greater need for small-cell deployment. This is particularly true for initial deployments using high band spectrum above 6 GHz (24, 28, 39 GHz), where the signal travels far less distance than existing low and mid band frequencies. The main candidates for these sites in outdoor small-cell locations are local authority/municipality-owned assets such as street lights and utility poles. In connection with these assets, it is important that any attachment fees be cost-based. For in-building coverage (e.g. offices, hotels, etc.), building owners will need to collaborate with multiple service providers to provide high-speed 5G access, potentially using shared infrastructure.

Better identification of site locations, and streamlined approval processes, could help facilitate small-cell deployments both outdoors and indoors. Since there can be significant local differences in planning requirements for small cells, new national-level guidelines might be required, supported by better local-level collaboration (e.g. greater transparency on available assets, streamlined processes to avoid lengthy deployment delays, and pro-infrastructure siting and sharing policies aimed at ensuring that small cells can be more widely deployed).

2 Introduction, and context for the study

5G is being developed to address the market demands and business environments of the global digital economy over the coming years.

Benefits from 5G over and above today's mobile networks will come about through deployment of ultra-fast, highly reliable, scalable, and very low latency connectivity networks with the flexibility to meet user needs across many sectors of industry and business.

With a wide range of potential 5G use cases, the potential socio-economic benefits of 5G are highly substantial. A study[4] published by Accenture in 2017 concluded that 5G could create USD500 billion in additional GDP and 3 million jobs in the US, through USD275 billion in investment by telecom operators. A similar study[5] conducted by the European Commission (EC) estimated that the benefits of 5G in Europe by 2025 will reach EUR113 billion per annum in four key sectors (automotive, healthcare, transport and energy), creating 2.3 million jobs. At a global level, a report[6] recently commissioned by Qualcomm concluded that 5G will enable USD12.3 trillion of economic output in 2035, with the 5G value chain supporting 22 million jobs.

As a result, governments and operators around the world are ambitious to 'win the race' to 5G. Governments, mobile operators, vendors, and other players in the 5G value chain are seeking to be the first to realize the benefits of 5G, and to be the pioneers of its deployment and commercialization.

Significant progress was made during 2017 by the wireless industry to produce initial specifications for 5G technology.[7] Many telecom companies around the world are now making plans to launch 5G services, with advanced testing of 5G connectivity and end-to-end solutions being undertaken in many markets. Commercial launches are being driven forward by strong co-operation between telecom operators and equipment vendors. Several operators are preparing pilot 5G launches in specific locations, from 2018 onwards. There is evidence of 5G planning being accelerated in several markets, which has been driven, in part, by the accelerated process for defining initial 5G new radio (NR) specifications, which the industry completed in December 2017.

In view of this, CTIA asked Analysys Mason to undertake this research on 5G readiness in different world markets, and to prepare this report to contrast the spectrum and infrastructure policies being proposed in different markets towards early 5G implementation.

4 See https://www.ctia.org/docs/default-source/default-document-library/how-5g-can-help-municipalities-become-vibrant-smart-cities-accenture.pdf

5 See https://ec.europa.eu/digital-single-market/en/news/5g-deployment-could-bring-millions-jobs-and-billions-euros-benefits-study-finds

6 See https://www.qualcomm.com/media/documents/files/ihs-5g-economic-impact-study.pdf

7 See http://www.3gpp.org/release-15

2.1 Summary of study objectives and approach

The objectives of this study were twofold:

- To evaluate actions taking place in markets worldwide, including the US, regarding the development and commercialization of 5G, and the extent to which governments and regulators in other markets are viewing 5G as a race that they are intent on winning.

- To compare what is happening on 5G in the US to other markets in terms of 'readiness' for 5G commercial launch, with a focus on two key areas of policy making to support 5G network deployment: spectrum availability and infrastructure policies.

Within our research both on spectrum and infrastructure policy, we have focused on comparing the state of the US 5G market readiness to nine other leading markets: Canada, China, France, Germany, Japan, Russia, Singapore, South Korea, and the UK (the 'benchmark countries').

We have considered preparations for 5G spectrum award in each of the ten benchmark countries, as well as future plans for the release of further spectrum for 5G. We have also investigated specific policy changes being proposed to facilitate new mobile infrastructure deployment within the selected markets, with a focus on policies aimed at accelerating 5G deployment and/or addressing specific infrastructure issues (e.g. facilitating small-cell deployment). Spectrum and infrastructure considerations have been combined with several other relevant metrics (such as commitment from national governments towards 5G leadership, and commitment from industry parties towards early commercialization and widespread availability of 5G services) to make an overall assessment of '5G readiness' within the markets being considered.

Our analysis and conclusions reflect the 5G preparations taking place around the world at the time of producing this report and are based on comparison between countries in accordance with the metrics identified within the report. It is noted that other inherent factors within the wireless market – such as in relation to supply-side changes or changing priorities within planned network deployments – could influence the outcomes identified.

2.2 Structure of report

The remainder of this document is laid out as follows:

- **Section** 3 gives an overview of key 5G spectrum issues globally
- **Section** 4 compares the US to our benchmark countries in terms of the currently allocated spectrum for mobile, and planned allocation of new spectrum for 5G
- **Section** 5 provides international examples of infrastructure policies for 5G
- **Section** 6 assesses the overall '5G readiness' of our benchmark countries and the US, contrasting readiness against five key metrics that we have identified during the study as being relevant to successful 5G deployment, which are: spectrum availability for commercial launch, 5G trials, 5G roadmap in place at national level, government policies and commitments

(including in relation to infrastructure policies) and industry commitment to dates for commercial launch

- **Section** 7 provides our conclusions and recommendations.

The report includes two annexes containing supplementary material:

- Annex A summarizes the abbreviations used in the report
- Annex B provides 5G case studies for each of our benchmark countries, as well as the US.

3 Overview of global 5G spectrum designations and use

This section describes the market context for 5G, including the ongoing surge in mobile data traffic worldwide, the emerging demand for new mobile services and the developments in 5G technology. It discusses the technological specifications, and spectrum needs, which will form the foundation of 5G networks. Finally, it describes the latest progress being made with 5G launch, including equipment specifications, industry trials, and spectrum assignment to accelerate 5G deployment.

From this section, we identify that there is a readiness to launch 5G networks in several markets worldwide, supported by significant efforts of global wireless vendors together with operators to progress 5G technology development, and network trials. We also identify that 5G will deliver a range of different services, and that the characteristics of those services could differ between markets (e.g. embracing fixed, and well as mobile broadband services, and delivering wireless connectivity to multiple industries with different connectivity needs). These market differences will affect the underlying demand for 5G services in different markets, and the spectrum and related policies that are needed to progress initial 5G implementation.

3.1 Defining 5G

5G refers to the fifth generation of mobile technology and is the next generation of mobile and wireless broadband technology, capable of delivering ultra-fast speeds (ten times those of the latest 4G networks), along with better scalability, lower latency, and higher reliability. 5G networks will use new radio technology, and will embrace virtualization and associated innovations within the core network,

Migration to virtualized architectures will create opportunities for new forms of mobile service and will potentially provide a path for mobile networks to converge with the cloud architectures supporting the broader IT ecosystem today.

5G services are broadly considered as being of three main types: very high-speed mobile and wireless broadband services; ultra-reliable, low-latency communications; and massive IoT or machine-type connections. 5G system operation will bring a range of performance improvements compared to today's 4G mobile broadband (MBB) services, including greater capacity, lower latency and better scalability, resulting in significant improvement in user experience. 5G networks will potentially deliver connectivity in a range of mobile environments (including in vehicles, on trains and other high-mobility environments) and provide mobile and fixed broadband services to consumers, businesses and industries in the home, at work or on the move. 5G technology is hence being designed from the outset to have the necessary flexibility and scalability to deliver wireless connectivity in a wide range of use cases, including in both fixed and mobile environments.

One of the core targets of 5G is to provide high-performing wireless connectivity for different types of devices and machines used in vertical industries with varying network requirements. These 5G

use cases include highly reliable, wide-area network connectivity for connected and automated vehicles (CAVs), high-speed wireless connectivity in smart cities, highly resilient wireless networks for public protection and disaster relief (PPDR), and a range of secure mobile applications for healthcare, utility and logistics, and the Internet of Things (IoT). Many pre-commercial 5G trials currently taking place around the world are aimed at fostering collaboration between the telecom industry and a broad range of potential industrial users of 5G networks, alongside many trials of 5G mobile and fixed broadband connectivity, to the home and to consumers on the move.

The published literature describing potential 5G use cases is extensive. A white paper published by CTIA in 2016, "The next generation of wireless: 5G leadership in the US", describes several examples of 5G use cases and the benefits these will bring, from video entertainment to remotely controlled sensors, robots and cars.[8] A summary of these is reproduced below.

Figure 3.1: 5G use cases and the benefits consumers and businesses will experience [Source: CTIA, 2016]

New video applications	▪ Fast access to ultra HD including 4k and 8k content on tablets, laptops and other large-screen devices, enabling rapid download of films and videos ▪ Immersive video, gaming and entertainment, allowing user to interact with simulated elements to enrich the user experience
Smart cities	▪ Remote monitoring of roads, bridges, buildings, parks and venues, enhancing efficiency and providing additional safety for citizens ▪ Digital signage and real-time information on traffic and parking offer greater convenience and improve productivity and efficiency of urban travel
M-health and telemedicine	▪ Improved remote monitoring and healthcare monitoring, to actively monitor patient conditions, rapidly diagnose problems and effect more rapid medical outcomes ▪ Robotic telepresence, to provide video conference applications for healthcare and other situations (e.g. education)
Automotive	▪ Vehicle solutions with several modes of operation, which will provide rich information and safety option to assist future driverless vehicles to make real-time decisions based on information going beyond the individual sensors on the vehicle ▪ Sensing with vehicles at speed, contributing to improved vehicle safety and fewer collisions

3.2 International context for 5G development

The substantial growth in volumes of data traffic being carried by mobile networks that has occurred since the launch of 4G services is well documented. There is widespread evidence that consumers and businesses are increasingly reliant on mobile devices to connect to the internet, to use a range of advanced data and video services, and to perform daily tasks at work and at home.

Recent years have seen a significant surge in mobile data traffic worldwide, and as more markets have launched 4G services, the increase in mobile data traffic is expected to continue. Data traffic growth is being driven by substantial increases in the data traffic generated per mobile subscriber,

8 https://www.ctia.org/docs/default-source/default-document-library/5g_white-paper_web2.pdf

as well as more subscribers migrating from legacy 2G/3G networks, to 4G, and propensity to use sophisticated smartphone devices that generate higher levels of network traffic due to widespread use of these devices for video as well as data consumption. Forecasts are that mobile data traffic levels will continue to grow, as operators deploy further advanced features in 4G networks to meet market demand for increased reliability and data speeds, in parallel with 5G networks being prepared for launch.

Recent mobile data traffic forecasts published by Analysys Mason's Research division are shown below.[9] As can be seen, strong growth is expected in global mobile data traffic over the coming years, with both total traffic and traffic per connection forecast to more than quadruple between 2017 and 2022.

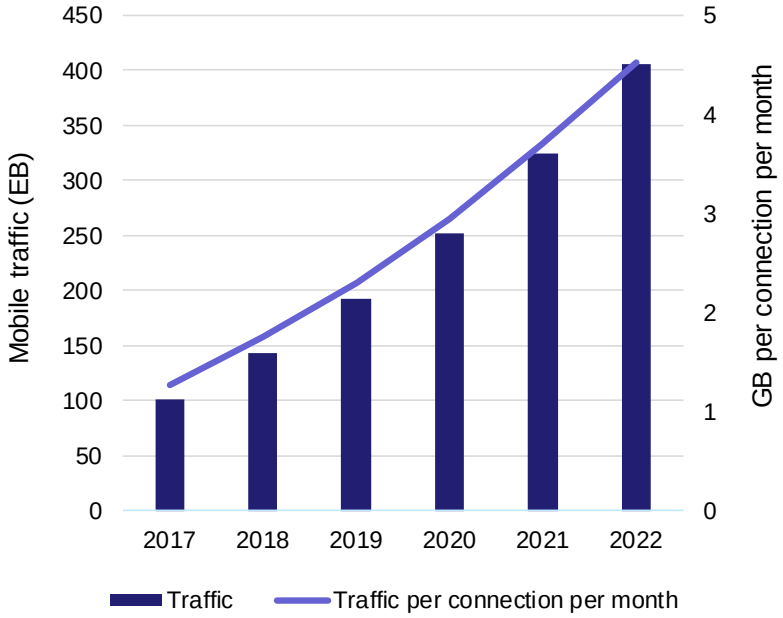


Figure 3.2: Worldwide mobile data traffic forecast [Source: Analysys Mason, 2018]

As in the global market, continued growth in mobile data usage is widely forecast in the US, with migration from 4G to 5G expected to generate greater volumes of mobile broadband data traffic.

The forecasts of the role of 5G within mobile broadband services in the US are shown in the figures below. It is noted that initial 5G services in the US are also expected to include fixed broadband (i.e. high-speed wireless connectivity into the home or business). The characteristics of these 5G technology-based fixed broadband services fit well with deployment in millimeter-wave (mm-wave) spectrum which, as discussed later in this report, has been one of the focus areas for 5G spectrum policy in the US (i.e. to ensure sufficient spectrum availability in the mm-wave frequency range). Nevertheless, it is clear that 5G will be built upon networks using low, mid-, and high-band spectrum, as operators have made clear, from 600MHz, to 2.5GHz, and higher.

9 These illustrations refer to mobile connections, and mobile data traffic. 5G fixed wireless services (e.g. fast internet to homes) is excluded from these forecasts.

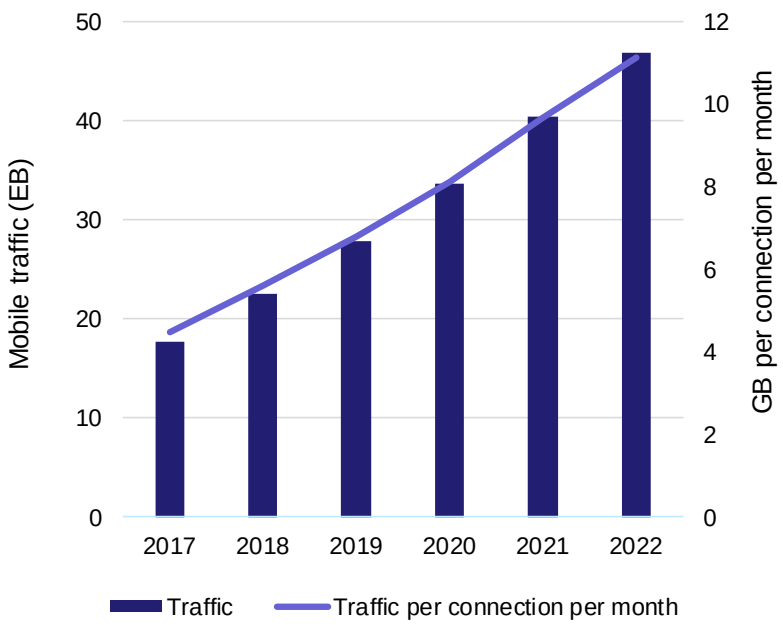


Figure 3.3: Forecast of mobile data traffic in the US [Source: Analysys Mason, 2018]

3.3 5G specification phases

The first phase of the evolution to 5G is being defined within Release 15 of the specifications of the Third Generation Partnership Project (3GPP). The 3GPP community has been responsible for publishing 3G and 4G specifications, and the requirements for 5G development are being addressed in phases.

Initial specifications will include options for non-standalone and standalone new radio (NR) deployments,[10] providing alternative deployment options for initial 5G launch.

The first stage of the 3GPP Release 15 specifications (R15 in the diagram below) was finalized by the 3GPP in December 2017, and defines the 5G new radio (NR) 'non-standalone' (NSA) configuration.[11] The second stage of Release 15 specifications will complete the standalone (SA) configuration and is expected to be ready in June 2018.

The December 2017 release represents an acceleration in development of the 5G NR specifications, to meet industry demand for more rapid completion of initial specifications ahead of commercial launches. The industry expectation is that 5G NR will reach commercial readiness in 2018, based on the December 2017 specifications, followed by further commercialization (based on the June 2018 specifications) from 2019. A subsequent Release 16 of the 3GPP specifications (R16)

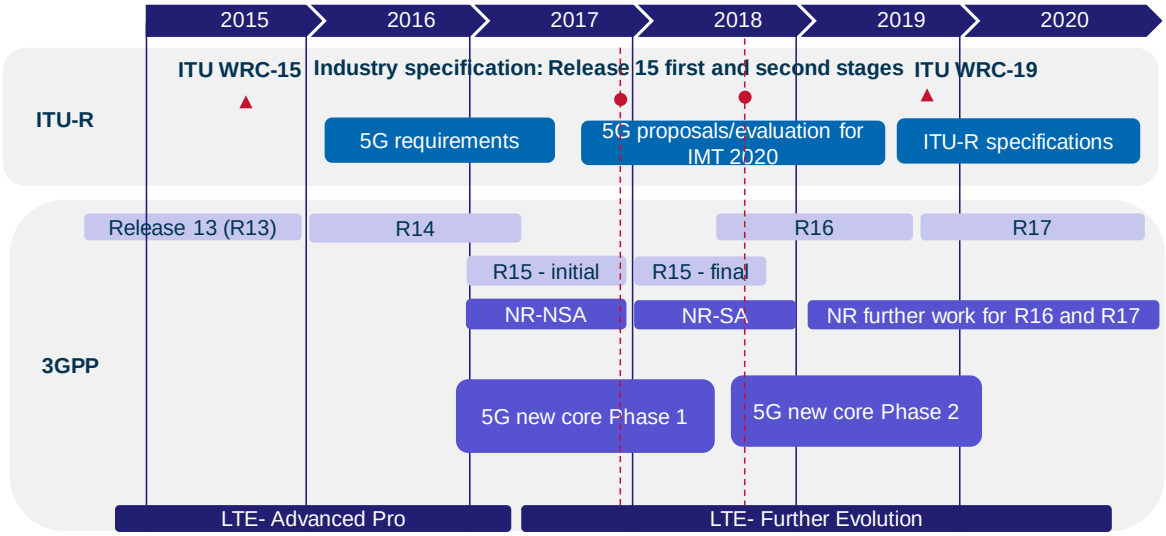
10 Non-standalone NR refers to deployment whereby NR carriers will be deployed in conjunction with existing 4G/LTE frequency carriers, with the network utilizing the 4G evolved packet core (EPC). Standalone NR refers to 5G frequency carriers being deployed independently of 4G, and with a 5G core network.

11 http://www.3gpp.org/news-events/3gpp-news/1934-nr_verticals

will produce a further set of 5G specifications, broadening the supported use cases to cover the full range of envisaged applications as described in Section 3.1.

Figure 3.4 below shows key ITU and 3GPP milestones (completed and planned) regarding the development of 5G.

Figure 3.4: Milestones in definition of 5G technology, and specifications release [Source: Analysys Mason, 2018]



Irrespective of the core network options, the new 5G radio interface can be deployed using several frequency bands. The key characteristics of the 5G NR interface (which will drive 5G spectrum needs for operators) include:

- Bandwidth increase of at least ten times compared to current LTE-Advanced services (e.g. over 1GHz of spectrum for 5G NR deployment, per operator, is envisaged as the target amount of spectrum needed in mm-wave spectrum is envisaged).
- Use of new spectrum bands where wider contiguous frequency carriers are possible to deploy, to bring better efficiencies and lower latency (e.g. multiples of 100MHz carriers in the mid and high bands), in addition to low-bands (e.g. 600MHz, 700MHz and 800MHz, including re-farming of 2G, 3G, and 4G spectrum).

Although it is expected that many of today's existing mobile spectrum bands (currently used for 2G, 3G and/or 4G services) will be used for 5G NR in due course, the initial global focus for 5G NR deployment (reflected in the 3GPP Release 15 specifications) is on 'mid-band' frequencies (e.g. around 3.5GHz), and in the mm-wave portion of spectrum, in the 26GHz and 28GHz bands.[12] Several other mm-wave bands show promise for subsequent 5G deployment (such as at 39GHz, 42GHz and 66–76GHz). Spectrum priorities for 5G are further described in Section 3.5.

12 'Millimeter' refers to the wavelength of radio signals above 30GHz, which is below 10mm.

3.4 Technological features of 5G relevant to infrastructure requirements

Whilst other published reports describe 5G network capabilities in more detail, the main techniques and technologies that will form the foundations for 5G networks, relevant to spectrum and infrastructure requirements, include:

- **A new radio interface (5G NR)**, which can be deployed either to inter-work with the 4G core network, or as a standalone deployment. For inter-working purposes with the 4G radio interface, different deployment options are possible. Initial deployments using non-standalone can be done more expeditiously by leveraging the existing 4G LTE core network.

- **Use of mixed spectrum environments**, including licensed, and license-exempt (unlicensed) spectrum use. The latter is facilitated via the 3GPP 'licensed assisted access' technology, which might use 5GHz unlicensed spectrum, with lower powers within smaller cells, for example. Regulators in several markets are considering unlicensed mm-wave spectrum between 60GHz and 70GHz for 5G. Outdoor small-cell deployments rely on operators being able to plan street-level siting for smaller cells in appropriate locations (e.g. ultra-dense urban networks using street-level sites, for example). Within buildings, there could be a greater need for neutral-host networks to facilitate small-cell indoor overage for multiple service providers.

- **Network virtualization**, which will allow flexible provisioning of network capabilities along with deployment and cost efficiencies is well underway. In addition, in 5G networks there will be an ability to deliver different vertical user requirements in a flexible way ('network slicing') will also provide greater flexibility and scalability for operators. For example, network slicing allows the network to serve the necessary resources for a high definition video stream with a different slice from a low bandwidth IoT device. From an infrastructure perspective, this might mean that operators will achieve more efficient resource utilization from the network across a broad and diverse set of use cases.

- **Use of sophisticated antenna array technology** (i.e. massive MIMO), in conjunction with the base station, and in devices. Massive MIMO is expected to be a key feature of 5G NR deployments, both in mid-band spectrum (e.g. 3.5GHz) and in higher bands (e.g. 26GHz or 28GHz). In the higher bands, a larger number of antenna combinations is possible, due to the smaller physical size of antennas. Today, 4x4 MIMO combinations are possible in 4G; arrays of 64 or 128 are being planned in 5G, which enable the high throughputs expected. In the case of 3.5GHz deployments, it is likely that operators will wish to deploy 5G NR frequency carriers, with massive MIMO, on existing macro sites. For some deployments (e.g. fixed wireless access, to provide high-speed wireless into homes or to office buildings[13]), operators might also opt to deploy new sites designed to provide coverage to the targeted homes and office buildings.

13 Since massive MIMO uses narrower beams compared to conventional antennas, coverage can be improved, making 5G suitable for the delivery of high-performance wireless broadband services into homes and offices, via mm-wave fixed wireless links.

Small cells will potentially play a significant role in operators' programs to roll out 5G. Operators in several markets are already densifying their 4G networks in this way, and are using small cells in several ways, including to boost coverage in outdoor areas, to provide coverage to indoor locations, and to overlay macro-cell sites to increase capacity where needed (e.g. within urban environments).

For large-scale, small-cell deployments, however, planning and roll-out challenges can result in high costs to operators, due to delays or the inability to secure appropriate sites, such that deployments become unviable. In the 5G era, ability to attach to existing structures, modernized approval and reasonable fees for small-cell deployment could help lower these barriers.

3.5 Spectrum priorities for 5G

Delivering commercial 5G services relies on spectrum being available for 5G network deployment, as well as 5G technology being commercially available for network launch. Global equipment vendors have been investing heavily over several years in research and development in relation to 5G equipment and devices and have tested the network capabilities of new 5G technologies together with multiple operators worldwide.

There is an expectation that large amounts of spectrum will potentially be needed to deliver 5G services with higher speeds, better reliability and lower latency. Access to significantly more spectrum than exists within today's mobile ecosystem will be required in localized 5G 'hotspots' (e.g. with the mm-wave bandwidth used per network being 1GHz, or more to deliver truly differentiated 5G services). Mid- and low-band spectrum will also be needed to support increased capacity for 5G services, over a wider area, as previously described. Operators will require licenses to operate multiple frequency layers in parallel, appropriate to the 5G services they plan to deliver. Hence, the need for regulators to plan for timely availability of spectrum in these bands, with sufficient bandwidth in several bands (e.g. in the mid-range and in higher bands) being made available within similar timeframes, is a key requirement for 5G markets to develop, and will be instrumental for markets to secure 5G leadership, as we discuss later in this report.

Network equipment and device vendors view global harmonization of spectrum for 5G as a key factor for the success of new 5G technology. Spectrum harmonization is particularly relevant in the mm-wave frequency bands where significant technological development has occurred to enable 5G utilization in frequencies that have not previously been used for mobile technology (and hence, where entirely new components are needed to develop a mobile ecosystem for equipment and devices).

Agenda item 1.13 of the International Telecommunications Union (ITU) World Radio Conference in 2019 (WRC-19) will consider global mobile allocations in the mm-wave portion of spectrum, and identification of sufficient spectrum for 5G use. This agenda item identifies multiple bands above 24.25GHz for study, grouped around several mm-wave bands (below 30GHz, around 40GHz, around 50GHz and around 80GHz), which are indicated in the diagram below.

Figure 3.5: mm-wave bands under study for global 5G use, in preparation for WRC-19 [Source: Analysys Mason, 2018]

Regulators in countries in different world regions are taking steps to make spectrum available for 5G. 5G spectrum auctions are scheduled to take place in some markets during 2018 (e.g. Italy, Spain, and the UK). Examples of selected approaches to 5G spectrum assignment in several markets are summarized below.

Frequency bands for 5G

US: The FCC has adopted rules[14] to make a large amount of high-band spectrum available for 5G: 3.85GHz of licensed spectrum in the 28GHz band (27.5–28.35GHz), the 37GHz and 39GHz bands, 7GHz of unlicensed spectrum in the 64–71GHz band, as well as 700MHz in the 24GHz band and 1GHz in the 47GHz band. Indications are that the FCC intends to conduct an auction of 28GHz spectrum, followed by 24GHz spectrum, in November 2018. The FCC also plans to make spectrum available in the 3.5GHz CBRS band on a shared basis and has announced a Notice of Inquiry into the 3.7-4.2GHz band. The NTIA has also announced a study into the availability of the 3.4-3.5GHz band for 5G services.

China: In November 2016, the MIIT stated that it intended to assign over 100MHz of spectrum per MNO in the mid-band, and 2GHz of spectrum per MNO in the high-bands for 5G. In November 2017 the MIIT confirmed that it had reserved the 3.3–3.6GHz and 4.8–5.0GHz ranges for 5G, with the 3.3–3.4GHz range limited to indoor use. In July 2017, the MIIT approved two mm-wave bands (24.75-27.5GHz and 37-42.5GHz) for research and testing.

14 The FCC operates using a 'rule making' process, meaning that the FCC develops new rules – which are notified to the market, consulted on and revised based on industry comment – to implement decisions about changing the use of a spectrum band or making spectrum available for a particular purpose.

Japan: The Ministry of Internal Affairs and Communications (MIC) has launched a strategy to make 5G a reality by 2020, in time for the 2020 summer Olympics. Spectrum in the following frequency bands is expected to be released for 5G by March 2019: 3.6–4.2GHz, 4.4–4.9GHz and 27.5–29.5GHz.[15]

Korea: The Korean government has announced plans to award 5G spectrum licenses by mid-2018, and an auction of licenses to use spectrum in the 3.5GHz and 28GHz bands for commercial 5G networks is expected. Trials between SK Telecom and Samsung using the 3.5GHz band have already taken place, demonstrating speeds of over 1Gbps and latency of around 1millisecond.

Hong Kong: The Communications Authority plans to make spectrum in both the 26GHz and 28GHz bands available for 5G. Current users of the 26GHz band are required to vacate this band by 2019. The 28GHz band is already vacant and the Communications Authority plans to assign both bands to 5G in 2019 at the earliest. The Authority is also proposing to assign the 700MHz and 3.4–3.7GHz bands for mobile services by 2020.[16]

Italy: The Italian regulator is expected to auction spectrum in the 3.4–3.8GHz band to develop 5G services during 2018 as well as spectrum in the 700MHz and 26GHz bands.

Spain: An auction of the first tranche of 5G spectrum in Spain is scheduled in early 2018. Spectrum to be awarded includes 200MHz in the 3.6–3.8GHz band and 40MHz in the L-band.

UK: In line with proposals agreed with other countries in the European Union (EU), Ofcom is planning to make spectrum in the following bands available for 5G: 700MHz, 3.4–3.8GHz and 24.25–27.5GHz. The 700MHz band will be made available by Q2 2020, with 150MHz of spectrum being awarded in the 3.4GHz band, along with spectrum in the 2.3GHz band, in early 2018. A call for input on making the 26GHz band available for 5G was published by Ofcom in 2017, and it is understood that Ofcom will publish further proposals on making mm-wave spectrum available for 5G during 2018.[17]

3.6 5G development timelines

5G services are being planned for introduction in leading markets beginning in 2018, with rapid deployment across many developed and developing nations expected thereafter. Recently, operators in several leading markets have accelerated their 5G plans to launch commercially before 2020.

This section compares the timelines of 5G development in the benchmark countries. For each market, we constructed a timeline showing the key 5G developments to date (including MNO- and/or government-led trials, publication of key 5G strategy/roadmap documents by the regulator, government commitment to 5G leadership including funding, policies for infrastructure development, etc.), as well as forecast commercial launch dates of MNOs.

It should be noted that (for purposes of simplicity) the events shown in the diagrams below represent Analysys Mason's view of the key milestones in each country towards 5G launch; further detailed information can be found in the individual country case studies in Annex B. It should also be noted

15 See Annex B for details.

16 http://www.coms-auth.hk/en/media_focus/press_releases/index_id_1423.html and http://www.ofca.gov.hk/en/media_focus/press_releases/index_id_1441.html

17 See Annex B for details.

that the timelines do not generally feature spectrum-related events (such as dates of spectrum auctions occurring), which are considered separately in Section 4.

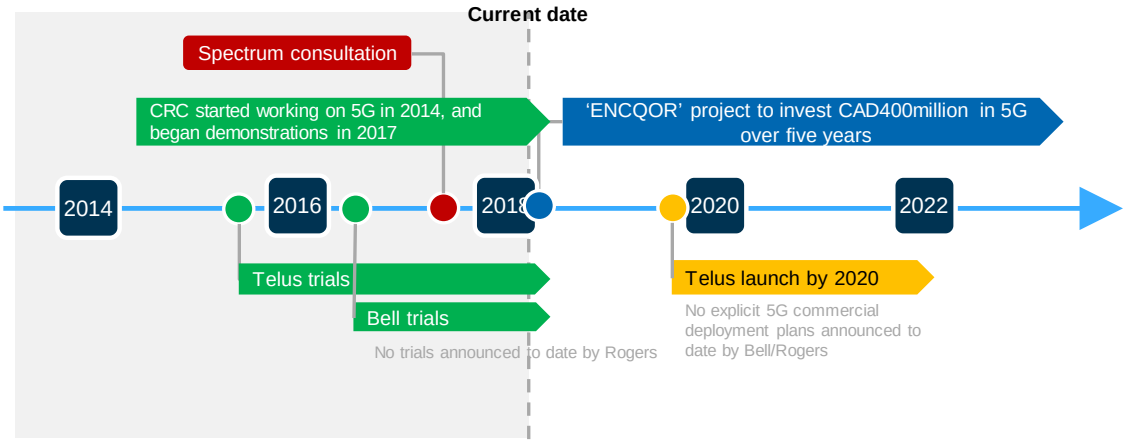
The color coding used in the timelines is shown in Figure 3.6 below.

Figure 3.6: Color coding used in the 5G launch timelines [Source: Analysys Mason, 2018]

Canada

In Canada, the Communications Research Centre (CRC), which is a part of the government department with overall responsibility for spectrum management, ISED, has been conducting 5G R&D since 2014, however licensing of spectrum for 5G networks is still at a preliminary consultation stage. To date, one operator (Telus) has made an explicit commitment to a commercial 5G launch, by 2020.

Figure 3.7: Canada – 5G launch timeline[18] [Source: Analysys Mason, 2018]



China

In China, the government's 'Made in China 2025' initiative[19] and its latest Five-Year Plan aim for a commercial launch of 5G by 2020. China's three MNOs have each committed to this timeline, with recent reports also suggesting that steps are being taken within China to accelerate 5G

18 In Canada, Innovation, Science and Economic Development (ISED) is the government department responsible for spectrum management. The Communications Research Centre (CRC) is part of ISED.

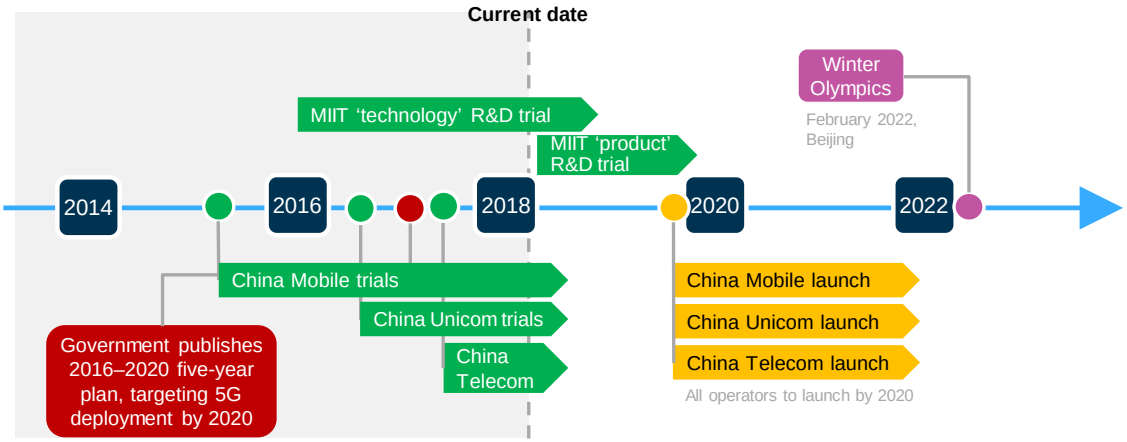
19 'Made in China 2025' is a national initiative to transform China into a leading nation globally for high-quality manufacturing across multiple priority sectors, including information technology, robotics, vehicles and rail.

technology research and development, to 'gain a lead in the race towards commercializing the next-generation communication technology'.[20]

Of particular note in relation to the timing of 5G launch in China is that the Ministry of Industry and Information Technology (MIIT) has initiated a third phase of research and development (R&D) tests on pre-commercial 5G products ahead of schedule. This is reportedly to ensure that pre-commercial products have been fully tested by the time that 3GPP finalizes its Release 15 specifications in June 2018.[21]

GSMA and others have forecasted over 400 million 5G connections in China by 2025.[22]

Figure 3.8: China – 5G launch timeline [Source: Analysys Mason, 2018]



France

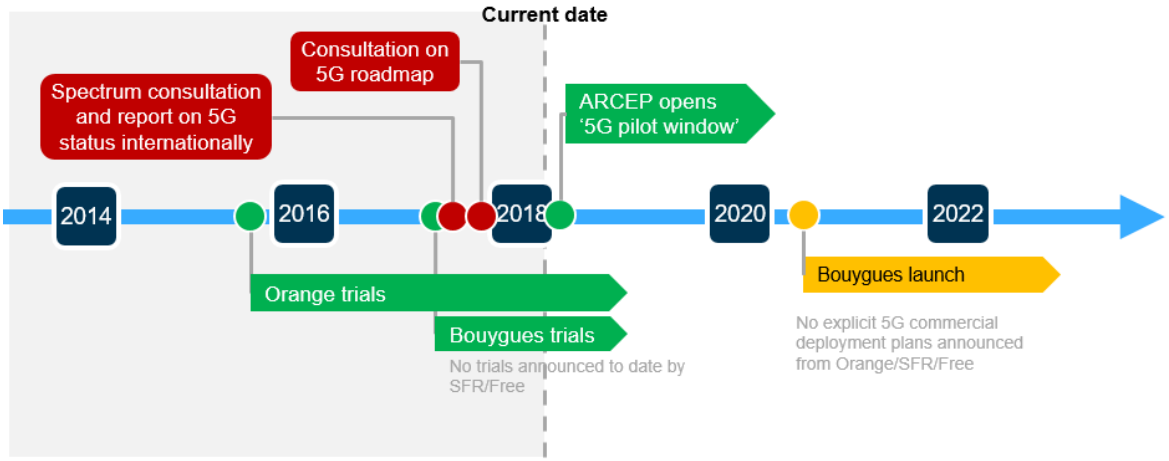
In France, ARCEP issued a statement in early 2018 indicating that it wishes to promote the establishment of 5G trial networks. As an encouragement for operators to do so, ARCEP has opened a '5G pilot window' at the beginning of 2018, offering trial licenses in selected locations within spectrum that is envisaged to be released for commercial 5G deployment in France (which, in line with European policy, is in the 3.5GHz and 26GHz bands). At the time of producing this report, we are only aware of one MNO (Bouygues) that has made an explicit commitment to a commercial launch date, although other MNOs are conducting extensive 5G trials.

20 http://www.chinadaily.com.cn/business/tech/2017-11/25/content_34969958.htm

21 http://www.china.org.cn/china/2017-11/26/content_41945867.htm

22 https://www.gsmaintelligence.com/research/?file=67a750f6114580b86045a6a0f9587ea0&download

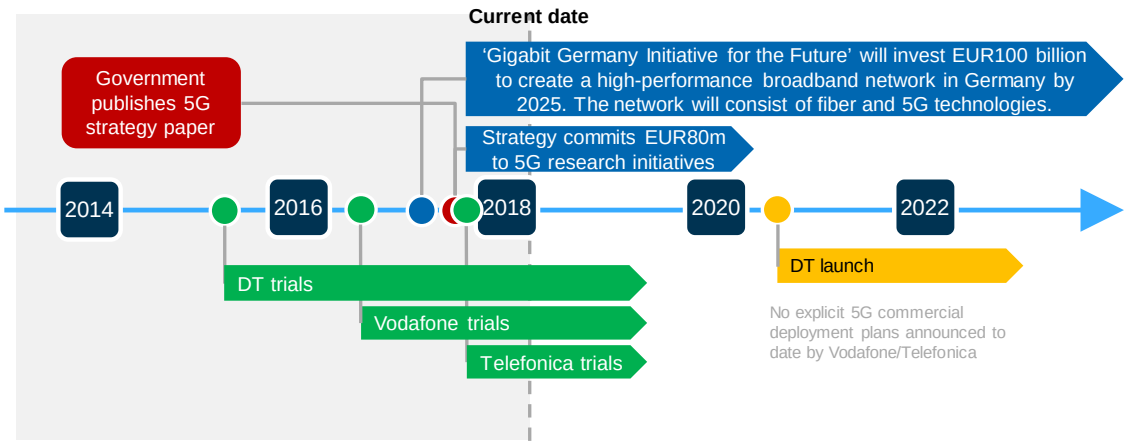
Figure 3.9: France – 5G launch timeline [Source: Analysys Mason, 2018]



Germany

In Germany, the federal government published a formal 5G strategy paper in September 2017, which commits EUR80 million of funding to 5G research initiatives. More broadly, the government's 'Gigabit Germany Initiative for the Future' will see investment of EUR100 billion to create a high-performance broadband network in by 2025. The network will consist of the "most sophisticated technologies available" such as "fiber optics and […] 5G". To date, one of Germany's three MNOs, Deutsche Telekom, has published plans for a commercial launch in 2020, although other MNOs are conducting 5G trials.

Figure 3.10: Germany – 5G launch timeline [Source: Analysys Mason, 2018]

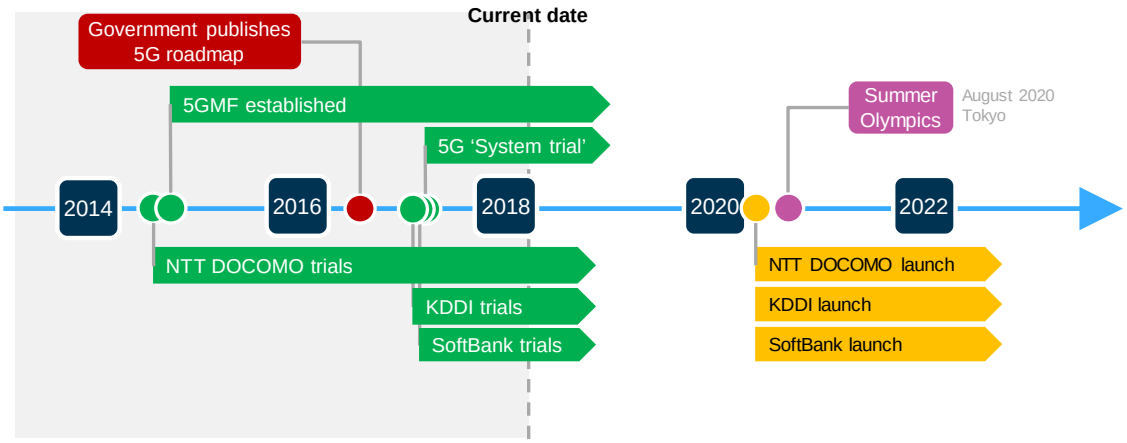


Japan

In Japan, all three MNOs have committed to launching 5G services for the August 2020 Summer Olympics in Tokyo. The Japanese government established the 5G Mobile Forum (5GMF) in September 2014 to promote 5G development and has since published a number of 5G strategy/roadmap documents. We understand, based on the research conducted for this study, that

spectrum authorization for commercial 5G launch is anticipated both for mid-band frequencies and in mm-wave bands.

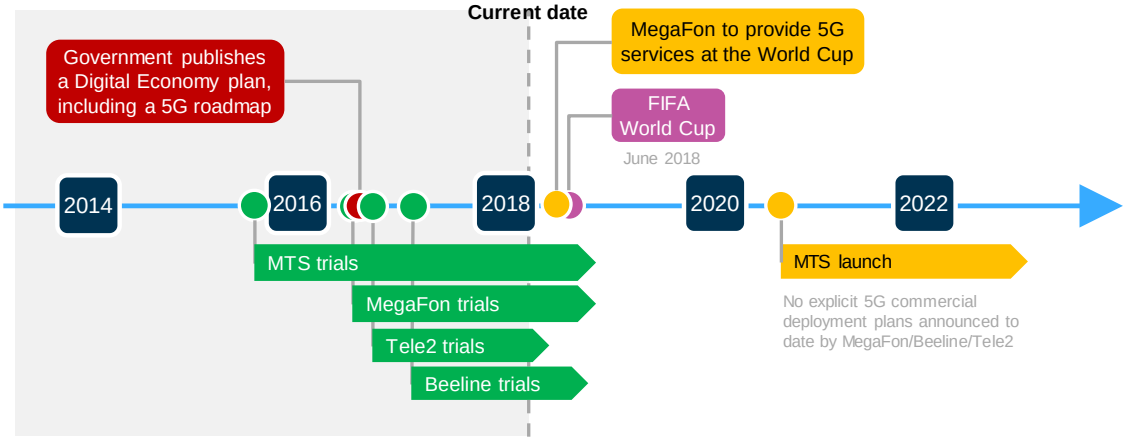
Figure 3.11: Japan – 5G launch timeline [Source: Analysys Mason, 2018]



Russia

In Russia, the government published its 'Digital economy of the Russian Federation' plan, which includes a 5G roadmap, in July 2017. One operator, MTS, has indicated a commercial launch date, but it is understood that other operators, including MegaFon, aim to provide pre-commercial 5G services at the 2018 FIFA World Cup. Timelines for 5G spectrum licensing have not been published.

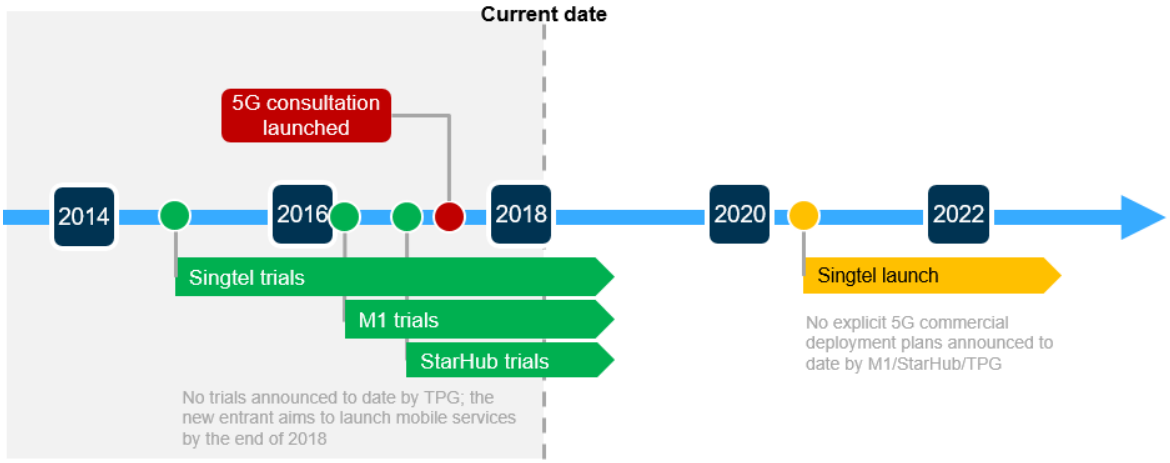
Figure 3.12: Russia – 5G launch timeline [Source: Analysys Mason, 2018]



Singapore

In Singapore, 5G development is underway, with the government launching its first consultation in May 2017. Singapore's MNOs (excluding new entrant TPG) have announced 5G trials, and Singtel has stated plans to launch commercial services in 2020. It is understood that the Singaporean regulator, IMDA, is currently studying the use of several frequency bands for 5G ahead of detailed 5G spectrum assignment plans being confirmed.

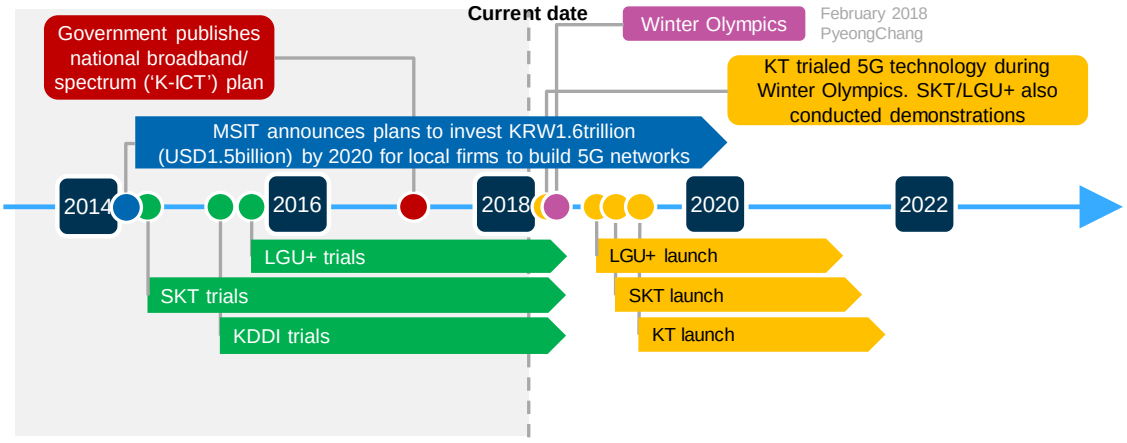
Figure 3.13: Singapore – 5G launch timeline [Source: Analysys Mason, 2018]



South Korea

In South Korea, the Ministry of Science and ICT (MSIT, formerly MSIP) announced plans to commit funding to 5G in January 2014. The plan promised to invest KRW1.6 trillion (USD1.5 billion) by 2020 for local firms to build 5G networks. The Winter Olympics, held in PyeongChang in February 2018, was a significant focus for showcasing 5G technologies. KT was an official partner of the Olympics and offered a range of 5G-based services, while SK Telecom and LG UPlus also conducted 5G demonstrations. All three operators are competing to offer the first 5G services, committing to dates in 2018/19.

Figure 3.14: South Korea – 5G launch timeline [Source: Analysys Mason, 2018]

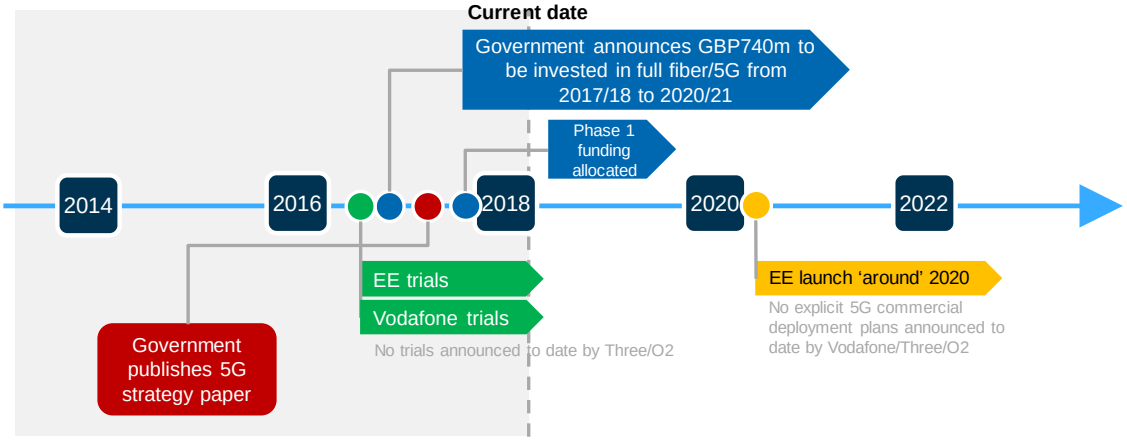


United Kingdom (UK)

In the UK government's autumn budget statement in 2016, the government announced its National Productivity Investment Fund (NPIF), committing GBP740 million (USD1 billion) of government seeded funding to 5G trials and to 'full fiber' deployment across the UK by 2020/21. The government published a 5G strategy paper in March 2017, providing more detailed descriptions of

the government's aims to foster the development and deployment of 5G in the UK. The 2017 government budget announcement also included a further GBP160 million of funding (USD222 million) to invest in 5G infrastructure. One MNO (EE) has made an explicit commitment to 5G commercial deployment by 2020, and at least one other MNO is undertaking 5G trials in the UK.

Figure 3.15: UK – 5G launch timeline [Source: Analysys Mason, 2018]



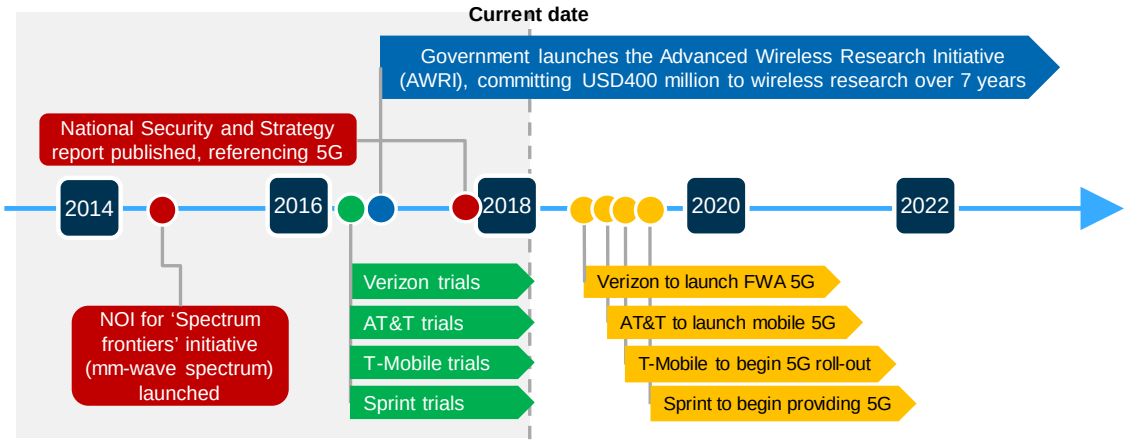
US

In the US, a Notice of Inquiry (NOI) for the 'Spectrum Frontiers' initiative, which aimed to release a large amount of mm-wave spectrum for 5G, was released in October 2014, followed by a notice of proposed rulemaking (NPRM) in 2015 and a further notice of proposed rulemaking (FNPRM) in 2016, aimed at making available spectrum in the 27.5–28.35GHz, 37–40GHz and 64–71GHz bands for 5G use. In 2017, a report and order (R&O) and further FNPRM were published in relation to additional high-frequency spectrum availability for terrestrial wireless use in the 24GHz and 47GHz bands. Recent reports suggest that the FCC is seeking to auction additional mm-wave spectrum in the 28GHz band, followed by the 24GHz band, in November 2018.[23]

All four national operators reported conducting trials towards the start of 2016 and have committed to commercial 5G launch prior to 2020. Verizon and AT&T have announced plans to launch in specific areas during 2018, while T-Mobile and Sprint expect to deploy 5G networks in 2018 and 2019. T-Mobile has stated that it expects to begin a 5G mobile roll-out using 600MHz spectrum in 2019 and is targeting a full nationwide network by 2020. T-Mobile recently announced plans for the initial build-out of 5G in 30 cities by the end of 2018. Sprint announced it would use its 2.5GHz spectrum holdings and deploy massive MIMO in key cities to prepare for its 5G network launching in 2019.

23 https://www.fiercewireless.com/5g/fcc-chief-wants-to-auction-28-ghz-spectrum-november

Figure 3.16: US – 5G launch timeline [Source: Analysys Mason, 2018]*



* The AWRI initiative is not a specific 5G initiative (see Section B.10 for details)

4 Making new spectrum available for 5G

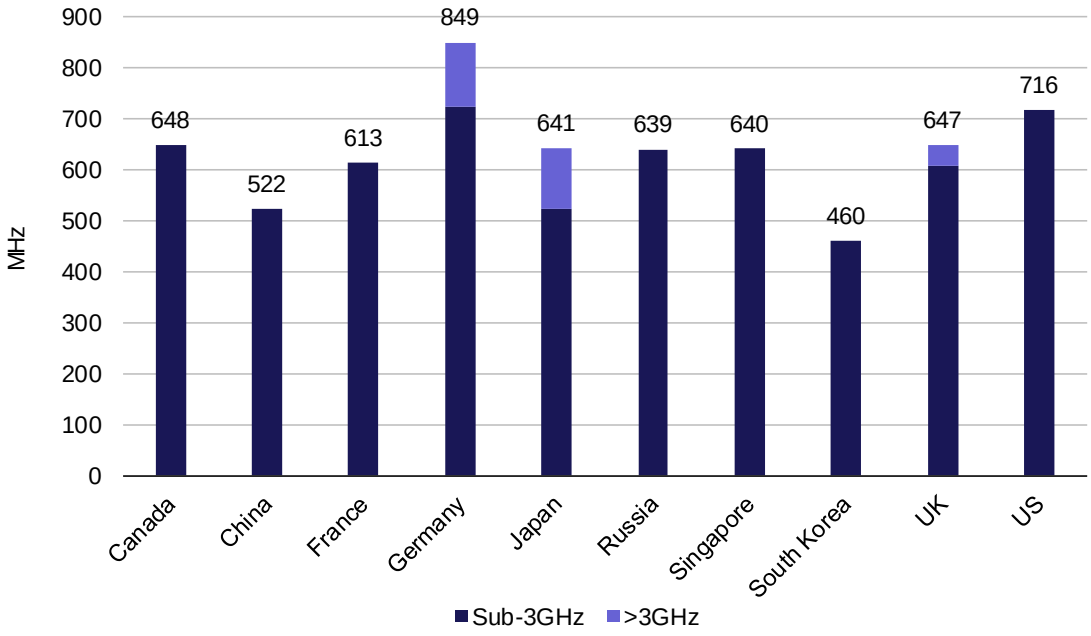
This section provides a detailed assessment of the planned availability of 5G spectrum in the benchmark countries that we have studied as part of this work. We assess the status of planned spectrum awards for 5G in low-, medium- and high-frequency ranges that might be suited to 5G deployment, considering the amount of spectrum to be awarded, type of licensing regime, and timelines for release. We also consider the amount of spectrum currently assigned for mobile use in each market.

4.1 Description of current mobile spectrum utilization in different markets

The spectrum used for mobile services in different countries today has typically been harmonized internationally for mobile use, resulting in economies of scale for equipment functioning in these harmonized bands. These existing bands are expected to remain within the mobile ecosystem as networks evolve to 5G, and operators are likely to progressively re-purpose existing mobile bands for 5G use as the demand for new services evolves. To date, the frequency bands used by mobile networks have historically been concentrated in bands from around 600MHz to 3.5GHz. 5G will additionally use higher bands, in the mm-wave range, with the lower bands providing possibilities of some early 5G services being delivered over wider geographical areas, depending on the operator's approach to 5G launch.

Figure 4.1 below shows a summary of the current spectrum licensed for mobile use in the countries that we have studied for this report. Currently awarded spectrum is grouped by frequency range (with the ranges shown as below 3GHz, and above 3GHz). As can be seen, all countries studied currently have a comparable amount of awarded mobile spectrum, with South Korea having the least spectrum of those countries (460MHz allocated across the 850/900/1800/2100/2300/2600MHz bands) and Germany the most (849MHz across the 700/800/900/1400/1800/2100/2600MHz and 3.5GHz bands).

Figure 4.1: Currently awarded mobile spectrum in different markets[24,25] [Source: Analysys Mason, 2018]



Further details of currently awarded spectrum are provided in the tables below.

Figure 4.2: Currently awarded total mobile (uplink and downlink) spectrum (by band), countries in ITU regions 1 and 3 [Source: Analysys Mason, 2018]

Country	450	700	800	900	1400	1800	2100	2300	2600	3400	Tot. (MHz)
China	-	-	20	52	-	140	140	70	100	-	**522**
France	-	60	60	70	-	150	133	-	140	-	**613**
Germany	-	60	60	70	40	150	153	-	190	126	**849**
Japan	-	60	60	30	70	70	151	-	80	120	**641**
Russia	9	60	60	50	-	150	120	-	190	-	**639**
Singapore	-	90	-	60	-	150	135	40	165	-	**640**
S. Korea	-	-	50	20	-	110	120	60	100	-	**460**
UK	-	-	60	70	40	143	119	-	175	40	**647**

24 Sub-1GHz bands include the 450, 600, 700, 800 and 900MHz bands (and the 800MHz SMR/Cellular band in the US). 1–3GHz bands include the 1400, 1800, 2100, 2300 and 2600 bands (ITU regions 1 and 3), and the PCS, AWS-1/2/3/4, WCS (2.3GHz) and EBS/BRS (2.5GHz) bands in ITU region 2 (US and Canada). The >3GHz spectrum currently consists exclusively of the 3.4–3.6GHz range. It should be noted that while spectrum is held by operators, it may not necessarily have been deployed, or in current use for providing mobile services.

25 In the US and Canada, spectrum is auctioned and assigned on a regional basis. Values shown for the US represent national weighted average holdings summed across all licensed operators (including non-mobile players such as satellite broadcaster DISH, see Annex B for details).

Figure 4.3: Currently awarded total mobile (uplink and downlink) spectrum (by band[26]), countries in ITU region 2 [Source: Analysys Mason, 2018]

Country	600	700	Cell.	SMR	PCS	H-block	AWS-1	AWS-3	AWS-4	WCS	BRS/EBS	Tot. (MHz)
Canada	-	68	50	-	130	-	90	50	40	30	190	**648**
US	70	70	50	14	130	10	90	65	40	20	156	**715.5**

In several of our benchmark countries, regulators have already awarded spectrum to operators in parts of the 3.4–3.6GHz band, for fixed service use, which is one of the main bands being promoted for early 5G use globally. Under legacy licenses, this spectrum is often used at present to provide a mixture of FWA and nomadic wireless services (or has not yet been deployed). For example:

- Germany has assigned spectrum in the 3410–3452/3510–3552MHz range to Telefonica[27] and in the 3452–3473/3552–3573MHz range to DT. We are not aware of services being offered using this spectrum, though the GSA indicates that Telefonica has been trialing an LTE TDD network using its 3.5GHz spectrum.

- Japan has assigned 40MHz of unpaired spectrum to each of NTT DOCOMO, KDDI and Softbank in the 3.48–3.6GHz range. The exact status of the usage of this spectrum is unclear, though we understand that licenses permit mobile LTE services to be offered.

- UK operator UK Broadband provided LTE TDD FWA services in specific locations of the UK, using its national license in the 3480–3500/3580–3600MHz range. The operator was bought by UK MNO Three in early 2017. The spectrum held by UK Broadband also includes a national license in the 3605–3689/3925–4009MHz range, although it is understood that this spectrum was previously used only for fixed (point-to-point/point-to-multipoint) links, within the UK broadband services.

These 3.4–3.6GHz spectrum holdings have been included in the chart of current mobile spectrum holdings above.[28] However, we note that where the spectrum is used to provide (or has been licensed for) FWA use, licenses may need to be re-awarded for the purposes of delivering 5G services (and that regulations enabling mobile devices to operate in these frequencies might also be required).

We also note that certain markets have already assigned significant amounts of spectrum for testing in this range. In particular, we understand[29] that at least two of the Chinese MNOs have had access

26 Abbreviations for spectrum bands: Cell. (Cellular), SMR (Specialized Mobile Radio Service), PCS (Personal Communications Service), AWS (Advanced Wireless Service) WCS (Wireless Communications Service), BRS (Broadband Radio Service), and EBS (Educational Broadband Service).

27 Telefonica recently announced that it had sold half of this spectrum to Vodafone (until 2021). See https://www.telefonica.de/fixed/news/6094/more-high-speed-for-germany-vodafone-and-telefonica-deutschland-to-cooperate-over-fast-fibre-optic-connections-for-mobile-networks.html

28 Canada has allocated 2×75MHz FDD (3475–3550/3575–3650MHz) and 1×25MHz TDD (3550–3575MHz) on a regional basis to a number of FWA broadband providers (including Bell, Rogers and Telus), which operate TD-LTE networks in 3GPP band 42. However, we understand that this spectrum is specifically not considered to be available for commercial mobile services by ISED, and so has not been included in Figure 4.1.

29 See http://www.zdnet.com/article/zte-and-china-unicom-complete-5g-nr-trials/ and https://www.androidauthority.com/qualcomm-zte-china-mobile-5g-trial-814959/

to 100MHz contiguous blocks of mid-band spectrum for 5G testing purposes (see Section B.2 for further details).

4.2 Assessment of 5G spectrum plans in different markets

Based on industry consensus on the spectrum needed for early 5G launch, regulators are making provision for 5G spectrum across a range of frequencies, which we have categorized into low band, mid band and high band (defined as sub-3GHz, 3–24GHz and above 24GHz, respectively). Below we assess 5G spectrum plans in each of these ranges in turn.

Low-band spectrum (sub-3GHz)

Regarding low-band (sub-3GHz) spectrum, various mobile auctions/assignments are being scheduled. Figure 4.4 below shows relevant plans for the release of new[30] sub-3GHz spectrum suitable for 5G mobile use, as announced by different regulators.

Figure 4.4: Upcoming mobile spectrum allocations in the sub-3GHz range [Source: Analysys Mason, 2018]

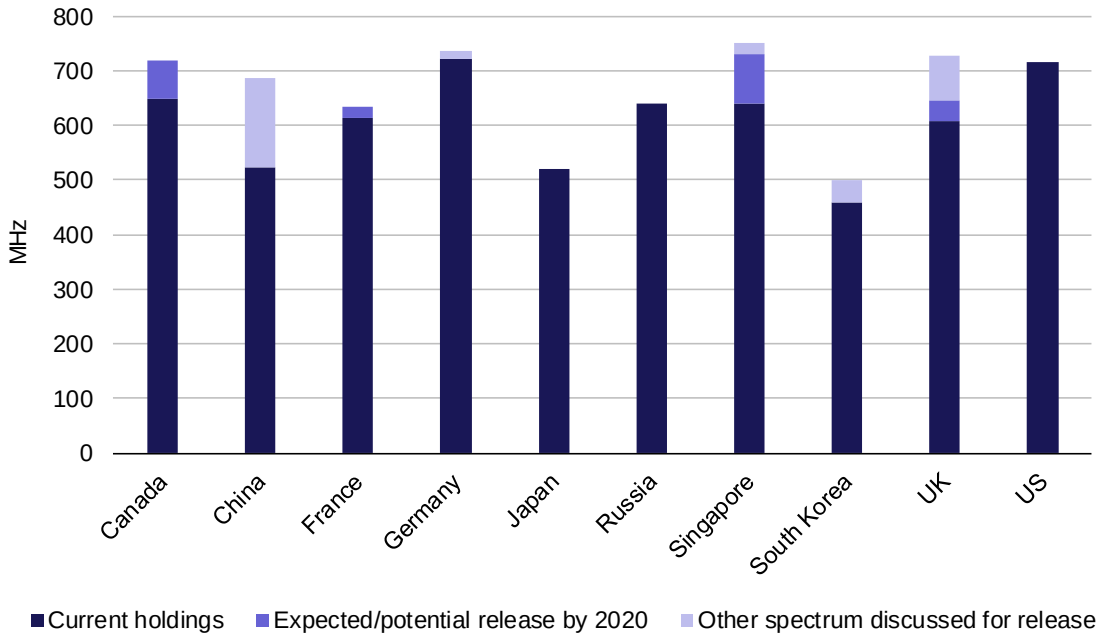
Country	Details
Canada	• A 'residual auction' is scheduled for the beginning of 2018, which will sell regional licenses across a number of bands that went unsold in previous auctions. • A 600MHz auction is expected, which will repurpose 84MHz (614–698MHz) of spectrum and free 70MHz for commercial mobile. A consultation on the band concluded at the end of 2017. • ISED plans to release AWS-2 (1915–1920/1995–2000MHz, 'H-block') spectrum for mobile, and will consult on this band in the future. • ISED has also identified the following 'potential frequency bands that could be made available between 2018 and 2022': 800MHz (806–824/851–869MHz), 900MHz (896–960MHz), L-band (1427–1518MHz) and the AWS-3 unpaired 'I-block' (1694–1710MHz). The regulator will review these bands over the next five years.
China	• A total of 687MHz of spectrum is planned for IMT (4G) use, of which 522MHz has already been assigned. It is not clear in which bands the remaining 165MHz will be identified, although it is understood that assignment of the 700MHz band is likely. • Chinese operators already use the 850MHz and 900MHz bands for pre-5G mobile networks.
France	• ARCEP conducted a public consultation on spectrum availability for 5G from January to March 2017 which focused on assigning additional spectrum to mobile use in the 2.6GHz band and to FWA and public mobile in the 3.4–3.8GHz band (see below). • The consultation also discussed spectrum in the L-band (although unlikely to be auctioned until the entire 1427–1518MHz range is available), the 2.3GHz band (unlikely to be assigned for national use due to current defense use, but might be available in some locations on a shared basis), part of the 700MHz band and the 450MHz band. • Mobile operators in France already use 800MHz and 900MHz spectrum for existing 2G, 3G and 4G mobile services.

30 The focus here is on the release of *new* spectrum (i.e. spectrum previously allocated to non-mobile services).

Country	Details
Germany	• The German regulator was the first regulator in Europe to auction licenses for use of the 700MHz band, in 2015. • The regulator is understood to be preparing for release of spectrum in the 450MHz band for critical infrastructure use. • Mobile operators in Germany already use 800MHz and 900MHz spectrum for existing 2G, 3G and 4G mobile services.
Japan	• A consultation was published by the Japanese Ministry of Communications (MIC) in July 2017, indicating that the in order to make more spectrum available for mobile use, the regulator would promote frequency sharing or reallocation of incumbent services in the 1.7GHz (1710–1750/1810–1850MHz), 2.3GHz (2300–2330/2370–2400MHz) and 2.6GHz (2500–2545/2645–2690MHz) bands. In December 2017, the MIC consulted on assigning the 1700MHz spectrum by March 2018 (along with the 3.4–3.48GHz range).
Russia	• An auction of spectrum in the 450MHz band for mobile use in five Russian regions is scheduled to take place by Q2 2018. • 5G spectrum award plans are unclear, with the government's 5G roadmap scheduling that a formal decision regarding spectrum is to be made in 2018.
Singapore	• The IMDA ran a 5G consultation in mid-2017. Noting that a 2×10MHz portion of the 800MHz band is scheduled to be released for mobile telecom around 2021, the consultation sought comment on whether further sub-1GHz spectrum for mobile usage is needed. • The consultation also states that the IMDA is 'exploring the possibility' of allocating the 1427–1518MHz (L-band).
South Korea	• In South Korea's most recent auction (May 2016), spectrum in the 700MHz band (2×20MHz) remained unsold; we expect MSIT may choose to re-auction this block in the future.
UK	• In July 2017, Ofcom announced final rules for the award of spectrum in the 2.3GHz and 3.4GHz bands for mobile. 40MHz of 2.3GHz spectrum and 150MHz of spectrum in the 3.4–3.6GHz band is scheduled to be auctioned in early 2018. • Ofcom is also in the process of clearing the 700MHz band for mobile use, which is expected to make available 2×30MHz of paired spectrum and 1×20MHz of unpaired spectrum in accordance with the harmonized European frequency plan for the 700MHz band. • In December 2017, Ofcom stated that 'our current objective is to make the 700MHz band available for mobile services by Q2 2020', with the auction itself expected in 2018/19. • UK mobile operators already use 800MHz and 900MHz spectrum for existing 2G, 3G and 4G mobile services.
US	• The FCC completed its 600MHz auction in April 2017, repurposing 2×35MHz of spectrum for licensed mobile use. The newly awarded 600MHz spectrum adds to the existing sub-1GHz spectrum already in use in the US in the 700MHz and 850MHz bands. T-Mobile has stated they will use their 600MHz and mm-wave holdings to offer 5G services. • The US Congress introduced legislation in August 2017 identifying the 1300-1350MHz and 1780-1830MHz bands as candidates for reallocation from federal users to non-federal use, and directing the NTIA to submit a report to Congress on relocating incumbent federal users from those bands.

Current and future sub-3GHz mobile spectrum holdings are summarized in Figure 4.5 below.

Figure 4.5: Current and future sub-3GHz spectrum holdings[31] [Source: Analysys Mason, 2018]



Mid-band spectrum (3-24GHz)

The 3.4–3.8GHz range has the most support from vendors globally for 5G use, and regulators in several markets have already released spectrum for mobile in this range (see above).

In all of the benchmark countries studied in this report, regulators have announced plans to release parts of this band for 5G over the coming years under exclusive-use mobile licenses, with the exception of the US (whose three-tiered CBRS band is based on shared spectrum access and is near the bottom of this range), Russia (who has not publicly released any 5G spectrum plans), and Japan (where the regulator plans to award spectrum in the 4.5GHz band for 5G use).

In Europe, the 3.4–3.8GHz range is considered to be the primary band suitable for the introduction of 5G-based services before 2020.

Various countries are also planning or considering the release of other mid-band spectrum for 5G, such as spectrum around 4.5GHz in Japan, and from 4.8–5GHz in China. Figure 4.6 below shows all relevant plans for the release of new mid-band spectrum for mobile in our benchmark countries.

Figure 4.6: Upcoming mobile spectrum allocations in the sub-3GHz range [Source: Analysys Mason, 2018]

Country	Details
Canada	• Canada's 2013 'Spectrum Outlook' intended to make 100–175MHz of spectrum in the 3.4–3.8GHz band available for mobile by the end of 2017, however this target was not reached due (in part) to 'delays in international development' in the band.

31 We have not included spectrum for which assignment plans are at a very preliminary stage. This includes the 2.3GHz and L-band in France, the 700MHz SDL band in Germany, and the 2.3GHz and 2.6GHz bands in Japan.

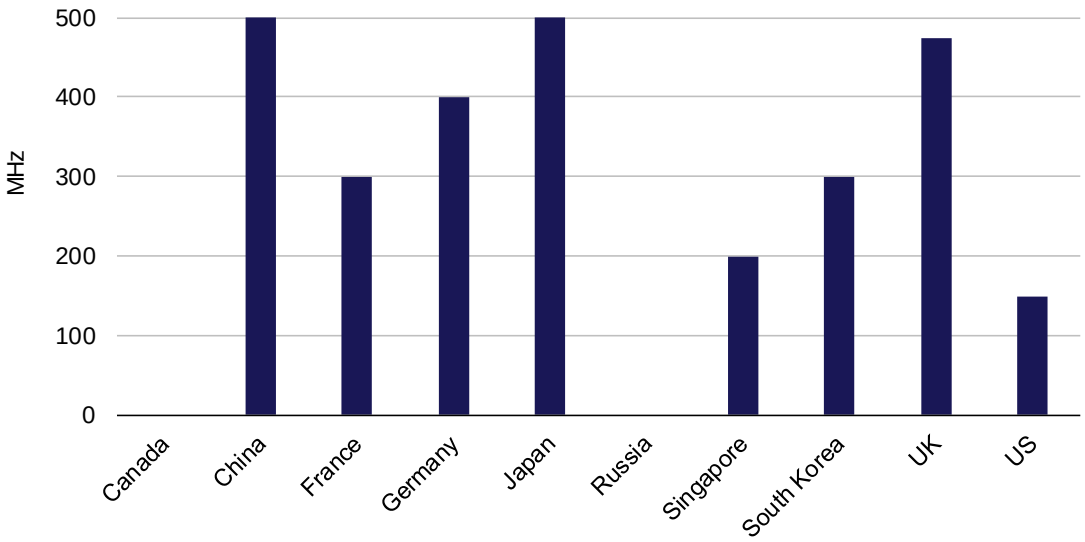
Country	Details
	• Canada's recent 2017 'Spectrum Outlook' (for 2018–2022) stated that ISED will consult on the extended 3.4–4.2GHz range in the future.
China	• In November 2017 the MIIT confirmed that it had reserved spectrum in the 3.3–3.6GHz and 4.8–5.0GHz ranges for 5G, with the 3.3–3.4GHz range limited to indoor use. • Reports also indicate that China is likely to assign the 3.6-4.2GHz range to 5G use in the future, subject to coordination with existing satellite uses.
France	• ARCEP ran a public consultation on new spectrum for 5G from January to March 2017, focusing on the 2.6GHz and 3.4GHz bands. • 40MHz of 3.4GHz spectrum (3420–3460MHz) is to be reserved for FWA in currently underserved areas (with an additional 10MHz (3410–3420MHz) in certain areas, depending on 'coexistence constraints'). • We understand that an auction of the remaining spectrum (up to 3800MHz) is expected in 2018/19. A decision published after the consultation states that ARCEP expects 300MHz of contiguous spectrum to be available for 5G by 2020, and 340MHz (390MHz in areas with no FWA) by 2026.
Germany	• In January 2018, BNetzA published a draft decision confirming its intention to auction spectrum from the 3400–3700MHz (3.5GHz) band (for nationwide use) in 2018; the 3700–3800MHz band is to be made available on a regional basis. Most of the band will not become available until 2022, when incumbent licenses expire.
Japan	• The MIC's July 2017 5G consultation states that in order to address the current mobile spectrum shortage, it will consider the early migration of existing users in the 3.4–3.48GHz range (incumbent licenses expire in November 2022), and aim to release spectrum for mobile use by March 2018. • The MIC has subsequently confirmed intention for spectrum in the 4.4–4.9GHz range to be made available for 5G use, along with spectrum in the 3.6–4.2GHz range.
Russia	• 5G spectrum allocation plans are unclear, with the government's 5G roadmap scheduling a formal decision regarding spectrum to be made in 2018. • However, the SCRF has allocated test licenses in the 3.4–3.8GHz range to some operators.
Singapore	• The IMDA's 2017 5G consultation states that the regulator is 'exploring the possibility' of assigning spectrum from the 3.4–3.6GHz band for mobile use.
South Korea	• South Korea's K-ICT plan released in early 2017 indicates that MSIT plans to release the 3.4–3.7GHz range for 5G by 2018 (auctions are expected in March).
UK	• Spectrum from the 3.4–3.6GHz band will be auctioned by Ofcom during early 2018, along with spectrum in the 2.3GHz band. • In October 2017, Ofcom issued a statement confirming the release of the 3.6–3.8GHz band for mobile use, and beginning the process of vacating existing users. The NRA stated that it expects the spectrum to be 'be deployed in many areas from around 2020, and nationwide by 2022'. This was confirmed in a recent update on spectrum availability in this band for mobile use, issued in February 2018. • In 2016, Ofcom ran a 'Call for Input' on the 3.8–4.2GHz range as 'a candidate band for enhanced spectrum sharing', and for 'potential new innovative applications'. In December 2017, the regulator stated that it would publish a further consultation on further sharing in the 3.8–4.2GHz band in 2018.
US	• The FCC is in the process of licensing the citizens broadband radio service (CBRS) band (3550–3700MHz) for shared wireless broadband use. The spectrum will be made available on a three-tiered sharing basis, designed to allow commercial users to share spectrum with existing federal and non-federal C-band spectrum users. Priority access licenses (PALs) – Tier 2 - will potentially enable mobile operators to provide 5G services within defined geographic areas. The lower tier – Tier 3 – offers use of spectrum on a non-exclusive basis and can be used as soon as the necessary equipment has been certified. A maximum of seven PALs, each of 10MHz in size, will be licensed in any

Country	Details
	given area and these are expected to be auctioned in 2018 or 2019[32] As such, the bandwidth available within the PALs is not sufficient to provide operators with contiguous 100MHz frequency blocks within this band. • In August 2017, the FCC issued a Notice of Inquiry (NOI) on three specific mid-range bands (3.7–4.2GHz, 5.925–6.425GHz and 6.425–7.125GHz) for 'expanded flexible use'. The 3.7-4.2GHz band offers opportunities for application to 5G, building upon the benefits of adjacency to the 3.55-3.70GHz band. • In February 2018, NTIA also identified the 3450–3550MHz band to be studied for potential repurposing to commercial wireless broadband service, potentially fostering international spectrum harmonization, creation of a global equipment market including these bands, and supporting broadband deployment and American leadership in 5G.

Plans for mid-band spectrum in our benchmark countries are illustrated in the following figures, which show the current mobile allocation in the 3.4–6.0GHz range, and the expected amounts of spectrum available in this range for mobile use by the end of 2018, 2019, 2020 and 2022.

A summary of the total amount of mid-band spectrum which has been confirmed for assignment to 5G by 2022 is shown in Figure 4.7 below.

Figure 4.7: Total amount of mid-band spectrum confirmed for assignment to 5G by 2022 [Source: Analysys Mason, 2018[33]]*



(*) China includes 100MHz of spectrum which is dedicated for indoor use. In Japan a maximum of 500MHz will be assigned to 5G across the 3.6–4.2GHz and 4.4–4.9GHz ranges.[34] Existing IMT assignments are included for Germany and the UK.

32 See, for example, https://www.cablelabs.com/meet-cablelabs-tech-policy-whisperer-rob-alderfer

33 Mid-band spectrum is shared among services (terrestrial and satellite), and hence the spectrum available to 5G in different markets will depend on protection requirements to satellite services.

34 In Japan, we exclude the existing and future IMT assignments in the 3.4-3.6 range, since it is not clear whether these will be used for 5G (we note that Japanese MNOs have not conducted 5G trials in these bands – see Section B.5). Furthermore, the MIC's 5G consultation only refers to 3.6-4.2/4.4-4.9GHz ranges with regard to mid-band 5G.

As can be seen, apart from Canada and Russia who have not yet confirmed 5G spectrum plans in this range, the US ranks as one of the lowest in terms of mid-band spectrum availability. While additional spectrum in the mid-band is at an initial consultation stage in the US (see Figure 4.6), only 150MHz of CBRS spectrum has been confirmed for 5G (on a shared basis with existing federal and non-federal uses).

Due to differences in licensing approaches in different markets (including exclusive vs. shared spectrum, national vs. regional licenses, indoor vs. outdoor use, licenses geographically phased-in vs. licenses beginning simultaneously, etc.) as well as variations in the extent to which spectrum is confirmed for commercial use (vs. 'considered', 'potential', or at consultation stage), we have used the color coding shown in the figure below to indicate the status in different countries, and annotated the charts with further details.

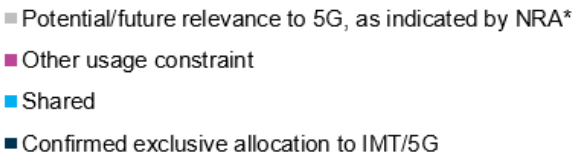


Figure 4.8: Color-coding key for figures [Source: Analysys Mason, 2018]

(*) It should be emphasized that not all spectrum which has been classified as having 'potential/future relevance to 5G' will be assigned to 5G for use in all geographical areas. Mid-band spectrum has several existing uses, and bands are allocated on a co-primary basis between mobile, fixed and satellite services.

Figure 4.9: Current status of mid-band spectrum available for mobile use [Source: Analysys Mason, 2018]

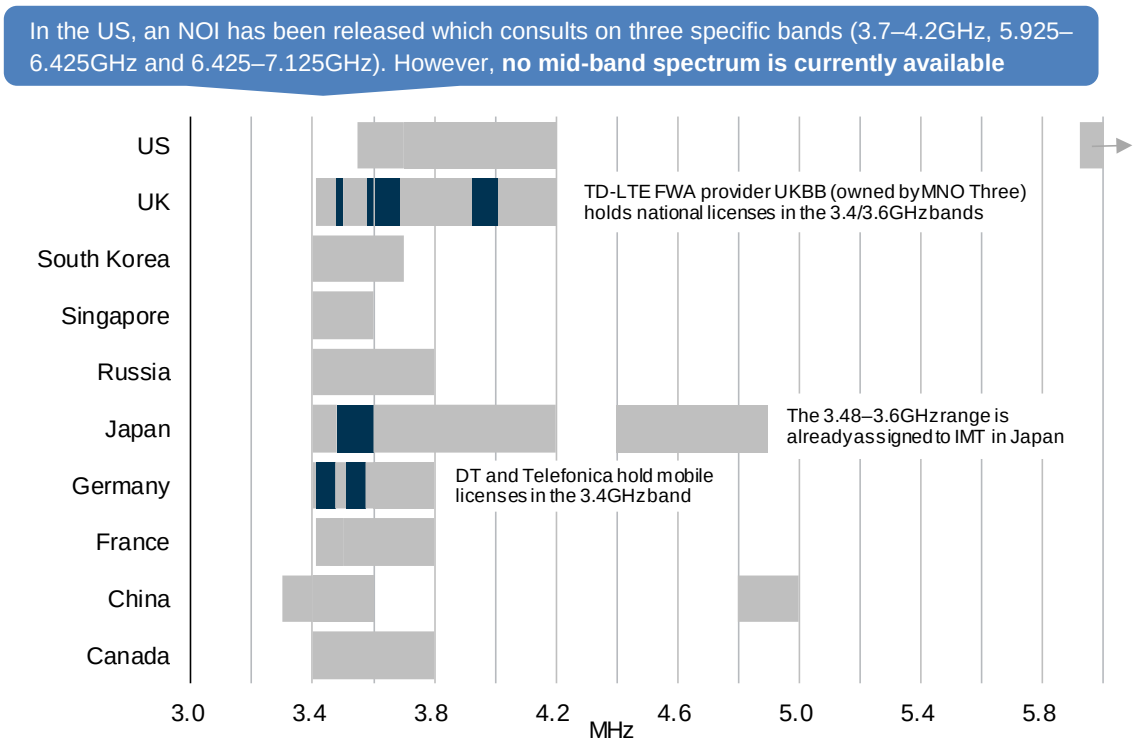


Figure 4.10: Projected status of mid-band spectrum available for mobile use by end of 2018 [Source: Analysys Mason, 2018]

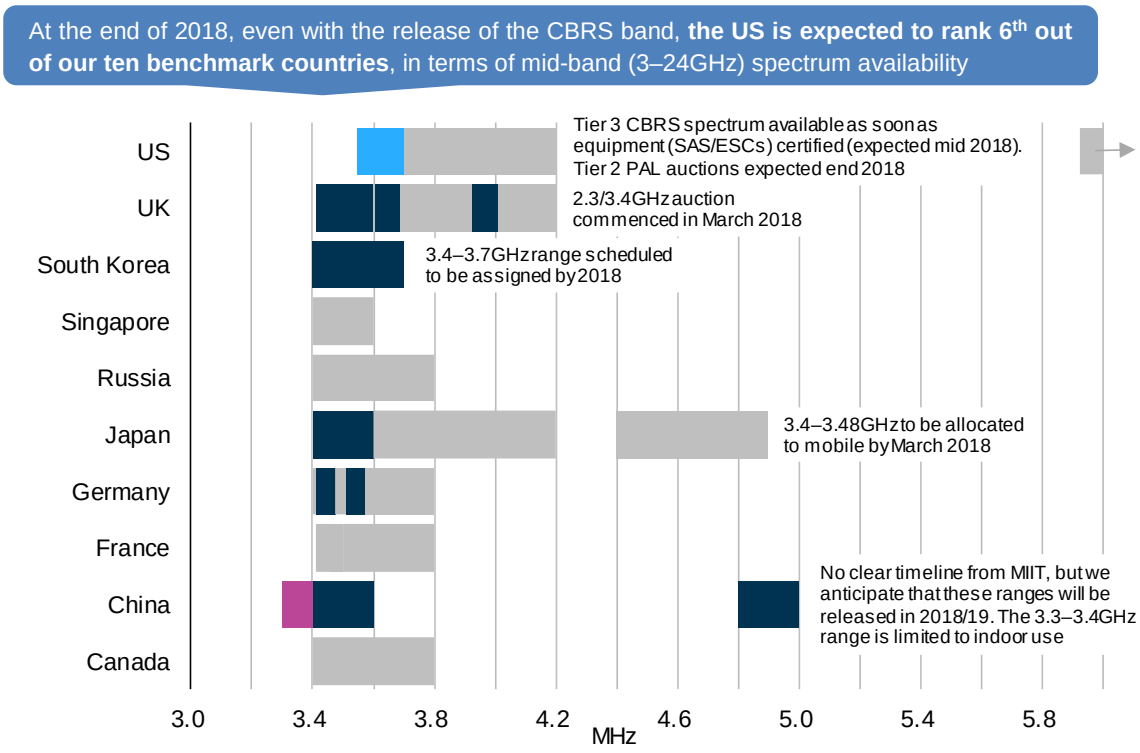


Figure 4.11: Projected status of mid-band spectrum available for mobile use by end of 2019 [Source: Analysys Mason, 2018][35]

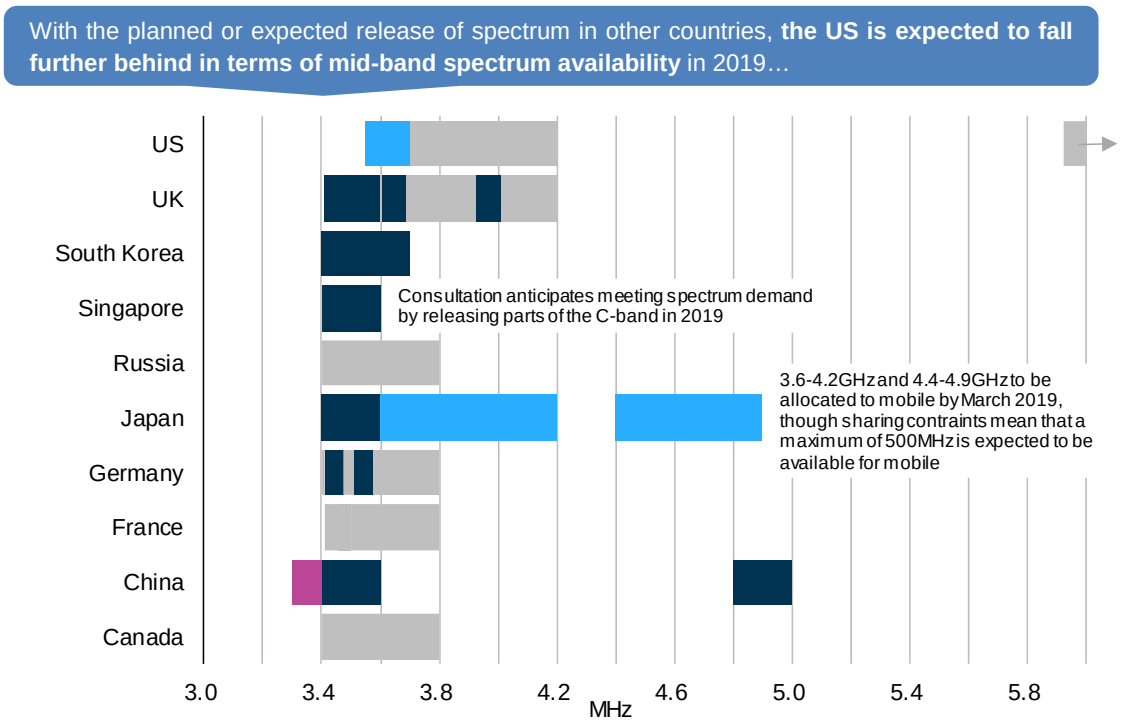
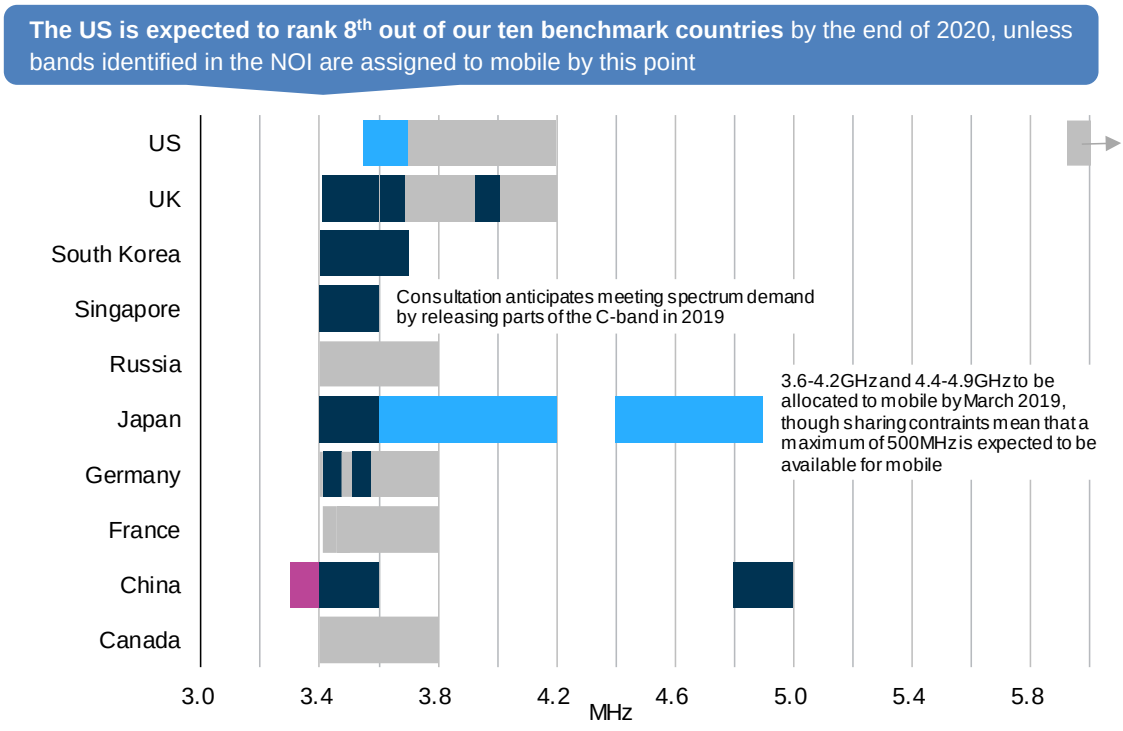
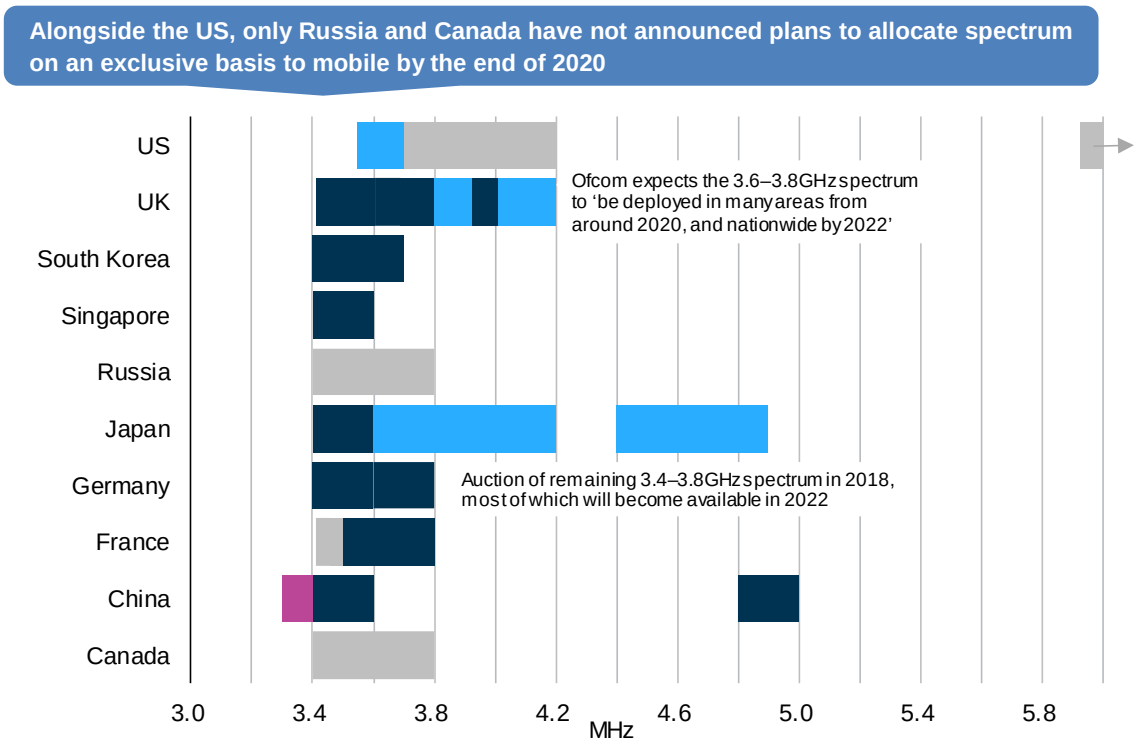


Figure 4.12: Projected status of mid-band spectrum available for mobile use by end of 2020 [Source: Analysys Mason, 2018]



35 As previously noted, there have been recent reports that more mid-band spectrum could be released for 5G in the US, in the 3450–3550MHz range. This spectrum release is being c-ordinated between the National Telecommunications and Information Administration (NTIA), Department of Defense (DOD) and other federal agencies, see https://www.fiercewireless.com/wireless/ntia-could-release-100-mhz-3450-3550-mhz-band-for-5g

Figure 4.13: Projected status of mid-band spectrum available for mobile use by end of 2022 [Source: Analysys Mason, 2018]



High-band spectrum (above 24GHz)

High-band 'mm-wave', referring to bands above 24GHz, has been the focus of significant research and development for 5G by global wireless equipment vendors. A number of bands in this range are being considered for commercial 5G use. The initial 3GPP Release 15 specifications published in December 2017 include specifications for 5G NR use in the 26GHz and 28GHz bands, with further bands expected to be added in subsequent 3GPP releases.

A summary of the plans for mobile spectrum award above 24GHz in each of the countries under study is shown in the table below.

Figure 4.14: Upcoming mobile spectrum allocations in the mm-wave range [Source: Analysys Mason, 2018]

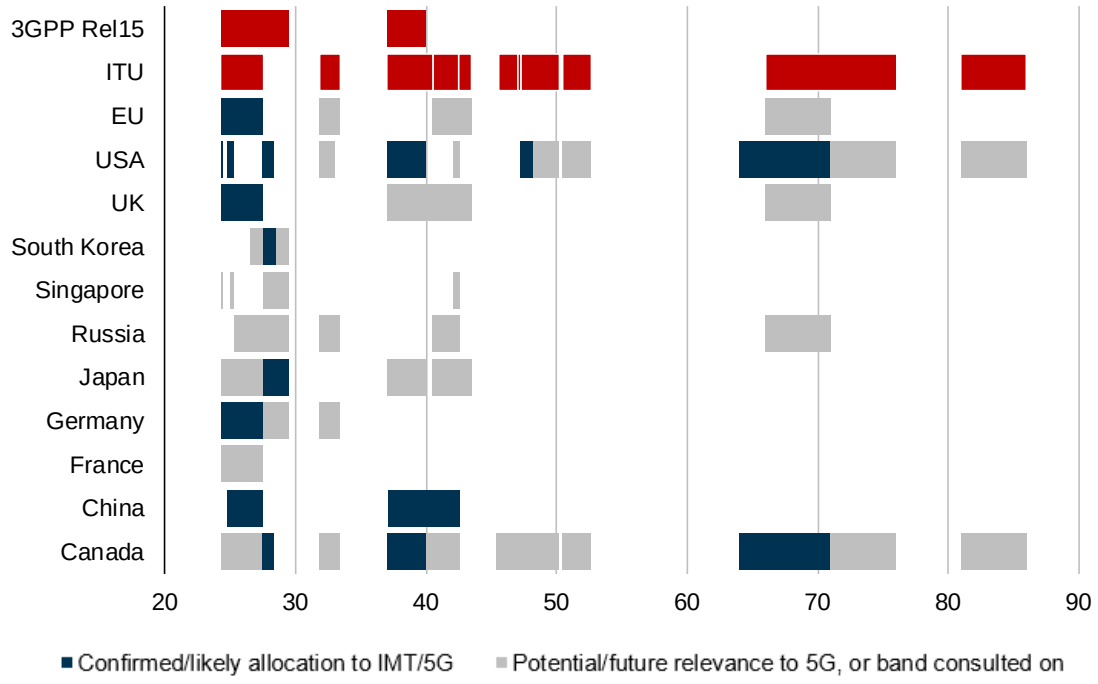
Country	Details
Canada	• ISED is seeking comments on developing a flexible use licensing model for fixed and mobile services in the 28GHz (27.5–28.35GHz) and 37–40GHz frequency bands, and allowing license-exempt use of the 64–71GHz frequency band ahead of WRC-19 and before 5G technology standards are finalized. • ISED's 'Spectrum Outlook' also identifies potential for 5G in a number of other mm-wave bands: 24.25–27.5GHz, 31.8–33.4GHz (32GHz), 40–42.5GHz, 45.5–50.2GHz, 50.4–52.6GHz (51GHz), 71–76GHz and 81–86GHz.
China	• In July 2017, the MIIT approved two mm-wave bands (24.75–27.5GHz and 37–42.5GHz) for research and testing. • The MIIT has stated that it will continue to consider more bands (both low and high frequency) for 5G development.

Country	Details
France	• ARCEP's 2017 consultation on new spectrum for 5G considers usage of the 26GHz mm-wave band for 5G services. We understand that this band would require extensive refarming, and that no firm date has been set for its assignment.
Germany	• BNetzA's June 2017 framework document considers the 26GHz (24.25–27.5GHz), 28GHz (27.5–29.5GHz) and 32GHz (31.8–33.4GHz) ranges, with 26GHz being the most important having been designated an RSPG pioneer band for 5G. • BNetzA aims to develop an approach to releasing these bands for 5G (starting with 26GHz) 'as early as possible so that usage can start in 2020'.
Japan	• Japan's aims to allocate up to 2GHz to mobile by March 2019 (sharing with existing systems) in the 27.5–29.5GHz range. • The MIC's July 2017 consultation also considers all eleven mm-wave ITU bands to be studied internationally ahead of the ITU WRC-19 (in accordance with agenda item 1.13), with a particular focus on bands below 43.5GHz, to enable 5G launch in 2020.
Russia	• 5G spectrum allocation plans are unclear, with the government's 5G roadmap scheduling a formal decision regarding spectrum to be made in 2018. • However, the SCRF has allocated test licenses in the 25.25–29.5GHz range to certain players.
Singapore	• The IMDA's 2017 5G consultation asks for general responses on the role of mm-wave bands, but focuses on the 28GHz band. • The consultation models meeting future spectrum demand with 2GHz in the 28GHz band and 900MHz of other mm-wave spectrum (i.e. 24.25–24.45GHz, 25.05–25.25GHz and 42–42.5GHz, which are 'potential bands for harmonization' in Singapore).
South Korea	• South Korea's K-ICT plan released in early 2017 indicates that MSIT plans to release 1GHz in the 28GHz band (27.5–28.5GHz, with a possible 2GHz extension to 26.5–29.5GHz) for 5G by 2018 (auctions are expected in March).
UK	• Ofcom is undertaking work to make the 26GHz band (parts of 24.25–27.5GHz) available for 5G. • Ofcom also considers the 66–71GHz, and bands around 40GHz (37–43.5GHz) to have significant potential for 5G deployment, with the former band potentially available on a license-exempt basis.
US	• The FCC adopted an R&O in July 2016 that opens up ~11GHz of spectrum for flexible, mobile and fixed use: 3.85GHz of licensed spectrum (27.5–28.35, 37–38.6, 38.6–40GHz) and 7GHz of unlicensed spectrum (64–71GHz). • A second R&O adopted in November 2017 makes a further 1700MHz available for flexible terrestrial wireless use (700MHz in the 24GHz band and 1GHz in the 47GHz band). • An FNPRM also issued in November 2017 seeks comment on another 18GHz of spectrum encompassing 8 additional high-frequency bands: 24.25–24.45GHz together with 24.75–25.25GHz (24GHz band), 31.8–33GHz (32GHz band), 42–42.5GHz (42GHz band), 47.2–50.2GHz (47GHz band), 50.4–52.6GHz (50GHz band), 71–76GHz band together with the 81–86GHz bands (70/80GHz bands), and bands above 95GHz. • In February 2018 the FCC announced plans to auction 28GHz spectrum in November 2018, followed by the 24GHz shortly thereafter.

Figure 4.15 below shows the mm-wave bands confirmed or being considered for 5G in each of the countries under study. Timelines for the release of high-band spectrum are generally less well developed than those for mid-band spectrum in several of the markets under study. Due to uncertainty regarding the precise bandwidth to be available for 5G use in different mm-wave bands in most of the countries studied, we have not projected precise availability of bandwidth at different points in the future. Rather, we have illustrated all bands under study in each country, with a color

code to distinguish between bands in which 5G authorization has been confirmed or is expected to be confirmed for 5G, and bands which are 'potential' or under some other type of preliminary study.[36]

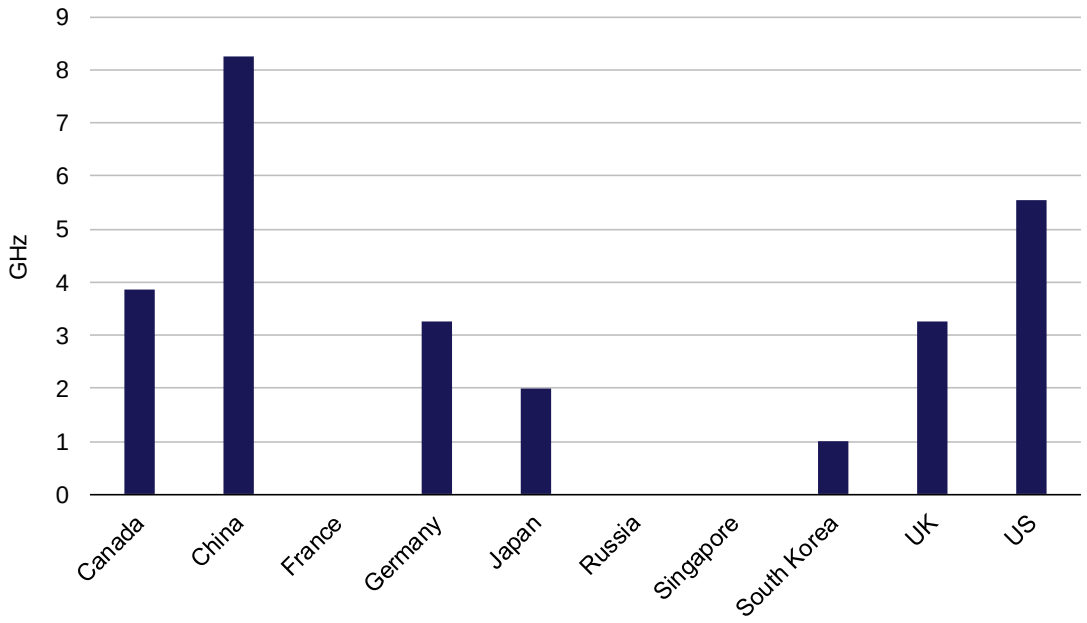
Figure 4.15: Mm-wave spectrum considered/confirmed for 5G [Source: Analysys Mason, 2018]



The total amount of high-band spectrum confirmed for assignment to 5G (on a licensed basis) in each of our benchmark countries is shown in the figure below.

36 It is noted that different forms of authorization might apply between different mm-wave bands for 5G, e.g. spectrum in the 60–70GHz range is typically being considered for use under an unlicensed authorization, whereas individual authorizations are more commonly being considered for 5G use in other bands. In some markets, licenses to use some of the mm-wave bands under consideration for 5G have already been issued, but further 5G-specific authorizations (e.g. to allow mobile devices to operate in these bands) will be needed.

Figure 4.16[37]: Total amount of high-band spectrum confirmed for assignment to 5G on a licensed basis [Source: Analysys Mason, 2018]*



* This excludes the 66-71GHz unlicensed band.

As can be seen, China has potentially confirmed the largest amount of high-band spectrum as being awarded for 5G use amongst our benchmark countries[38]. However, details of the bandwidth to be assigned for 5G use in these bands in China, taking account of existing uses, is not known. Hence, the usable spectrum for 5G could be less than that shown.

37 An earlier published version of this report incorrectly counted the 66-71GHz band for the US in Figure 4.16.

38 In China we count the two mm-wave bands (24.75–27.5GHz and 37–42.5GHz) which the MIIT has released for 5G research and testing. While these bands have not formally been confirmed for 5G, we consider it to be a likely indication of spectrum which will be awarded in China.

5 International examples of infrastructure policies for 5G

As discussed in Section 3.4, there are several infrastructure-related challenges inherent in the evolution of mobile networks to 5G, both to deploy 5G technology at existing macro sites, and to densify networks using small cells.

There has been discussion in several markets about overcoming these barriers. This section provides several examples of infrastructure policies from around the world[39] that we have identified through our research for this study as being designed to facilitate the deployment of 5G technology. In each case, we have provided an overview of the policy being implemented (or considered for implementation), and a description of the observed or anticipated impact on 5G deployment.

We have categorized our examples into two groups: policies formulated at a national (or supra-national) level, and policies implemented at a local (city, borough or state) level. The former tends to comprise regulations concerning planning, rights of access and taxation, as well as broader government strategies at a nationwide level. The latter may simply consist of the implementation of national legislation at a local level, or independent policies adopted by local governments.

The examples are not intended to be an exhaustive account of mobile infrastructure policies adopted in different jurisdictions. Rather, they are intended as a selection of the approaches being implemented in the countries we have studied in relation to 5G planning, which shed light on the importance of (and approach to) 5G infrastructure policy in the race to 5G.

It is noted that emphasis by several policy makers to 'remove barriers' to infrastructure deployment might be motivated by several goals including more rapid initial deployment, and encouragement of additional investment (e.g. to extend coverage from new networks to a wider proportion of users). Desire to accelerate the rate of deployment of new infrastructure might be motivated by international examples from the 3G/4G era of rapid infrastructure deployment in some markets – such as in China, where rapid deployment of 4G base stations (exceeding typical industry benchmarks for wireless site deployment rates) has been achieved.[40]

5.1 National-level examples

Singapore – allowing MNOs space to deploy equipment within buildings

The main piece of legislation in Singapore relevant to the deployment of (mobile) telecommunications infrastructure is the Code of Practice for Info-communication Facilities in Buildings (COPIF). Singapore is updating the Code to make it easier for MNOs to deploy equipment in buildings.

39 We have considered both specific legislative reforms and more general policy statements.

40 https://technology.ihs.com/423948/china-mobile-jumps-ahead-of-domestic-rivals-in-4g-deployment

Main goals: The purpose of the COPIF is to ensure that developers/owners of buildings provide adequate space and facilities to telecommunications providers, so that they can deploy and operate the equipment required to provide services to their buildings.

What is being proposed: In April 2017, the IMDA[41] launched a public consultation,[42] proposing the following revisions to the COPIF:

- Expand the scope of the Mobile Deployment Space (MDS[43]) by designating building rooftops as the preferred MDS location, and allowing the use of the MDS to serve external areas.
- Allow MNOs to determine the location of the MDS, in consultation with building developers or owners.
- Clarify that the Mobile Coverage Area (MCA), which is used to calculate the MDS, should be based on the floor area of the buildings, as well as the total site/land area.

Implementation timing: The consultation closed on June 21, 2017, and the IMDA has published the responses.[44] As of February 2018, the implementation of the proposed changes remains pending.

Impact for 5G deployment: The revisions are designed (amongst other things) to ease the deployment of mobile infrastructure (including small cells). The consultation specifically states that the changes to the scope of the MDS will "allow every Mobile User, building and development to benefit from the enhanced mobile coverage derived from inter-dependent rooftop deployments". While 5G is not explicitly mentioned, the intention is to "keep pace" with the evolution of the telecommunications market in Singapore, and the "pervasive adoption of smartphones and other mobile broadband enabled devices".

Singapore – partnering with MNOs to establish a HetNet

Singapore's 'Infocomm Media 2025' plan,[45] published in 2015, aims to "create a globally competitive infocomm media ecosystem that enables and complements Singapore's Smart Nation vision". A key component of the plan is the implementation of a heterogeneous network (HetNet), which the IMDA is trialing in partnership with industry parties.

41 The Infocomm and Media Development Authority, in charge of the regulation and development of the mobile sector (among other infocomm sectors) in Singapore.

42 See https://www.imda.gov.sg/-/media/imda/files/inner/pcdg/consultations/consultation-paper/copif-review---consultation-paper.pdf?la=en

43 The MDS is an amount of rent-free space within a building which the building owner/developer must set aside, at the request of an MNO, to facilitate the deployment of mobile equipment to ensure good in-building mobile coverage.

44 See https://www.imda.gov.sg/regulations-licensing-and-consultations/consultations/consultation-papers/2017/public-consultation-on-the-review-of-the-copif

45 See https://www.mci.gov.sg/~/media/data/mci/docs/imm%202025/infocomm%20media%202025%20full%20report.pdf

Main goals: The intention of the HetNet is to provide "the underlying communications backbone for a pervasive and robust connectivity, and more efficient utilization of spectrum and network resources".[46]

What is being proposed: The HetNet will enable "seamless switching between different networks, such as cellular and Wi-Fi networks".[47] It will use small cells to "complement existing macro cells, to bolster network capacity and improve the mobile user experience".[48]

Implementation timing: We understand that the IMDA has worked with four partners (M1, MyRepublic, Singtel and StarHub) on a series of HetNet trials.[49] In August 2016, M1 and Nokia announced plans to deploy Singapore's first commercial HetNet roll-out. The pair announced plans to progressively roll out an overlay of integrated Nokia small cells and Wi-Fi equipment across Singapore, which would complement the MNOs' existing 4G network. In August 2017, M1 reported successful trials of the new technology, and stated plans to roll out small cells to around 500 high-traffic hotspots.[50]

Impact for 5G deployment: The concept of a HetNet is seen as increasingly important with the advent of 5G technology and ever more devices and demand for constant connectivity. M1 has described its HetNet roll-out as "an integral part of our 5G network roadmap, [and] the infrastructure on which we will build a ubiquitous on-demand, high-performance 5G service".[51]

France – updating taxation policies to suit massive small cell deployments

The current regulatory taxation framework in France stipulates that base stations whose power requires "an opinion, an agreement or a statement" from the National Frequency Agency (ANFR) are subject to a flat tax.[52] The value of the tax depends on the transmission power, the type of installation and the deployment location. France has recognized that reforms to its taxation framework will be needed to encourage 5G deployment.

Main goals: Given expectations of cell densification, we understand that a number of stakeholders have encouraged ARCEP to adapt the current framework, such that massive small-cell deployments will not impose an excessive tax burden on MNOs.[53]

46 *Ibid.*

47 *Ibid.*

48 See https://www.imda.gov.sg/industry-development/infrastructure/next-gen-national-infocomm-infrastructure/heterogeneous-network-hetnet

49 See https://www.imda.gov.sg/infocomm-and-media-news/buzz-central/2015/5/smart-nation-leaps-into-prototyping-phase

50 See https://www.channelnewsasia.com/news/singapore/m1-extends-hetnet-rollout-sets-out-plan-for-iot-network-7861918

51 See http://telecoms.com/474969/nokia-helps-m1-singapore-roll-out-commercial-nb-iot-and-hetnet/

52 ARCEP '5G: issues and challenges' report, March 2017.

53 *Ibid.*

What is being proposed: We are not aware of specific proposals, though ARCEP appears to have acknowledged that suitable tax reforms will be required.

Implementation timing: ARCEP's '5G: issues and challenges' report[54] published in March 2017, notes that the process of tax reform is already underway, 'notably with a view to decreasing taxes on base stations in locations that are hard to cover [Act No. 2016-1888]'.

Impact for 5G deployment: According to the report, the current tax levied on an urban base station is EUR1607 per annum per installation for an EIRP of >5W, and EUR160.70 per annum per installation (i.e. ten times less) for an EIRP of between 1W and 5W. ARCEP states that small cells are likely to transmit at powers of between 1W and 25W, and that estimates indicate that 5G will require at least 10 small cells per macro base station in an urban setting. The impact of a favorable taxation framework on the cost of 5G deployment therefore has the potential to be significant.

EU – stimulating infrastructure investment and simplifying small cell procedures

On September 14, 2016, the European Commission published[55,56] a draft Directive to establish a new European Electronic Communications Code (the 'Code', or (E)ECC). Amongst other things, the Code is designed to stimulate investment in 5G infrastructure. Part II of the European ECC, dealing with networks, includes several amendments aimed at:

- Limiting the time taken for applications to install telecommunications infrastructure, and removing possibilities for extensive appeal procedures for third parties on decisions to install infrastructure. Under the new proposals, a six-month limit on approving siting applications applies
- Ensuring that any conditions attached to infrastructure siting (including costs) are determined based on 'transparency and non-discrimination'[57]
- Encouraging deployment of street-level cells (e.g. 'small-area wireless access points') through requiring that these should not be subject to any fees other than administrative charges

Main goals: The Code aims to harmonize regulation of electronic communications across the EU. The EC states that the Code will "stimulate competition which drives investments and strengthens the internal market and consumer rights".[58] This is part of a larger set of initiatives and legislative proposals designed to place the EU "at the forefront of internet connectivity", as part of its wider Digital Single Market strategy.

54 See https://www.arcep.fr/uploads/tx_gspublication/Report-5G-issues-challenges-march2017.pdf

55 See http://europa.eu/rapid/press-release_MEMO-16-3009_en.htm

56 See https://ec.europa.eu/digital-single-market/en/news/proposed-directive-establishing-european-electronic-communications-code

57 https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-590-EN-F1-1.PDF

58 See http://europa.eu/rapid/press-release_IP-16-3008_en.htm

What is being proposed: The full text of the draft directive is publicly available.[59] Examples of proposals relevant to 5G infrastructure include:

- Article 70, which supports greater infrastructure competition by ensuring access to civil infrastructure, such as ducts, poles, etc., where these are held by operators with SMP.
- Articles 55 and 56, which simplify the conditions for the deployment and provisions of small cells to reduce costs of deploying very dense networks.

Implementation timing: Member States will implement the new Code once the directive is finalized. We understand this is expected in early 2018.[60]

Impact for 5G deployment: It is hoped that the EECC will "make it more attractive for all companies to invest in new top-quality infrastructures [including 5G infrastructure], everywhere in the EU, both locally and across national borders. The investments triggered by the new framework could boost [EU] GDP by an additional EUR910 billion and create 1.3 million new jobs over the next decade (by 2025)".[61]

UK – reforming legislation to make it easier to deploy telecommunications infrastructure

The primary legislation in the UK relating to telecommunications infrastructure is the Electronic Communications Code (the 'Code' or ECC, not to be confused with the European level Code described above). The ECC regulates the relationship between electronic communications network operators and site providers (e.g. landowners). The UK recently amended the ECC, aimed at making legislation more appropriate to future networks as they evolve, including making it easier to deploy new mobile sites and to modify existing sites, without incurring significant delays, or cost, through the need to re-plan sites (e.g. for addition of new antennas). A key goal is to apply a consistent approach to calculating site and infrastructure rental costs, so that operators can continue to use existing sites, and roll out new sites, without uncertainties concerning the site rental costs that might be applied.

The code reforms are part of a new 'Digital Economy Act', which completed its passage through the UK parliament in April 2017.[62]

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59 See http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=comnat:COM_2016_0590_FIN

60 See http://europa.eu/rapid/press-release_MEX-18-1503_en.htm

61 See http://europa.eu/rapid/press-release_IP-16-3008_en.htm

62 https://www.gov.uk/government/collections/digital-economy-bill-2016

Main goals: Recent reforms to the Code[63] are intended to make it easier for telecommunications operators to rollout infrastructure for mobile/fixed networks on public and private land.

What was proposed: The key changes made include:

- Increasing the scope of the code to legislate on access to infrastructure (e.g. masts) as well as land used to site wireless transmitters.
- Providing mobile operators with additional rights (e.g. rights of access, rights to remain).
- Amending the rental regime for land and infrastructure upon which wireless transmitters are installed (e.g. to implement a consistent approach to calculating site and infrastructure rental costs).

Implementation timing: The Code reforms became UK law in December 2017.[64]

Impact for 5G deployment: The new Code gives additional flexibility to mobile operators to upgrade, share, access and remain on their existing sites. This may be significant in facilitating 5G rollouts, e.g. by enabling MNOs to avoid 'ransom rents' when upgrading infrastructure (i.e. changing or adding antennas for 5G).

US – excluding DAS and small cells from certain regulations

In the US, the construction of a new tower requires approval from local authorities and compliance with the FCC's environmental rules (NEPA, NHPA and ESA).

Main goals: Recognizing the significant economic benefits that 5G will bring, the FCC's goal is to ensure that any regulatory barriers are identified, and solutions found to reduce or eliminate these barriers. Hence, noting that "[5G] high-speed wireless depends on high-speed deployment",[65] the FCC has attempted to reduce or eliminate regulatory burdens, especially where new facilities have no significant adverse impact on the environment or historic resources.

What was proposed: In September 2013, the FCC adopted an NPRM[66] initiating a review of its wireless infrastructure policies. The NPRM sought comment on:

- Streamlining the environmental/historic preservation review processes for newer technologies, including DAS and small cells.
- Removing barriers to the deployment of temporary towers.
- Clarifying obligations on state/local government to approve requests for modifying existing towers.

63 See https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/523788/Electronic_Communications_Code_160516_CLEAN_NO_WATERMARK.pdf

64 See https://www.out-law.com/en/articles/2017/december/uk-electronic-communications-code-to-become-law-on-28-december/

65 See https://www.fcc.gov/5G

66 See https://apps.fcc.gov/edocs_public/attachmatch/DOC-323449A1.pdf for press release. Full document available here: https://www.fcc.gov/document/fcc-proposes-remove-barriers-wireless-infrastructure-0

- Clarifying the time period within which state/local government must complete the review of mobile siting applications.

Implementation timing: The new rules were adopted in the FCC's October 2014 Infrastructure R&O.[67] NEPA and NHPA exclusions specific to DAS and small-cell deployments, which were indicated in the R&O, were executed in an Amendment passed in August 2016.[68]

Impact for 5G deployment: It is hoped that "these new exclusions will reduce the cost, time, and burden associated with deploying small facilities in many settings, and provide opportunities to increase densification at low cost and with very little impact on historic properties. Facilitating these deployments thus directly advances efforts to roll out 5G service in communities across the country".[69]

In March 2017, the FCC proposed a further round of infrastructure deployment review. An NPRM was issued[70] on March 30, 2017, stating that "there is evidence that despite Commission action to reduce delays and costs of infrastructure review, providers continue to face significant costs and delays".

As such, the NPRM sought comment on how current local, state, and FCC rules affect the speed and cost of infrastructure deployment, and what time limits should apply to the review process. The NPRM also opened a wide-ranging review concerning FCC rules and procedures for historic preservation (NHPA) and environmental (NEPA) review.

On November 16, 2017, the FCC adopted[71] an R&O "eliminating the need for historic preservation review in instances where there is no potential effect on historic properties". In particular, the decision eliminates "the requirement for a review when utility poles are replaced with substantially identical poles that can support antennas or other wireless communications equipment".

The FCC's March 2018 Open Meeting is preparing to adopt the Second Report & Order in the FCC's Wireless Infrastructure docket, reforming the rules applying to infrastructure deployment, streamlining the process of deploying next generation wireless facilities, addressing the types of deployment subject to National Historic Preservation Act (NHPA) and National Environmental Policy Act (NEPA) review, and establishing timeframes for the FCC to act upon Environmental Assessments.[72]

67 See https://www.fcc.gov/document/wireless-infrastructure-report-and-order

68 The 'First Amendment to Nationwide Programmatic Agreement for the Collocation of Wireless Antennas' establishes new exclusions from Section 106 of the NHPA. See:
https://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0808/DOC-340687A1.pdf
https://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0808/DA-16-900A1.pdf

69 See https://apps.fcc.gov/edocs_public/attachmatch/DA-16-900A1.pdf

70 See https://transition.fcc.gov/Daily_Releases/Daily_Business/2017/db0330/DOC-344160A1.pdf

71 See https://apps.fcc.gov/edocs_public/attachmatch/FCC-17-153A1.pdf

72 See https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0301/DOC-349528A1.pdf

5.2 Local-level examples

London, UK – encouraging the deployment of small cells through its smart-city plan

In 2013, the Mayor of London initiated a strategy to drive digital technology and connectivity improvements in the UK capital, known as the 'Smart London Plan'.[73]

In 2017, the new Mayor of London recommitted to the Smart London Plan as a roadmap towards London being "the world's leading Smart City". In January 2018, a 'Listening Exercise' (consultation) was launched,[74] seeking industry feedback on the plan.

Main goals: The main goal of the Smart City London Plan is to improve digital connectivity across London and prepare for 5G, by encouraging collaboration between the public sector and commercial digital technology companies, and by harnessing opportunities provided by digital technology to improve the living and working environments in London – for example, bus route planning to match public demand, use of data crowd-sourcing (e.g. to track pollution levels), and improved public services.

What is being proposed: The consultation looks at five different areas, one of them being what measures the GLA (local government) can take to 'make London the best-connected city in Europe and prepare for 5G'.

In January 2018, local newspaper the London Evening Standard reported[75] that the GLA believes a network of "up to 500,000 small cells will help London to leapfrog rivals such as New York and Paris and rank alongside the most technologically advanced cities of Asia".

Implementation timing: The final plan will be announced in June 2018 (a consultation exercise is ongoing at the time of producing this report).

Impact for 5G deployment: The Small Cell Forum (SCF), a carrier-led organization supporting the wide-scale adoption of small cells, noted that, alongside the Smart London Plan, Transport for London is currently making a major bid for government funding to tackle 'not-spots' and provide better digital connectivity for Londoners. The SCF states[76] this "points … to the case for densification, mobilizing small cells as a means of providing 5G, but also using them in the interim to improve connectivity and black spots in coverage".

73 See https://www.london.gov.uk/sites/default/files/smart_london_plan.pdf

74 See https://www.london.gov.uk/press-releases/mayoral/londoners-to-help-bid-to-become-leading-smart-city and https://medium.com/@SmartLondon/a-smarter-london-together-listening-exercise-for-a-new-smart-london-plan-51be7d9ca203

75 See https://www.standard.co.uk/news/london/minimasts-to-be-installed-on-lampposts-across-capital-to-boost-mobile-coverage-a3747381.html

76 See https://www.smallcellforum.org/blog/smart-london-plan-aims-pave-way-dense-network-small-cells-across-capital-keep-city-competitive/

Minneapolis, US – promoting deployment of small-cell technology by streamlining planning processes

In 2017, new legislation was passed in Minneapolis to streamline and standardize planning rules for deployment of small-cell technology, to improve connectivity and to prepare for 5G. As a result of the new rules, mobile operators accelerated small-cell deployment in the Minneapolis / St. Paul area, working to deploy more than 660 small cells across the area to serve both peak demand during the Super Bowl, and permanently expanding the capacity of the wireless networks available to users in the future.[77]

Main goals: The main goal is to encourage commercial wireless operators to invest in small-cell and next-generation wireless technology, as a means of supporting the local economy, bringing better connectivity to metropolitan areas and for large-scale events, and position the city for 5G deployment.

What is being proposed: The new laws (now in place) establish a 90-day process to issue or deny permits for small-cell deployment and set a standard fee (USD150 per year) as a small-cell pole attachment rate (with an additional USD25 per year maintenance fee, and monthly fee for electricity use). This new legislation seeks to remove previous barriers to deployment such as lengthy planning processes and unpredictable rental fees for use of street poles.

Implementation timing: The new legislation was signed into law in June 2017.

Impact for 5G deployment: AT&T has said that 5G will rely on denser mobile networks and use of small cells, and has announced Minneapolis as a '5G evolution market'. This includes trials of mm-wave technology, and G.fast, to increase broadband speeds.[78] The new laws will attract investment, facilitate infrastructure deployment, and improve the speeds, coverage, capacity, reliability, and performance of the wireless networks available to users in Minneapolis.[79]

Indiana, US – Promoting small-cell deployment through revised permitting legislation

In 2017, the Indiana General Assembly enacted new legislation to ease the permitting process for small-cell deployment.[80] A key part of the legislation is to limit the delays in obtaining small-cell permits, and to reduce the number of instances where permits to install small cells are denied.

77 https://finance.yahoo.com/news/law-accelerate-t-deployment-small-131500006.html
https://www.attpublicpolicy.com/consumer-broadband/leaning-toward-our-5g-future/
https://www.fiercewireless.com/wireless/minneapolis-super-bowl-lii-stands-as-proving-ground-for-small-cell-deployments

78 https://www.attpublicpolicy.com/consumer-broadband/leaning-toward-our-5g-future/

79 http://bgr.com/2018/02/02/super-bowl-best-network-att-vs-verizon/

80 https://iga.in.gov/legislative/2017/bills/senate/213

Main goals: The main goal is to streamline, and harmonize, planning processes for telecom installation on street poles, with a view to making deployment of small cells easier and faster, ensuring that residents and businesses in Indiana have access to the most advanced mobile broadband services.

What is being proposed: The new legislation proposes a streamlined approval process for small-cell deployment, improving transparency, reducing delays, and avoiding discriminatory practices (e.g. exclusive agreements with one service provider preventing wider deployment across the market).[81] The streamlined planning process allows small-cell deployment to occur within 60 days of the permit being applied for.[82]

Implementation timing: Legislative changes were adopted in 2017,[83] and further amendments are being considered in 2018.[84]

Impact for 5G deployment: AT&T has selected Indianapolis as a test market for its mobile 5G service and has stated that a variety of network upgrades have been implemented, including deployment and activation of small cells in the heart of the city, carrying public traffic, and "paving the way to the next generation of connectivity".[85]

Amsterdam, Netherlands – small-cell pilot project

In 2014, a small-cell pilot project was conducted in Amsterdam, where 160 small cells were installed on bus shelters, connected by fiber. The project was aimed at overcoming two of the major challenges of small-cell deployment, which are site acquisition and transmission. Since the pilot project was completed, several mobile operators in the Netherlands, including Vodafone and KPN, have announced large-scale small-cell deployments.[86]

Main goals: The main goal of the Amsterdam small-cell pilot project was to demonstrate solutions to overcome two major challenges to small-cell deployment, i.e. site acquisition and transmission, with a view to reducing the time and costs associated with upgrading mobile networks with small cells.

What is being proposed: The pilot project used innovative technology solutions on bus stops and on billboards to provide outdoor small-cell connectivity, with backhaul provided via fiber connections.

81 http://www.tribstar.com/opinion/flashpoint/flashpoint-small-cell-legislation-would-put-indiana-on-cutting-edge/article_6a62d75e-9981-5fa6-a70f-512b8c641ac9.html

82 https://www.attpublicpolicy.com/consumer-broadband/leaning-toward-our-5g-future/

83 https://iga.in.gov/legislative/2017/bills/senate/213

84 https://iga.in.gov/legislative/2018/bills/house/1050

85 https://www.attpublicpolicy.com/consumer-broadband/leaning-toward-our-5g-future/

86 http://telecoms.com/310301/vodafone-jcdecaux-sign-global-small-cell-deployment-deal/

Implementation timing: The pilot project was undertaken during 2014. Since then, mobile operators have progressed wider-scale commercial roll-out in busy areas of Amsterdam, creating 'outdoor performance zones',[87] with the aim of improving coverage and connectivity speeds.

Impact for 5G deployment: Amsterdam has subsequently become known as a pioneer of 'smart cities', with a range of projects aimed at transforming urban life, such as improving traffic management, facilitating access to parking spots, and transforming public services. Deploying 5G technologies can therefore be expected to open up further opportunities within the existing smart-city infrastructure.

87 https://www.mobileworldlive.com/featured-content/home-banner/vodafone-netherlands-talks-small-cell-gains/

6 Comparison of 5G readiness across markets

To provide a view on the relative positioning of the different countries under study in terms of promoting 5G development and deployment of commercial services, we have undertaken an assessment of '5G readiness' in different markets, based on establishing a series of spectrum and infrastructure-related metrics that we have identified from our research as being relevant to the overall success of 5G.

This section describes our overall comparison of 5G readiness between countries. The section includes an overview of our analysis, a description of the metrics we have identified as being relevant to 5G success in different markets, a summary of how we have undertaken a quantitative comparison of readiness for 5G across different markets, and an overall summary of our findings.

6.1 Overview of 5G readiness analysis

Our 5G readiness analysis is based on an assessment of five different metrics:

1. **Amount and timeline for 5G spectrum release**. This is based on three criteria: the total amount of spectrum being released in each market for 5G, the amount of spectrum being made available across different bands (low, medium and high), and the timescale for spectrum being made available to operators for commercial use. The highest scores in this category are indicative of countries where sufficient amounts of 5G-suitable spectrum are scheduled to be released imminently (or are already available), in each of the sub-3GHz, 3–24GHz and mm-wave ranges.

2. **5G spectrum roadmap published**. This metric provides a comparison between countries in relation to overall spectrum planning for 5G, guided by whether regulators have published detailed roadmaps with indication of bands that are to be made available for 5G use, and/or are under study. A roadmap is a necessary first step for 5G licensing, but could also indicate plans for equipment testing, schemes to facilitate early commercial trials, such as availability of trial licenses, etc. as well as providing a more detailed schedule for spectrum release. A high score in this category is indicative of a country where the regulator has published a detailed 5G roadmap (or equivalent).

3. **Government backing and infrastructure policy**. This metric aims to capture the extent to which national governments are proactively aiming for 5G deployment, and are putting policies in place aimed at encouraging further technological development and early commercial launch of 5G services. This metric includes policies aimed at easing 5G infrastructure deployment, as well as government backing for early 5G deployment (e.g. direct allocation of government funding or other relevant government initiatives aimed at accelerating 5G developments, technological advancement and encouragement of collaborative trials). Favorable policies towards 5G commercialization might include policies aimed at encouraging new infrastructure developments such as small cells, as well as broader policies aimed at streamlining planning

processes for mobile operators relating to macro sites used within today's 4G networks, which will also be important to 5G. A high score for this metric reflects proactive government policy making (evidenced by public documentation) supportive of 5G, which might include specific infrastructure-based policies, funding being allocated to further the development of 5G technology in-country, or to facilitate large-scale, collaborative test and development.

4. **Industry 'proof-of-concept' trials**. This metric aims to compare different markets on the extent of 5G network and equipment trials being conducted by industry parties, aimed at demonstrating 5G technology and/or establishing technology capability ahead of commercial network deployment. A high score indicates that all major MNOs within the market have conducted extensive 5G trials (which might suggest competitive 5G launches amongst several operators in a market), across a range of bands, technologies, and vendor solutions. A high score in this category also indicates that several industry players (vendors, research groups, universities, key stakeholders in potential 5G verticals, as well as cross-industry collaborations) might be active in 5G research and development within this country.

5. **Industry commitment to 5G launch**. This metric assesses the progress that is being made by network operators towards commercial 5G launch. This is measured to a large extent by public announcements made by MNOs which explicitly commit to commercial 5G launch dates combined with an assessment of the maturity of pre-commercial activity such as widespread trials and pre-commercial service launches. A high score indicates that most or all MNOs have explicitly committed to an accelerated 5G commercial launch prior to 2020.

Our scoring between countries has been performed as follows:

- Each country is assigned a score between 0 and 4 for each of the five metrics. These scores are denoted as S_1, S_2, S_3, S_4 and S_5, and are depicted visually using Harvey balls, in accordance with the following scale.

Figure 6.1: Harvey ball scoring code [Source: Analysys Mason, 2018]

- A final *5G readiness score* is then calculated according to the following formula:

$$5G\ readiness\ score,\ S_{Total} = S_1 \times (S_2 + S_3 + S_4 + S_5)$$

Two points should be emphasized regarding this scoring approach:

- Market-readiness for 5G is an inherently qualitative concept, and quantitative scoring will not necessarily capture all the nuances of the real-life situation.

- The five metrics are intended to be broad, allowing a large range of relevant issues to be captured, but they are therefore not easily separable (and indeed often significantly overlap).

In our scoring, we have chosen to give additional weighting to the first metric (amount and timeline of spectrum to be released) by using its score as an overall scaler to the composite score achieved by summing the other scores. This is because, in our view, the availability of sufficient spectrum underlies all other activity in enabling the deployment of 5G services.

Below, we provide analysis and scoring for each of the five metrics being considered.

Amount and timeline for 5G spectrum release

The following table provides a summary of the 5G spectrum plans in each country.

Based on the likely spectrum availability in each country, we have assigned an overall score for comparative purposes, to illustrate differences in spectrum availability across the markets under study, based on the detailed information described in the previous Section 4.

From the table below, we have identified that the countries that have made the most substantial progress (up to this point, and expected during 2018) with spectrum authorizations for 5G commercial use (other than the US) are South Korea, Japan, and China. Several other markets (including several markets in Europe, some of which are not shown in the table below) are actively planning for 5G authorization.

The spectrum needs for 5G in different markets are being driven by different market demands between countries, as well as being influenced by the frequencies that have been identified by the global equipment industry as being most favorable for initial 5G technological development and network deployment. Compared to other markets, it is evident that spectrum demand for 5G in the US is being driven by strong growth in mobile broadband traffic as well as by industry desire to provide fixed wireless, as well as mobile, broadband services in the initial phases of 5G deployment – evidenced by the significant progress being made in the US market towards release mm-wave spectrum. In other markets, where initial 5G services are more specifically mobile broadband based, there have been greater efforts made to release spectrum in lower bands (e.g. around 3.5GHz in Europe, or 4.4–5GHz in China and Japan) alongside mm-wave spectrum.

Figure 6.2: Country scores for Metric 1 (amount and timeline of spectrum to be released) [Source: Analysys Mason, 2018]

Market	S_1	Details
Canada		Canada has proposed a 'flexible use licensing' model in the 28GHz and 37–40GHz bands, and license-exempt authorization for spectrum the 64–71GHz range. ISED aims to make mm-wave spectrum available by 2020. A 3.5GHz consultation is expected, but is yet to be released. Canada has committed to releasing 600MHz spectrum for mobile, in coordination with the US.
China		China is one of the highest scoring countries in terms of spectrum, with the MIIT committing to releasing 100MHz of mid-band spectrum per MNO, and 2GHz of high-band spectrum per MNO, for 5G. At least two of the Chinese MNOs tested 5G capability using 100MHz contiguous blocks in mid-band spectrum in 2017, indicative of subsequent commercial intentions. In November 2017, the MIIT confirmed that the 3.3-3.6GHz and 4.8-5.0GHz ranges had been reserved for 5G,

Market	S_1	Details
		with reports further indicating that the assignment of the 3.6-4.2GHz range to 5G is likely. While exact details and timings of spectrum award are unclear, we expect an assignment in 2018/19, in line with announced commercial launch timelines, The MIIT has made spectrum in the 24.75–27.5GHz and 37–42.5GHz ranges available for test licenses.
France 		France may auction spectrum in the 3.4–3.8GHz band during 2018, with the goal that 300MHz of contiguous spectrum will be available for 5G by 2020 (340MHz by 2026, and 390MHz in areas without FWA reservation, which is currently in the lower part of this spectrum). Plans for other bands (700MHz unpaired, 26GHz, etc.) are less developed.
Germany 		Germany has already awarded more spectrum for mobile use than most other European countries, and has confirmed that it will award the 3.4–3.7GHz range in 2018 (though the spectrum will not be usable until 2022). The 3.7–3.8GHz band is to be made available on a regional basis. Additional 700MHz unpaired spectrum is to be considered at a later date, while spectrum in mm-wave bands (starting with 26GHz) is to be awarded 'as soon as possible', with several bands under consideration: 26GHz (24.25–27.5GHz), 28GHz (27.5–29.5GHz) and 32GHz (31.8–33.4GHz).
Japan 		To address a recognized mobile spectrum shortage, the Japanese regulator will consider frequency release/sharing in the 2.3GHz and 2.6GHz bands, and aims to assign 2×40MHz in the 1700MHz band and the 3.4–3.48GHz range to mobile during early 2018. For 5G, the MIC plans to make available up to 500MHz spectrum in the 3.6–4.2GHz and 4.4–4.9GHz bands, and up to 2GHz in the 27.5–29.5GHz band by March 2019.
Russia 		Russia has scheduled a formal decision on 5G spectrum for 2018, but some spectrum in the 3.4–3.8GHz and 25.25–29.5GHz ranges has been released to certain operators for trials.
Singapore 		In Singapore, a detailed plan for 5G spectrum release has not been published. However, a 5G consultation in 2017 notes that spectrum demand forecast for 2022 could be met by releasing the L-band (91MHz) and the extended C-band (200MHz from 3.4–3.8GHz) in 2019, and the 28GHz band (2000MHz) possibly along with other mm-wave spectrum in 2022.
South Korea 		The regulator in South Korea has scheduled 1300MHz of spectrum to be released for 5G by 2018 (300MHz in the 3.5GHz band and 1GHz in the 28GHz band), with a possible further 2GHz mm-wave extension. Spectrum awards are expected to take place in the first half of 2018. It is noted that the South Korean market has the least amount of spectrum currently assigned to current mobile use of any of the countries studied in this report.
UK 		The UK has plans to auction 190Hz in the 2.3/3.4GHz bands (expected 2018), 2×30MHz and 1×20MHz of 700MHz (assignment expected 2018/19, with spectrum becoming available in 2020) and 3.6–3.8GHz (to be deployed from 2020–22). Work is also being undertaken to make parts of the 24.25–27.5GHz range available for 5G authorization. The 66–71GHz band, and spectrum around 40GHz (37–43.5GHz) has also been identified as a priority for 5G authorization.
US 		In July 2016, the FCC confirmed that approximately 11GHz of mm-wave spectrum was to be released for flexible mobile/fixed use: 3.85GHz of licensed spectrum (27.5–28.3, 37–38.6 and 38.6–40GHz) and 7GHz of unlicensed spectrum (64–71GHz). In November 2017, the FCC decided to make a further 1700MHz available for mobile in the 24GHz and 47GHz bands. The FCC has scheduled the 28GHz and 24GHz spectrum to be auctioned in November 2018, while release dates for the remaining spectrum bands are pending. 150MHz (3550–3700MHz) is to be released in the CBRS three-tier licensing structure, with second-tier auctions

Market	S_1	Details
		expected in 2018-2019. Further mid-band spectrum is also under study, including bands immediately above and below the CBRS band.

5G spectrum roadmap published

The following table summarizes our assessment of the 5G spectrum roadmap published in each of our benchmark countries. The assessment identifies that in several countries under study – specifically Germany, the UK and the US – regulators have published detailed 5G spectrum roadmaps, and notices of intention/call for industry input, to prepare for 5G licensing. These roadmaps give a strong signal to the national industry in each of these countries of the likely actions of the regulator over the next 3–5 years, in relation to making further spectrum available for 5G.

Figure 6.3: Country scores for Metric 2 (5G spectrum roadmap published) [Source: Analysys Mason, 2018]

Market	S_2	Details
Canada 		• Our view based on research for this study is that the Canadian government and regulator are at an early stage with publishing 5G roadmaps in comparison to other countries studied, having issued a first 5G consultation (on high-band spectrum only) in June 2017. • The regulator's 'Spectrum Outlook' 2018–2022 document clearly recognizes the need for 5G spectrum, and references a number of possible bands, though limited detail on timings or spectrum release plans is provided.
China 		• The Chinese government has issued several broadly-based digital strategy plans which have relevance to 5G technological development and commercialization, including the 'Made in China 2025' plan and the government's most recent Five-Year Plan. • The MIIT published a 'consideration of spectrum for 5G' document in 2016, with a '5G promotion plan' from 2013–2020 covering availability of spectrum, 5G technology development plans and trials.
France 		• Plans/timings for assigning spectrum in the 3.4–3.8GHz band for 5G use have been clearly articulated, but plans to authorize mm-wave spectrum for 5G are less well developed. • In December 2017, the Ministry of Economy and Finance launched a consultation on establishing a 5G roadmap, which is scheduled to be finalized in the first half of 2018. • In January 2018, ARCEP formally opened a '5G pilot window', inviting industry players to apply for licenses. ARCEP also said it had launched work on the 'deployment conditions for 5G', stating that it would organize a workshop on the subject 'in the course of 2018'.
Germany 		• As with France, Germany has announced detailed plans for assigning spectrum from within the 3.4–3.8GHz band for 5G, but action to be taken in the 26GHz to authorize 5G use has not yet been announced. • An explicit '5G Strategy for Germany' paper was published in September 2017 which included five action points covering network roll-out, spectrum, cross-industry collaboration, research and 5G in towns/cities. • The German regulator has also been proactive in releasing mobile spectrum to the market, and was the first regulator in Europe to auction licenses for use of the 700MHz band (in addition to 800MHz and 900MHz spectrum that operators already use for 2G, 3G and 4G services).

Market	S_2	Details
Japan 		• The MIC launched its 'radio policy to realize 5G by 2020' in June 2016. As with China, this contains an explicit '5G roadmap towards 2020', which includes a timeline for promoting research and development into 5G technology, support for global 5G standardization work, trials, industry-academic-government collaboration, as well as discussion about spectrum. • The government has committed to a timeline for releasing spectrum in each of the low-, mid- and high-frequency ranges under consideration for 5G.
Russia 		• In July 2017, the Russian government published its 'Digital economy of the Russian Federation' plan, which includes a 5G roll-out plan, but no details regarding spectrum release or indication of government strategy specifically to accelerate 5G development and launch have been published, based on our research.
Singapore 		• Plans for release of 5G spectrum are at an early stage, with the IMDA having issued a first 5G consultation in 2017. The consultation considers 5G spectrum needs across the different frequency ranges that 5G technology might use and seeks comment on spectrum in low, medium and high frequency bands, and discusses how projected spectrum demand will be met by allocation in a range of bands.
South Korea 		• Specific details regarding license award for 5G spectrum in South Korea have been limited in the public domain. However, in early 2017, MSIT released a national broadband/spectrum plan ('K-ICT'). The government has committed to prompt timelines for allocating both mid- and high-band spectrum and it is understood that spectrum awards in the 3.5GHz and 28GHz bands will be announced during 2018.
UK 		• The UK regulator has published a 5G roadmap and a call for input on use of the 26GHz band for 5G. It plans to auction licenses for use of the 2.3GHz and 3.4–3.6GHz band in 2018 and is preparing to release spectrum in the 3.6–3.8GHz band for use from around 2022 onwards. The government has published a number of 5G strategy and roadmap documents aimed at developing 5G technological leadership in the UK.
US 		• The FCC has articulated detailed plans to meet the needs for 5G spectrum in low, mid and high bands, and relevant documentation for decision making in the FCC (NOI, NPRM and R&Os) has been released. However, there is no formal schedule for 5G roll-out in the US stemming from the government, which draws down the US score. • 600MHz spectrum was released in 2017. • The FCC decided at an early stage to focus industry effort on the 28GHz band for 5G use, and has subsequently signaled availability of spectrum in several other mm-wave bands. The FCC recently announced plans to auction 28GHz spectrum in November 2018, followed shortly by an auction of 24GHz spectrum. • A number of trial licenses have been made available.

Government backing and infrastructure policy

The following table summarizes our assessment of government commitments made to promote 5G leadership, including favorable policies towards 5G test and development, funding for 5G trials, and policies aimed at facilitating 5G infrastructure development (including streamlining of planning processes for existing mobile sites, and consideration of policies to encourage small-cell roll-out).

The table indicates that significant policy announcements targeting 5G development have been made in several of the markets under study, especially in China, Japan, South Korea, and the UK.

Figure 6.4: Country scores for Metric 3 (government backing and infrastructure policy) [Source: Analysys Mason, 2018]

Market	S_3	Details
Canada		The government's Communications Research Centre (CRC) has been working on 5G technological development since 2014. In March 2018, plans were announced for a public-private partnership in which the government and industry will invest CAD400million to develop 5G.
China		Details regarding direct funding initiatives for 5G technological development and/or trials are not known, however the Chinese government is explicitly backing 5G technology development, industry collaboration and commercial deployment through a range of policies and initiatives, such as the 'Made in China 2025' plan and the 13th Five-Year plan. The MIIT has conducted several of its own 5G compatibility trials, and scheduled 5G research and development into a number of specific phases prior to commercial launch in 2020.
France		The French government has not announced specific government funding for 5G technological development or trials, but has invested in improving fiber coverage which it hopes will stimulate 5G developments and infrastructure development in the longer term. The regulator, ARCEP, is actively encouraging 5G trials through offering test licenses for spectrum in the 3.4–3.8GHz band and in the 26GHz band.
Germany		The '5G Strategy for Germany' includes five action points specifically targeting 5G development. Under the 'promote cooperation between telecommunications and user industries' action point, the government set up the '5G Dialog Forum' in 2016. Under the 'targeted and coordinated research' action point, the government is making up to EUR80 million available for 5G research and development. In 2017, the government launched a program to invest EUR100billion in high-performance broadband (5G and fiber) by 2025.
Japan		The MIC's 2016 5G roadmap commits to a package of 'comprehensive promotion strategies for 5G'. These include conducting the '5G system trial' and promoting 5G research and development (through 'Industry-Academic-Government Cooperation') and the 5G Mobile Forum (5GMF). Details of direct 5G funding amounts from the government in support of 5G technological development or trials are not known.
Russia		Reports have indicated that the Russian government is discussing ways to encourage MNOs to work together to develop 5G, with authorities ready to 'ease administrative barriers' for the technology's deployment. However, we are not aware of any specific government-level initiatives in Russia to support the industry with 5G trials or commercial launch. Some trials licenses have been in issued.
Singapore		The Singapore government has published several strategies aimed at digital leadership. At the heart of the government's digital policy is the Infocomm Media 2025 vision, which complements Singapore's 'Smart Nation' vision. The smart nation vision embraces use of several wireless technologies including sensors, short-range wireless and cellular networks.
South Korea		The South Korean government is encouraging research and trials to enable accelerated 5G commercial launch. 5G technology was showcased at the 2018 Winter Olympics. In 2014, MSIT announced plans to invest KRW1.6 trillion (USD1.5 billion) by 2020 to enable local firms to build 5G networks.
UK		The UK government committed GBP740 million to 5G and to deliver 'full fiber' connectivity in its 2016 autumn statement. The 2017 budget also announced a further GBP160 million to invest in 5G infrastructure. DCMS published a 5G

Market	S_3	Details
		strategy paper in March 2017 and 'Future Telecoms Infrastructure Review' in November 2017. Specific industrial developments are also being promoted such as connected cars, and connected healthcare. A dedicated 5G unit exists within the UK Department for Media, Culture and Sport (DCMS) tasked with managing allocation of government funds for 5G testbeds and trials.
US 		The FCC's March 2018 Open Meeting Agenda includes reforming the rules applying to infrastructure deployment, streamlining the process of deploying next generation wireless facilities, addressing the types of deployment subject to National Historic Preservation Act (NHPA) and National Environmental Policy Act (NEPA) review, and establishing timeframes for the FCC to act upon Environmental Assessments. The US government has historically followed spectrum assignment strategies that have supported flexibility and technology innovation from operators and technology companies. Policies encouraging experimentation, innovation, and testing/trialing of 5G have been positive. The US government has also recently taken steps to ensure that 5G R&D investments are encouraged through tax reform and other actions.

Industry 'proof-of-concept' trials

This metric considers 5G test and development activity being conducted by operators and vendors in different countries.

We have gathered evidence on 5G tests and development based on the research conducted for this study, supplemented by Analysys Mason's own published research (i.e. as published in subscription research publications from our Research division). We have also compared our own research with other published sources of 5G trials information, such as the Global Supplier Association (GSA) Analyser for Mobile Broadband data (GAMBoD) 'Networks, Technologies & Spectrum' (NTS) database,[88] which lists MNO networks (including trial networks) by band category.

Figure 6.5 below presents a summary of 5G test and development being undertaken in the different countries under consideration in this study, including partners in the trial and dates. This table is not an exhaustive list of 5G-related trials in each country, but provides an example of recent trials in all of the frequency bands we understand operators to be testing. The results of our detailed research on industry trials and commitment to 5G launch are provided in Annex B.

From the table we have identified that most, or all, of the major mobile operators in the following markets have published details of 5G pre-commercial trials being undertaken: China, Japan, South Korea, and the US.

Figure 6.5: Country scores for Metric 4 (Industry trials) [Source: Analysys Mason, GSA GAMBoD NTS database]

Market	S_4	Operator	Band	Date	Vendor
		Bell	3.5/28	Nov 2017	Huawei
		Bell	73	2016	Nokia
		Rogers	*We are not aware of any 5G trials announced*		

88 GAMBoD (GSA Analyser for Mobile Broadband Data).

Market	S4	Operator	Band	Date	Vendor
Canada	◑	Telus	3.5	Dec 2017	N/d
		Telus	28	Jun 2017	Huawei
China	●	China Mob.	3.5	Nov 2017	Qualcomm, ZTE
		China Mob.	15 /28/73	Mar 2017	Various
		China Tel.	N/d	Sep 2017	China Electric Power, Huawei
		China Uni.	3.5	July 2017	ZTE
France	◑	Bouygues	N/d	Mar 2017	Ericsson
		SFR	*We are not aware of any 5G trials announced*		
		Free	3.7	Oct 2017	N/a – license authorization
		Orange	2.6	Feb 2017	Qualcomm. PSA, Ericsson
		Orange	3.7/10/17	Sep 2015	N/a – license authorization
Germany	◔	DT	3.7	Oct 2017	Huawei
		DT	*The GSA states that DT has conducted trials in the 6–24GHz range, though we are not aware of explicit announcements*		
		Telefonica	3.5	Oct 2017	Huawei
		Vodafone	3.5	Oct 2016	Huawei
Japan	●	KDDI	4.5/28	Sep 2017	Ericsson
		KDDI	28	May 2017	Nokia
		DOCOMO	39	Dec 2017	Huawei
		DOCOMO	28	Dec 2017	Huawei
		DOCOMO	4.5	Nov 2017	N/d
		DOCOMO	15	Nov 2015	Ericsson
		DOCOMO	70	Oct 2015	Nokia
		Softbank	28	Jun 2017	Ericsson
		Softbank	2.5	May 2017	Qualcomm
		Softbank	4.5/15	Aug 2016	Ericsson
Russia	◔	*Beeline*	*No trials announced, but agreement signed with Huawei in Jan 2018 to partner in 5G research and testing*		
		MegaFon	3.5/26	Nov 2017	Rostelecom
		MegaFon	70	Jun 2017	Huawei
		MTS	4.65-4.85	Sep 2016	Nokia
		MTS	1.8/5	Jun 2016	Ericsson
		Tele2	4.5	Jul 2017	N/d
Singapore	◑	*TPG*	*We are not aware of any 5G trials announced*		
		M1	73	Jan 2017	Huawei
		Singtel	2.5	Aug 2017	Ericsson, Huawei, ZTE
		StarHub	60-90	Jan 2017	Huawei
		StarHub	>3-30	Nov 2016	Nokia
South Korea	●	KT Corp	28	May 2017	Ericsson
		KT Corp	*KT is expected[89] to deploy 5G services in the 3.5GHz band, though we are not aware of explicit trial announcements*		
		KT Corp	70-80	Apr 2016	NEC
		LG Uplus	3.5/28	Nov 2017	Huawei
		SKT	3.5/28	Nov 2017	Nokia, Ericsson, Samsung
UK	◑	*Three*	*We are not aware of any 5G trials announced*		
		Telefonica	*Telefonica (O2) announced plans to launch a 5G test bed in London in 2018*		
		Vodafone	3.5	Dec 2017	Ericsson
		EE	3.5	Nov 2017	Huawei

89 See https://www.rcrwireless.com/20171018/5g/kt-plans-5g-services-tag23

Market	S4	Operator	Band	Date	Vendor
		EE	*The GSA states that EE has conducted trials in the 24–29.5GHz range, though we are not aware of explicit announcements*		
US	●	AT&T	37	Dec 2017	N/a – license application
		AT&T	39	Feb 2017	Nokia
		AT&T	15/28	Dec 2016	Intel, Ericsson
		AT&T	3.5	Dec 2017	Ericsson
		Sprint	2.5	Sep 2017	Ericsson
		Sprint	73	Jun 2016	Nokia
		T-Mobile	28	Jan 2018	Nokia, Intel
		T-Mobile	70-80	Dec 2017	N/a – license application
		T-Mobile	3.5	Sep 2017	Ericsson, Nokia
		T-Mobile	*T-Mobile has announced plans to deploy using the 600MHz band*		
		Verizon	3.5	Mar 2018	N/d
		Verizon	39	Oct 2017	Qualcomm
		Verizon	28	Feb 2017	Samsung

Industry commitment to 5G launch

The following table summarizes our assessment of industry commitment and progress towards a 5G launch in each of our benchmark countries. The table identifies that all major mobile operators have announced 5G launch dates in China, Japan, South Korea, and the US.

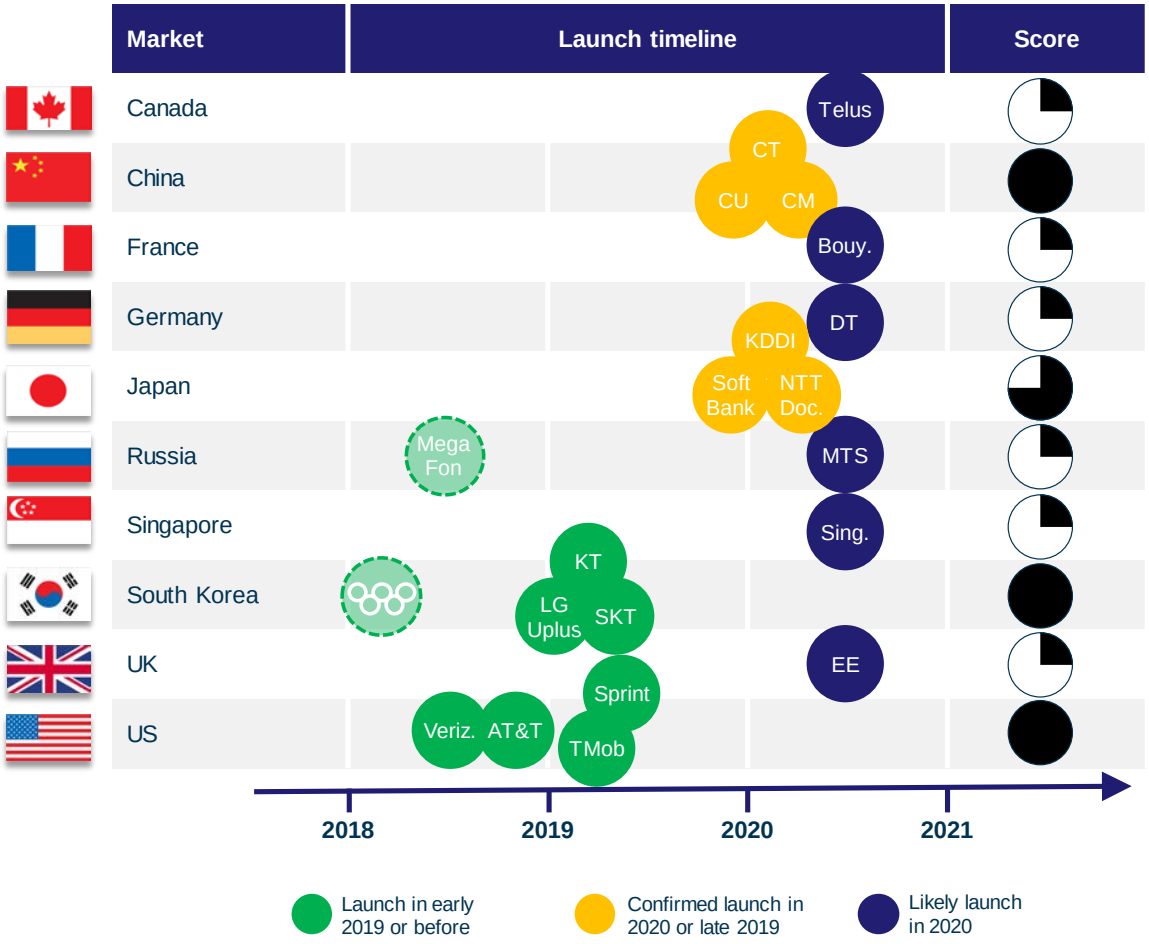
Figure 6.6: Country scores for Metric 5 (Industry commitment) [Source: Analysys Mason, 2018]

Market	S5	Details
Canada	◔	• Telus has stated that its anticipated deployment date is 2020. • Explicit commitments to 5G commercial launch from Rogers or Bell are not known.
China	●	• All Chinese operators have committed to large-scale 5G commercial launches from 2020.
France	◔	• Bouygues has stated that it plans to roll out 5G in 2020. • Explicit commitments to 5G commercial launch from Orange, SFR or Free are not known. However, we understand that 'Orange expects capital expenditure to peak in 2018 or 2019, as [it] prepares for the introduction of 5G'.
Germany	◔	• A news report in November 2017, citing DT's CTO, states that the MNO 'is aiming to have its 5G network go live post-2020'. • Explicit commitments to 5G commercial launch from Telefonica or Vodafone are not known.
Japan	◔	• All Japanese operators have committed to launching commercial 5G for the Tokyo Olympics in 2020. • NTT DOCOMO has provided further details: launch will take place in selected 'high performance' areas in 2020 (using the existing LTE EPC), before expanding nationwide by '202X' (eventually using a dedicated 5G core network). DOCOMO has identified three bands for initial 5G launch: 3.4–3.8GHz, 4.4–5GHz and 27.5–29.5GHz. • Softbank has indicated that it is planning to 'provide commercial services and devices in late 2019'.

Market	S_5	Details
Russia 		• MTS has announced that it will 'deploy first solutions based on 5G technologies starting 2020'. • Explicit commitments to 5G commercial launch from Beeline, Tele2 or MegaFon are not known. However, MegaFon is aiming to provide 5G services for the Russian FIFA World Cup in 2018.
Singapore 		• Singtel stated in 2015 that it is 'working towards being one of the first in the world to roll out 5G in the year 2020'. • Explicit commitments to 5G commercial launch from StarHub, M1 and TPG are not known.
South Korea 		There is strong competition amongst South Korea's three MNOs to be the first to 5G launch: • Reports indicate that KT is aiming to commercialize 5G services by March 2019. • In October 2017, SKT stated that the company aims to commercialize 5G in H2 2019. In January 2018, the Korea Times reported that SKT had a 200-member taskforce aiming to launch 5G services 'as soon as possible'. • In November 2016, LG Uplus stated that it hopes to provide 5G services by 2018 (although other comments indicate that these may be pre-commercial services). The February 2018 Winter Olympics have been a significant focus for early service availability. At the end of January 2018, official partner KT announced it was ready to provide 5G trial services at the event. We understand that both SKT and LG Uplus demonstrated trial 5G services during the event.
UK 		• One UK operator, BT/EE, has stated that it is aiming to launch a commercially available 5G service 'around 2020'. • Explicit commitments to 5G commercial launch from Three, Vodafone or Telefonica are not known (though there has been some indication of launch expectation around 2020 from the latter two MNOs).
US 		• In November 2017, Verizon stated that it would launch 5G FWA residential services in five markets in 2018 (the first being Sacramento, CA in H2 2018). • In January 2018, AT&T announced that it expected to launch a standards-based mobile 5G service in a dozen cities in the US by the end of 2018, and subsequently confirmed that three of the first markets would be Dallas, Atlanta, and Waco, Texas. • T-Mobile's initial build-out of 5G in 30 cities is planned by the end of 2018. T-Mobile has stated that it expects to begin a 5G mobile roll-out using 600MHz spectrum in 2019 and is targeting a full nationwide network by 2020. • Sprint has said that it plans to provide commercial 5G mobile services by H1 2019

The dates of expected commercial deployments in each country are illustrated on a timeline in Figure 6.7 below.

Figure 6.7: Timeline for 5G commercial deployments [Source: Analysys Mason, 2018]



6.2 5G readiness comparison

Our overall readiness comparison combines the individual scores per country for the five spectrum and infrastructure-related metrics that we have assessed. As previously described, the spectrum availability metric has been given a higher weighting in our overall scores in comparison to the other four metrics, as an indication of the importance of early spectrum release to incentivize network investment and commercial deployment.

The following table provides an overall summary of our 5G readiness assessment of each benchmark country, and total score. From this table, the highest-scoring countries from our analysis on 5G readiness (based on our weighted total of scores across the five metrics we have assessed for each market) are: South Korea, the US, China, and Japan.

Figure 6.8: Overall 5G readiness scores [Source: Analysys Mason, 2018]

Market	S_{Total}	Details
Canada	6	Canada is in the lowest tier of the countries considered, based on the research we have undertaken for this study. While the government aims to make mm-wave spectrum available by 2020, the process is at an early stage with the first consultation only recently completed. Consultations have yet to be released for

Market	S_{Total}	Details
		the 3.5GHz band. The CRC has been conducting 5G trials, and government policy aimed at promoting 5G technology development has recently been confirmed (through the ENCQOR project). Only one of the MNOs has explicitly committed to a 5G deployment date.
China 	45	China is the highest scoring country from our analysis in terms of 5G readiness. There is strong government backing for 5G research and development, combined with strong industry backing, with the government's '13th Five-Year Plan' aiming for commercial 5G launch by 2020. All MNOs have announced extensive trials and have committed to launching services in 2020. The government has committed to large amounts of spectrum to 5G in both the mid- and high-bands and operators have trialed 5G in 100MHz contiguous blocks of mid-band spectrum, demonstrating commercial intentions in this regard.
France 	14	France is one of the mid-scoring countries from our analysis. The regulator has already awarded licenses for use of the 700MHz band for mobile services, and intends to award spectrum licenses in the 3.4–3.8GHz band during 2018. It has also consulted on future award of the 26GHz band, but no explicit 5G roadmap has been published. Bouygues Telecom is the only operator to have made an explicit commitment to providing 5G services in 2020, and no direct government funding for 5G development and/or trials has been announced, although the regulator recently opened a 5G trial window and has encouraged applications for test licenses.
Germany 	18	The German government has published a detailed 5G strategy which aims for roll-out in 2020, and has developed plans for spectrum award in a number of bands. Germany has more spectrum currently assigned for mobile use than any of our other benchmark countries (including the 700MHz band and some C-band spectrum). A number of industry trials and initiatives have been announced, and a comprehensive 5G strategy. Spectrum in the 3.4–3.8GHz band is expected to be auctioned in 2018, with the timeline for mm-wave spectrum still to be confirmed.
Japan 	36	Japan scored well across each of the metrics that we have considered. The hosting of the 2020 Olympic and Paralympic Games in Tokyo is providing a strong focus for early 5G service availability, which is galvanizing 5G progress. Japan's MNOs are leaders in 5G testing and the regulator has committed to releasing spectrum in 5G mid and high bands by March 2019.
Russia 	5	Russia's overall score places it in the lower tier of our benchmark countries. The 2018 World Cup is incentivizing 5G progress, and there is industry commitment and government backing for pre-commercial services to be showcased at the event. However, only MTS has publicly committed to commercial deployment in 2020, the government's 5G roadmap does not contain detailed spectrum award plans, and there is little indication in the public domain of government policy targeted at 5G leadership and/or early 5G launch.
Singapore 	4	Singapore does not currently score highly on overall 5G readiness since detailed spectrum award timelines are not confirmed and to date only one operator has committed to a commercial deployment date. The government's initial consultation on 5G does provide some information on bands under study. It is expected that further plans will be progressed in 2018.
South Korea 	42	South Korea is set to be one of the global 5G leaders based on our research, scoring strongly on all metrics. The 2018 Winter Olympics provides a focal point for operator launch, and South Korean operators already compete intensively on high-speed 4G services. The government is committed to seeing 5G technology showcased at the Winter Olympics. SKT and KT Corp are amongst the world's leading MNOs for 5G development, and all of South

Market	S_{Total}	Details
		Korea's operators have ambitious deployment plans. The government is expected to release spectrum in the 3.5GHz and 28GHz bands in early 2018.
UK 	18	The UK scores highly in terms of government commitment, funding for 5G trials and regulatory backing to ease infrastructure deployment for mobile networks. The UK regulator Ofcom has released a detailed 5G roadmap and a large amount of supporting detail regarding spectrum plans and 5G strategy. The government has committed a significant amount of funding towards 5G development via funded trials to stimulate demand for services and to promote industry collaboration, though announcements of commercial launch dates from operators has been limited so far to one operator (BT/EE, which is committed to launching 5G in 2020). A 2.3/3.4GHz auction is expected in 2018/19 and 700MHz to be available in 2020. A call for input on 26GHz licensing was published in 2017 but next steps for authorization of this band for mobile use have not been confirmed.
US 	39	The US scores highly on industry-based metrics, with all the major US carriers conducting extensive trials and announcing ambitious deployment timelines. The FCC was one of the first regulators globally to confirm a strategy for availability of 5G spectrum in the mm-wave portion of spectrum and has modelled innovative licensing approaches to release parts of the 3.5GHz band, and the 600MHz band, for mobile use. However, the US scores less well in terms of broader government commitment towards 5G technological development and 5G leadership. Although a large amount of spectrum is planned for 5G use, most of this currently focuses on the mm-wave bands, where technological complexity to achieve wide-area coverage exists. The biggest gap is a specific plan for mid band spectrum.

These scores are plotted on a scale in Figure 6.9 below. As can be seen, the countries under consideration are grouped into three clusters or tiers based on our analysis, with the leading cluster including China, South Korea, the US, and Japan, followed by a second tier of countries in Europe. Some way behind are the remaining countries under study (Russia, Canada, and Singapore), where detailed plans to promote 5G commercialization (e.g. in terms of spectrum assignment) are yet to emerge.

This analysis represents a view of 5G readiness at this point in time, and other inherent factors – such as supply-side developments, changes to commercial launch plans, and other market or policy developments – could affect the eventual outcome of the 5G market globally. The shifts in 5G readiness which occurred in 2017 and early 2018 have already advanced timetables in some countries, affirming that the situation is fluid, and the current leadership rankings are not fixed. As noted earlier in this report for example, the third phase of R&D tests on 5G products in China have been accelerated by the Chinese MIIT, as a means of ensuring readiness of Chinese 5G products by the time that 3GPP specifications are finalized in June 2018.

Figure 6.9: Overall 5G readiness scores [Source: Analysys Mason, 2018]

The top tier (those most ready for 5G) consists of China, South Korea, the US, and Japan. Within this cluster, China is leading as a result of strong commitment to early 5G launch combined with government commitment to achieving 5G success. This is followed closely by the South Korea, the US, and Japan. The second tier consists of the three western European countries researched as part of this study: UK, Germany and France. Although these three countries were identified at the start of this project for analysis, it is possible that the first commercial 5G services might be launched in other European countries. Notable for early 5G commercialization plans in Europe are Italy and Spain, where regulators are at an advanced stage with release of 5G spectrum in mid-band and mm-wave bands, and there is operator commitment to early 5G commercialization.

The third tier of lowest-scoring countries from our analysis are Singapore, Canada and Russia. Plans for 5G launch in Singapore and Canada are at a preliminary (consultation) stage. Russia is hosting the 2018 FIFA world cup, and aims to showcase pre-commercial 5G technologies at the event. However, it is also not expected to be a global 5G leader: limited information has been released regarding government policies in support of 5G leadership, and only one operator so far has made a commitment to commercial launch, potentially due to lack of certainty in relation to spectrum availability.

Our research has found shifts in 5G readiness occurred during 2017 and early 2018, with the progress made in 2017 to define specifications for 5G new radio (NR) leading to accelerated plans for commercialization. This confirms the situation is fluid, and current leadership rankings are not fixed. Although several countries are at a preliminary stage with 5G planning, here, too, plans could develop rapidly during 2018–2019.

7 Conclusions and recommendations

From our analysis of 5G readiness, we have identified that the countries that are currently the furthest advanced with launching 5G services (at the time of producing this report) are China, South Korea, the US, and Japan. Within this first tier or cluster, China is leading, based on strong demand for early 5G launch combined with government commitment to achieving 5G success. This is followed closely by the South Korea, the US, and Japan. As reported above, our research found shifts in 5G readiness occurred during 2017 and early 2018, emphasizing the fluid nature of the race to 5G, and indicating that the current leadership rankings are not fixed.

As noted in the analysis, other inherent factors – including supply-side developments, shifts in commercial strategy, and other market developments – could influence how the 5G market will develop globally.

A summary of our conclusions from the study is as follows:

There has been a significant market shift in 5G readiness within the past 12 months	Our research points to a shift in 5G readiness having occurred during 2017 and in early 2018. Several 5G commercial launches are now likely to occur in the 2018–2019 timeframe. This confirms that the elements needed for 5G are now established (i.e. industry specifications are in place and operators are confirming large-scale procurements of 3GPP Release 15-compliant equipment).

We have developed five spectrum and infrastructure-related metrics in this report to compare 5G readiness across markets – of these five metrics, we have given spectrum availability the highest weighting	Our research has identified five spectrum and infrastructure-related metrics influencing how 5G networks might emerge in different markets – spectrum availability, widespread 5G trials, 5G roadmaps being established by the national regulator, government commitment (including favorable infrastructure policies), and industry commitment to early 5G launch. Of these metrics, we consider the first of these – spectrum availability for commercial launch – to be the most important, and have given this the highest weighting in our analysis. The reason for this is that operator commitment to large-scale 5G network launch is dependent on sufficient spectrum being available to support the network launch, and to incentivize network investment. The five metrics we have defined, and the importance of spectrum availability, align with industry experience of the factors that have had the most impact on development of previous generations of mobile technology (i.e. 3G, and 4G).

	Although in several of the countries under consideration in this study 5G test and development is underway, these trials will only progress to commercial services being launched once spectrum licensing is confirmed.

In our view, infrastructure for 5G is the other key policy areas that is important to 5G launch	Our view is that infrastructure for 5G is one of the two policy areas that is important to 5G launch. Infrastructure policy to streamline the siting procedures for mobile networks has been an ongoing area of policy development in many markets, and overcoming barriers for further infrastructure deployment will be relevant in the 5G market, especially with the introduction of smaller cells, at street level.

Globally the most referenced spectrum for initial 5G deployment has been in the 3.4–3.8GHz and 24.25–29.5GHz bands although adjacent bands are of interest, e.g. 3.7-4.2GHz in the U.S.	Globally, the most referenced spectrum for initial 5G deployment is in the 3.4–3.8GHz band, followed by spectrum in 24.25–29.5GHz (this range might include the 26GHz band in some countries, or 28GHz in others). Countries that have been given the highest scores in our 'spectrum availability' assessment in this report are those in which there is commitment to a timely release of sufficient spectrum for mobile use in both these frequency ranges i.e. 3.4–3.8GHz along with 26GHz and/or 28GHz.[90]

Market differences will affect the underlying demand for 5G services in several ways, impacting the spectrum and related policies being proposed, and the cross-industry trials that are taking place	5G will deliver a range of different services, and the characteristics of those services could differ between markets (e.g. embracing fixed as well as mobile broadband services, and delivering wireless connectivity to multiple industries with different connectivity needs). These market differences will affect the underlying demand for 5G services in different markets, and the spectrum and related policies that are needed to progress initial 5G implementation. In several of the markets that we have studied, large-scale 5G test and development, and cross-industry trials (some backed by governments) have been announced, which are likely to be helpful to stimulate demand for 5G commercial services. In our view, it remains to be seen whether these pre-commercial 5G trials will result in those markets obtaining 5G leadership, or not (with other relevant factors potentially

90 It is noted that detailed plans for mobile use of the millimeter-wave bands to enable sharing among the services using these bands (satellite and terrestrial) are not available at the time of producing this report. Spectrum in the 3.4-3.8GHz band is part of the C-band, also used for satellite services and hence the amount of spectrum available for terrestrial 5G use in the C-band in different markets depends on protections for C-band satellite services.

	including the timely release of spectrum and confirmed operator investment plans for commercial 5G launch).

Operators will follow different approaches to deploy 5G based on market need and operator strategy	The industry's initial specifications for 5G (i.e. 3GPP Release 15, published in December 2017) allow for different paths to 5G launch, i.e. operators can opt to deploy 5G NR as a non-standalone solution (connected to a 4G core network), or as a standalone network (i.e. 5G NR frequency carriers with a 5G core network). Global timescales are such that it appears that non-standalone and standalone solutions might be launched commercially within similar timeframes. Our research indicates that some markets will opt for the non-standalone deployment to accelerate the time-to-market and leverage their 4G core networks (e.g. US, Asia), whereas others may go for the standalone route first. Choices will depend on technological preferences in different markets, the nature of 5G services being launched, and network investment cycles. Both options will allow for 5G mobile broadband services to be offered that are differentiated from 4G in terms of superior speed and latency performance, provided sufficient spectrum is available. Deployments of 5G will allow for interoperability with existing 4G networks (and other radio access technologies), so that a customer may experience smooth transitions between areas of 5G deployment and existing 4G coverage.

We have identified the following recommendations from our work:

- Global equipment vendors have made significant commitments to 5G research and development over the past few years together with mobile operators. As a result, consensus has been reached over the frequency bands that are likely to be the most important for early 5G launch. These bands for initial global launch are the ones for which vendors expect to have commercial 5G network equipment, and devices, ready for use in the short term, broadly falling into two areas of spectrum – mid-band, around 3.5GHz, and mm-wave, between 24.25GHz and 29.5GHz (and several bands above this). Initial 5G services are likely to be mobile broadband-based (i.e. enhancements to today's 4G services, but with new 5G capabilities, such as very high throughput, and very low latency), but will expand into several verticals, and to provide a wide variety of use cases, over time.

Achieving these wide-ranging, dynamically changing 5G capabilities depends on operators having sufficient spectrum available to them within the bands that vendors are promoting for 5G use. This underlines the importance of governments and regulators planning for sufficient spectrum release, during 2018–2019, in these globally harmonized frequency ranges. Compared to several other markets, it is possible that further focus in the US should be directed towards release of spectrum in the mid-range for 5G.

- Mobile networks are already being densified to support the substantial increase in data traffic that networks are now carrying; it is widely expected that 5G will result in a greater need for small-cell deployment. The main candidates for these sites in outdoor small-cell locations are local authority/municipality-owned assets such as street lights and utility poles. For in-building coverage (e.g. offices, hotels, etc.), building owners will need to collaborate with multiple service providers to provide high-speed 5G access, potentially using shared infrastructure.

Streamlined approval processes and reasonable fee structures could help facilitate small-cell deployments both outdoors and indoors. Since there can be significant local differences in planning requirements for small cells, new national-level guidelines might be required, supported by better local-level collaboration (e.g. greater transparency on available assets, streamlined processes to avoid lengthy deployment delays, and pro-infrastructure sharing policies aimed at ensuring that small cells can be more widely deployed).

Annex A Abbreviations used in this report

AI	Artificial Intelligence
ARCEP	Autorité de Régulation des Communications Électroniques et des Postes (French NRA)
AWS	Advanced Wireless Services
BNetzA	Federal Network Agency (German NRA)
BRS	Broadband Radio Service
CA	Carrier Aggregation
CAV	Connected and Automated Vehicles
CBRS	Citizens Broadband Radio Service
CN	Core Network
C-RAN	Cloud Radio Access Network
DL/UL	Downlink/Uplink
EBS	Educational Broadband Services
eMBB	Enhanced Mobile Broadband
EC	European Commission
EPC	Evolved Packet Core
EC	European Union
FCC	Federal Communications Commission (US NRA)
FDD	Frequency Division Duplex
FNPRM	Further Notice of Proposed Rulemaking
FSS	Fixed-Satellite Service
FWA	Fixed Wireless Access
GAA	General Authorized Access
GSA	Global Supplier Association
GSM	Global System for Mobile Communications
GSMA	GSM Association
HD	High Definition
IMDA	Info-communications Media Development Authority (Singaporean NRA)
IMT	International Mobile Telecommunication system
IoT	Internet of Things
ISED	Department for Innovation, Science and Economic Development (Canadian NRA)
ISP	Internet Service Provider
ITU	International Telecommunications Union

LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MBB	Mobile Broadband
MBS	Mobile Broadband Services
MIC	Ministry of Internal Affairs and Communications (Japanese NRA)
MIIT	Ministry of Industry and Information Technology (Chinese NRA)
MIMO	Multiple Input, Multiple Output
MinSvyaz	Ministry of Telecom and Mass Communications (Russian NRA)
MSIT	Ministry of Science and ICT (South Korean NRA)
mm-wave	Millimeter-wave
MNO	Mobile Network Operator
MoU	Memorandum of Understanding
MU-MIMO	Multiple User, Multiple Input, Multiple Output
NB-IoT	Narrowband-Internet of Things
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rulemaking
NRA	National Regulatory Authority
NR	New Radio
NSA	Non-Standalone
Ofcom	Office of Communications (UK NRA)
OTN	Optical Transport Network
PAL	Priority Access License
PCS	Personal Communications Service
PHS	Personal Handy-phone System
PoC	Proof of Concept
PON	Passive Optical Network
PPDR	Public Protection and Disaster Relief
PPP	Public Private Partnership
QAM	Quadrature Amplitude Modulation
R&O	Report and Order
R&D	Research and development
RAN	Radio Access Network
RSPG	Radio Spectrum Policy Group
SA	Standalone
SDL	Supplemental Downlink
SU-MIMO	Single User, Multiple Input, Multiple Output
TDD	Time Division Duplex

TD-LTE	Time Division-Long Term Evolution
UE	User Equipment
UHD	Ultra-High Definition
UHF	Ultra-High Frequency
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra-Reliable Low Latency Communications
V2P	Vehicle-to-pedestrian
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
VR	Virtual Reality
vRAN	Virtualized Radio Access Network
WCS	Wireless Communications Service
WiMAX	Worldwide Interoperability for Microwave Access
WRC	World Radio Council
2G/3G/4G/5G	Second/Third/Fourth/Fifth Generation of mobile technology
3GPP	Third Generation Partnership Project

Annex B Country case studies

The following sections provide an overview of 5G developments (with a focus on spectrum, and deployment plans) in each of our benchmark countries (Canada, China, France, Germany, Japan, Russia, Singapore, South Korea, and the UK), as well as the US. We also have a separate case study covering proposals at the EU level, which influence the plans being developed in France, Germany, and the UK.

B.1 Canada

The federal government is responsible for spectrum policy in Canada. Innovation, Science and Economic Development Canada (ISED) is the department that manages the use of spectrum. The Communications Research Centre (CRC), which is a part of ISED, provides the department with scientific and technological evidence to support spectrum-management decisions. ISED launched a 5G consultation in June 2017 (focusing on three mm-wave bands: 28GHz, 37–40GHz and 64–71GHz), and announced that it aims to make spectrum available for 5G by 2020. A consultation is pending in the 3.5GHz band. Two of Canada's MNOs (Bell and Telus) have announced 5G trials, with Telus explicitly aiming for commercial 5G deployment in 2020. The CRC has been working on 5G technology since 2014, and began demonstrations in 2017. Shortly before publishing this report, the Canadian government announced the 'ENCQOR' project, a CAD400million public-private partnership focused on research and innovation in 5G.[91]

Overview and current spectrum holdings

ISED states[92] that it aims to position Canada 'at the leading edge of the digital economy through the release of mm-wave spectrum to support 5G', and that the technology is 'essential to Canada becoming a global center for wireless innovation'.

As shown in Figure B.1 below, 648MHz of spectrum is currently allocated to commercial mobile services in Canada.

Figure B.1: Current spectrum holdings[93] of MNOs in Canada, MHz [Source: ISED[94]]

Spectrum*	MBS	Cell.	PCS	AWS-1	AWS-3	AWS-4	WCS	BRS	Total
TDD	12	-	-	-	-	-	-	50	**62**
FDD	2×28	2×25	2×65	2×45	2×25	2×20	2×15	2×70	**2×293**
Total	**68**	**50**	**130**	**90**	**50**	**40**	**30**	**190**	**648**

* Amount made available per region

A 'residual auction',[95] which will sell regional licenses across several bands that went unsold in previous auctions, is scheduled for the beginning of 2018. Other upcoming auctions are discussed in the following section.

91 Evolution of networked services, through a corridor in Quebec and Ontario, for Research and Innovation, see https://www.encqor.ca/

92 See https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11298.html

93 Abbreviations for spectrum bands: MBS (Mobile Broadband Service), Cell. (Cellular), PCS (Personal Communications Service), AWS (Advanced Wireless Service), WCS (Wireless Communications Service) and BRS (Broadband Radio Service.

94 See http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11333.html#s6.1, Table 1 and http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08748.html

95 See https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11287.html

Main 5G spectrum proposals

In October 2017, ISED launched its 'Spectrum Outlook' consultation,[96,97] intended to 'inform ISED's overall approach and planning related to potential spectrum releases in the 2018 to 2022 timeframe'. The document lists a number of 'ongoing and planned spectrum releases' for commercial mobile:

- **600MHz**. In August 2015, ISED released a decision[98] to jointly repurpose the 600MHz band for fixed and commercial mobile use, in collaboration with the US. As determined by the recent US 600MHz auction, 84MHz (614–698MHz) of spectrum will be repurposed,[99] freeing up 70MHz for commercial mobile services. ISED ran a consultation[100] from August to October 2017 on a proposed licensing framework for the band; industry responses to the consultation were published in November 2017.

- **AWS-2 (1915–1920/1995–2000MHz, 'H-block')**. ISED notes that although this block was auctioned in the US in 2014, the equipment ecosystem has not yet developed, and the regulator will therefore 'continue to monitor developments'. ISED states that it will consult on this band in the future.

- **3400–3800MHz (3.5GHz)**. ISED 'recognizes that the 3500MHz band is being considered as one of the key bands for future 5G networks in many countries and that there have been developments in making the larger 3400–4200MHz band available internationally'. As such, ISED 'will be considering this when consulting on the 3500MHz band'.

  Furthermore, given the international interest in the extended 3.4–4.2GHz range for 5G, ISED will expand the band for the consultation to include a review of the full 3.4–4.2GHz range.

- **mm-wave**. In June 2017, ISED launched a public consultation[101] on releasing mm-wave spectrum, stating that the consultation marked the 'first step in a process that, by 2020, aims to make more wireless spectrum available for 5G mobile networks'. The consultation closed on August 4, 2017.

96 See http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11333.html#s6.1. Comments on the consultation were due by January 9, 2018, and replies to the comments were due by February 8, 2018.

97 The previous Spectrum Outlook was published in March 2013, and had planned to allocate up to 750MHz of spectrum specifically to commercial mobile services by the end of 2017. Three frequency bands considered as part of the 750MHz have not yet been released, namely the 600MHz, AWS-2 and 3500MHz bands (see http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09444.html). The 2013 Outlook envisions 80-120MHz being made available for commercial mobile in the 600MHz band and 100–175MHz in the 3500MHz band.

98 See http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11049.html

99 As in the US, existing Canadian broadcasters will be transitioned to lower parts of the band, and a spectrum auction will then be held to award licenses for mobile services.

100 See https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11316.html

101 See https://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/slpb-001-17-5G.pdf/$file/slpb-001-17-5G.pdf

ISED is seeking comments on developing a flexible use licensing model for deployment of fixed and mobile services in the 28GHz (27.5–28.35GHz) and 37–40GHz frequency bands, and allowing license-exempt use of the 64–71GHz frequency band.

The Spectrum Outlook consultation also identified the following 'potential frequency bands that could be made available between 2018 and 2022':

- 800MHz (806–824/851–869MHz). ISED states that it 'would be beneficial to review this band for potential commercial mobile services in the next five years'.
- 900MHz (896–960MHz). ISED believes that 'this frequency band should be reviewed to consider new uses'.
- L-band (1427–1518MHz). ISED considers that 'the L-band or portions thereof could be released for fixed and mobile use'.
- AWS-3 unpaired (1694–1710MHz, 'I-block'). ISED states that it expects equipment in this range will become available within the next five years. As a result, ISED considers that 'AWS-3 unpaired spectrum could be made available for commercial mobile'.
- Several mm-wave bands: 24.25–27.5GHz, 31.8–33.4GHz (32GHz), 40–42.5GHz, 45.5–50.2GHz, 50.4–52.6GHz (51GHz), 71–76GHz and 81–86GHz. ISED states that these bands 'have potential to be made available, in full or in part, in the coming five years to address spectrum demand for commercial mobile'.

Research, test beds and trials

Figure B.2 outlines 5G trials announced by the major MNOs in Canada:

Figure B.2: Announcements of 5G trials by major MNOs in Canada [Source: company press releases]

MNO	Details of 5G activity
Rogers	• We are not aware of any 5G trials announced by Rogers
Bell	• Bell's Q3 report for 2017, released on November 2, 2017, states that the company 'is now conducting further trials of 5G mobile technology in the 28GHz and 3.5GHz ranges with technology partner Huawei. Bell previously successfully demonstrated 5G capability in the 73GHz range in collaboration with Nokia in 2016'[102] • News sources, citing the executive vice president of Bell (speaking at Huawei's Global Mobile Broadband Forum in London in November 2017), state the company is transitioning to a software-based core networking system as is prepares for 5G
Telus	• On February 14, 2018, Telus and Huawei announced[103] that they had launched a 28GHz end-to-end user trial of 5G FWA at their 'Living Lab' in Vancouver (see below)

102 See http://www.bce.ca/investors/financial-reporting/2017-Q3/2017-q3-press-release.pdf

103 See http://www.huawei.com/en/press-events/news/2018/2/first-urban-5G-Wireless-Home-CPE-trial

MNO	Details of 5G activity
	• On December 15, 2017, Telus announced[104] a successful 'live-environment' MBB test using 3.5GHz in Edmonton, achieving peak DL speeds of 2Gbps. The MNO said this demonstrated 'how important the 3.5GHz spectrum is to enabling [future] 5G networks' • On June 23, 2017, Telus announced[105] a successful 'Wireless-to-the-Premise (WTTx)' [FWA] 5G pilot in partnership with Huawei, using spectrum at 28GHz. The pilot was part of Telus and Huawei's 5G 'Living Lab' in Vancouver, where the companies have been trialing next-generation technologies since 2015. In 2016 they reported achieving mobile speeds of 30Gbps and deployment of a Heterogeneous Network (HetNet)

In addition to the MNO activity outlined above, the CRC (in collaboration with the National Research Council of Canada and GGI Solutions) has been working on 5G technology since 2014,[106] and began demonstrations in 2017. The CRC states that it is 'looking at frequencies above 6GHz […] The frequency band we are currently using at Ottawa City Hall is 28GHz. The bandwidth for the 28GHz band is about 1GHz. We are currently using several different antennas for the demo, including omnidirectional antennas for the backpack, and both wide-beam and narrow-beam antennas at the base station'.

Industry plans and government commitments

Figure B.3 outlines 5G commercial deployment plans announced by the major MNOs in Canada:

Figure B.3: Announcements of 5G deployment plans by major MNOs in Canada [Source: company press releases]

MNO	Details of 5G activity
Rogers	• No explicit 5G commercial deployment plans publicly announced • A news source[107] quotes a Rogers spokesperson in May 2016 as saying that 'we don't have any details to share on future [5G] plans', but also notes that the company is 'taking part in standards setting through the various industry bodies'
Bell	• No explicit 5G commercial deployment plans publicly announced
Telus	• Telus's 2016 annual report[108] states that successful trials 'are progressing our anticipated deployment of 5G technology by 2020'. This date was reiterated in its WTTx 5G trial announcement on June 23, 2017 (see above)

In March 2018, the Canadian Minister of Innovation, Science and Economic Development announced[109] a joint investment between the government and industry on 5G, in the 'ENCQOR'

104 See https://www.telus.com/en/about/news-and-events/media-releases/scorching-fast-5g-performance-achieved-in-live-environment-as-telus-successfully-tests-ghz-spectrum

105 See https://www.telus.com/en/about/news-and-events/media-releases/successful-5g-pilot-places-canada-at-the-forefront-of-global-wireless

106 See http://www.ic.gc.ca/eic/site/069.nsf/eng/00083.html

107 See https://www.thestar.com/business/2016/05/22/canadas-major-telecoms-set-to-leap-in-to-5g-technology.html

108 See https://www.telus.com/en/about/investor-relations/reports/annual-reports

109 See https://www.canada.ca/en/innovation-science-economic-development/news/2018/03/strategic-innovation-fundencqor-investment.html

project. This is a CAD400million project to progress 5G technology research in Canada, with the objective to position Canada as a 5G leader.

Outlook

Our 5G outlook/assessment for Canada is summarized in Figure B.4 below.

Figure B.4: 5G outlook for Canada [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	'Flexible use licensing' model in 28GHz and 37–40GHz, and license-exempt use in 64–71GHz; ISED aims to make mm-wave spectrum available by 2020. 3.5GHz consultation yet to be released	1/4
5G spectrum roadmap published	mm-wave consultation completed in August 2017, and 2018–22 'Spectrum Outlook' recently published	1/4
Government commitments and infrastructure policy	The government's CRC has been working on 5G for several years, and a CAD400million public private partnership to promote 5G technology development and SME involvement was announced in March 2018	2/4
Industry trials	Bell and Telus have conducted trials. The CRC has been working on 5G research since 2014, and conducted demonstrations at 28GHz in 2017	2/4
Industry commitment and accelerated 5G launch	Telus: 2020, Bell, Rogers: N/d	1/4

B.2 China

The Ministry of Industry and Information Technology (MIIT) is responsible for radiocommunication regulation in China. The State Radio Regulation of China (SRRC) is a specialized technical agency of the MIIT responsible for radio monitoring and spectrum management. Government policy is to support both the development of 5G technological specifications and the commercial deployment of 5G networks through a range of policies and initiatives, including government support for technology research and network development. These include the 'Made in China 2025' plan and the 13th Five Year Plan, which aims for a commercial launch of 5G services by 2020.[110] The MIIT has confirmed the use of the 3.3–3.6GHz and 4.8–5.0GHz ranges for 5G and is conducting tests in a number of mm-wave bands. Each of China's three MNOs have announced plans for commercial 5G launch in 2020.

Overview and current spectrum holdings

A report published in June 2017 by the GSMA and China Academy of Information and Communications Technology (CAICT) forecasts 5G connections in China to exceed 400 million (almost 40% of the global total) by 2025. The CAICT has also forecast[111] that the total 5G expenditure from the country's three MNOs will exceed USD400 billion over the period 2020 to 2030, peaking at around USD45 billion in 2023.

A total of 687MHz of IMT spectrum has currently been planned for mobile in China,[112] of which 522MHz has already been awarded for use, as shown in Figure B.5 below:

Figure B.5: Current spectrum holdings of MNOs in China, MHz [Source: MIIT[113]]

MNO	700	800	900	1400	1800	2100	2300	2600	3400	Total
China Mobile	–	–	12	–	60	50	20	20	–	**162**
China Unicom	–	–	40	–	50	50	50	60	–	**250**
China Telecom	–	20	–	–	30	40	-	20	–	**110**
Total	**–**	**20**	**52**	**–**	**140**	**140**	**70**	**100**	**–**	**522**

Upcoming mobile allocation and 5G assignment plans in existing and new bands are discussed below.

110 See https://5g-ppp.eu/wp-content/uploads/2016/11/Opening-1_Qian-Hang.pdf. Wording taken from GSMA and CAICT's report: '5G in China: Outlook and regional comparisons' published in 2017. The 13th five-year plan (2016–2020) can be found at http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c5465203/content.html. The 'Made in China 2025' plan can be downloaded from http://www.cbbc.org/mic2025/

111 See http://www.scmp.com/tech/china-tech/article/2098948/china-plans-28-trillion-yuan-capital-expenditure-create-worlds

112 China's mobile frequency plan assigns a further 10MHz in the 1800MHz band, 35MHz in the 2100MHz band, 30MHz in the 2.3GHz band, and 90MHz in the 2.6GHz band. See 'Radio Spectrum Management in China', Bureau of Radio Regulation, MIIT, September 11, 2017 . For a discussion of 700MHz spectrum in China, see https://www.fiercewireless.com/wireless/china-issues-plan-to-use-3300-3600-mhz-4800-5000-mhz-for-5g https://www.fiercewireless.com/wireless/china-reserves-spectrum-for-5g-says-more-low-band-frequencies-coming-report

113 See https://5g-ppp.eu/wp-content/uploads/2016/11/03_9-Nov_Session-2_Chang-Ruoting-1.pdf

Main 5G spectrum proposals

A presentation released[114] in November 2016 states that 'to enable business success of 5G eMBB deployment' the MIIT intend to make available more than 100MHz of additional spectrum per operator in the 'medium' frequency range, and 2GHz of bandwidth per operator in the 24.25–43.5GHz range.

In June 2017, the MIIT released[115] a consultation on using spectrum in the 3.3–3.6GHz and 4.8–5.0GHz ranges for 5G technologies, with the 3.3–3.4GHz range limited to indoor use. These ranges were confirmed in a subsequent announcement[116] in November 2017, with the MIIT adding that it would not approve any further fixed or satellite licenses in these bands. Reports further stated[117] that China is likely to assign the 3.6-4.2GHz range to 5G in the future. The MIIT also approved[118] two mm-wave bands (24.75–27.5GHz and 37–42.5GHz) for research and testing in July 2017 and has stated[119] that it will continue to consider more bands (both low and high frequency) for 5G development.

We are not aware of an official timeline for the spectrum release, however we expect license awards might take place in 2018/19, in line with announced commercial launch timelines (as described below).[120]

Research, test beds and trials

Figure B.6 outlines 5G trials announced by the major MNOs in China:

Figure B.6: Announcements of 5G trials by major MNOs in China [Source: company press releases]

MNO	Details of 5G activity
China Mobile	• On February 27, 2018, China Mobile announced[121] at MWC plans to conduct a large 5G trial later in 2018

114 *Ibid*. The presentation also references the 4.4–4.5GHz range for 5G. See also 'Radio Spectrum Management in China', Bureau of Radio Regulation, MIIT, September 11, 2017

115 See https://www.fiercewireless.com/wireless/china-reserves-spectrum-for-5g-says-more-low-band-frequencies-coming-report. We understand that the MIIT also sought comment on non-exclusive use of the 24.75-27.5GHz and 37-42.5GHz bands in June 2017; see https://www.qualcomm.com/media/documents/spectrum-4g-and-5g

116 See http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757020/c5907905/content.html http://www.miit.gov.cn/n1146290/n4388791/c5906943/content.html, http://www.caict.ac.cn/xwdt/hyxw/201711/t20171115_2214806.htm and http://www.srrc.org.cn/en/news3434.aspx

117 See http://www.atimes.com/article/china-reserves-spectrum-5g-services/

118 See http://www.miit.gov.cn/n1146295/n1652858/n1653100/n3767755/c5677054/content.html and http://www.miit.gov.cn/n1146290/n1146402/n1146440/c5730538/content.html

119 See http://www.miit.gov.cn/n1146290/n4388791/c5906943/content.html

120 See http://www.scmp.com/tech/china-tech/article/2075179/china-mobile-targets-steady-build-out-5g-infrastructure-2018. Note that this source also references spectrum allocation in the 4.5GHz band.

121 See http://www.c114.com.cn/news/118/a1044094.html

MNO	Details of 5G activity
	• On February 25, 2018, China Mobile, Ericsson and Nokia announced[122] plans to expand their collaboration on 5G and IoT • On November 23, 2017, ZTE announced[123] plans to develop six 5G services with China Mobile • On November 17, 2017, Qualcomm, ZTE and China Mobile announced[124] an 'end-to-end 5G NR Interoperability Data Testing (IoDT)' based on 3GPP R15 standards. The system used 100MHz channel sizes in the 3.5GHz band • On June 13, 2017, China Mobile and Nokia announced[125] they were signing a one-year RMB9.927 billion (USD1.5 billion) 'frame' agreement. Under the agreement, Unicom will become the first customer of Nokia's 5G-ready 'AirScale' Base Station[126] • On June 9, 2017, China Mobile Research Institute, China Mobile Shanghai and Huawei announced[127,128] that had jointly established a '5G trial field to verify 5G High Band and Low Band Coordination Technology' at Huawei's Shanghai R&D Center • On March 1, 2017, news reports[129] stated that China Mobile would focus on proof-of-concept trials in 2017, pre-commercial trials for interoperability tests in 20 sites or cities in 2018, 'launch large-scale [over 100 sites or cities] pre-commercial 5G trials in China in 2019', before the roll-out proceeds to the commercial launch stage in 2020 (see below). The reports state that China Mobile has set up a large 5G trial in Huairou (northern Beijing) with six vendors (Huawei, ZTE, Ericsson, Datang, Samsung and Nokia), and conducted a number of trials in the 3.5GHz band, as well as mm-wave bands such as 15GHz, 28GHz and 73GHz • On November 9, 2016, Samsung announced[130] it had conducted a 5G prototype trial in Beijing in partnership with the China Mobile Research Institute (CMRI). Technologies such as spatial modulation and FBMC (Filter Bank Multicarrier) were tested in the 3.5GHz band; mm-wave spectrum was also tested • 5G testing and research was first announced[131] by China Mobile in 2015
China Unicom	• On January 17, 2018, reports[132] stated that Unicom is planning to conduct 5G trials in seven Chinese cities, and had submitted an application to the MIIT

122 See https://www.ericsson.com/en/press-releases/2018/2/ericsson-and-china-mobile-pursue-industry-4.0-iot-opportunities and https://www.nokia.com/en_int/news/releases/2018/02/25/nokia-and-china-mobile-to-jointly-explore-use-of-5g-to-drive-new-business-opportunities-for-vertical-industries

123 See http://www.zte.com.cn/global/about/press-center/news/201711ma/1123ma1

124 See https://www.qualcomm.com/news/releases/2017/11/16/qualcomm-zte-and-china-mobile-showcase-5g-leadership-completion-worlds

125 See https://www.nokia.com/en_int/news/releases/2016/06/13/nokia-and-china-mobile-sign-eur-136-billion-frame-agreement

126 Nokia will also provide additional elements of its mobile radio access and core portfolio in addition to fixed access, IP routing and optical transport, customer experience management, operational support system (OSS) and third-party products as well as its global services expertise.

127 See http://www.huawei.com/en/news/2017/6/Huawei-ChinaMobile-5G-Shanghai

128 The press release also provided some results from 5G testing conducted so far. The collaboration 'demonstrated that the average user data rate can reach to 1.7Gbps with a bandwidth of 200MHz on the low frequency. In the meantime, with the prerequisite of the high reliability, mm-wave frequency technology can improve the network capacity in hot spots effectively on dual connectivity modes with both 5G low frequency and mm-wave networks. The 5G dual connectivity network can provide 18Gpbs for single user peak throughput'.

129 See https://www.telecomasia.net/content/china-mobile-begin-large-scale-5g-trials-2019. Telecom Asia cites Wang Xiaoyun, general manager of China Mobile's technical department and vice chairman of IMT-2020 PG, China's 5G promotion group.

130 See http://www.samsung.com/global/business/networks/insights/news/samsung-successfully-conducts-5g-prototype-trial-with-china-mobile-communication-corporation

131 See https://www.shine.cn/archive/business/it/China-Mobile-eyes-5G-technology/shdaily.shtml

132 See http://finance.sina.com.cn/chanjing/gsnews/2018-01-17/doc-ifyqtycw8920855.shtml

MNO	Details of 5G activity
	• On July 10, 2017, Unicom announced[133] its first successful 5G NR field test, in partnership with ZTE. The test, which took place in Shenzhen, deployed a pre-commercial 5G base station using 100MHz of 3.5GHz spectrum with Massive MIMO, LDPC (low-density parity check) and 'other key 5G technologies', and achieved data rates of up to 2Gbps for single user-equipment. We also understand[134] that Unicom trialed 5G technology with both ZTE and Huawei in Shanghai and Guangzhou in 2017 • In 2016, Unicom started a 5G laboratory to 'verify the feasibility of potential key technologies and accelerate the development of 5G base station architecture and platforms'[135] • On May 11, 2016, Unicom and Ericsson announced[136] they had signed an MoU to collaborate on 'network architecture, 5G, cloud and IoT'. Other news sources indicate that Unicom has also partnered with Huawei and Nokia on 5G R&D[137]
China Telecom	• On December 11, 2017, reports[138] stated that China Telecom had deployed a new 5G base station in Lanzhou, expanding its pilot project for 5G networks to six cities • On September 18, 2017, China Telecom, China Electric Power and Huawei announced[139] they would co-operate on a 5G power slicing technology • In September 2017, reports[140] stated that 'China Telecom is building a 5G-oriented cloud radio access network (C-RAN) fronthaul network in the north-east Liaoning province, using Huawei's Blade optical transport network (OTN) solution' • On August 24, 2017, the Nikkei Asian Review, citing China Telecom Chairman and CEO Yang Jie, said[141] that the company would start trials in 2019 and commercial use from 2020. Yang Jie is quoted as saying 'we expect a more gradual process for 5G investment, unlike the spike we've seen for 4G'

In addition to the MNO trials outlined above, the MIIT is conducting several of its own 5G tests. On January 7, 2016, the Ministry launched[142] a trial to assess the compatibility between 5G IMT in the 3.4–3.6GHz band and FSS in the 3.6–4.2GHz bands. The MIIT is also conducting[143] compatibility studies in other WRC-19 AI 1.13 bands, such as 25.25–27.5GHz (between IMT and ISS) and 37–42.5GHz (see above). MIIT policy schedules MNO 5G research and development into 'phases' prior to commercial launch in 2020.[144]

133 See http://www.zte.com.cn/global/about/press-center/news/201707ma/0710ma1

134 See https://www.rcrwireless.com/20170703/5g/china-unicom-5g-timeline-tag23

135 See http://www.zte.com.cn/global/about/press-center/news/201707ma/0710ma1

136 See https://www.ericsson.com/en/press-releases/2016/5/china-unicom-and-ericsson-to-cooperate-on-5g-cloud-and-iot

137 See https://www.rcrwireless.com/20170703/5g/china-unicom-5g-timeline-tag23

138 See https://www.rcrwireless.com/20171211/5g/china-telecom-adds-5g-testing-sites-tag23

139 See http://www.huawei.com/en/news/2017/9/ChinaTelecom-StateGrid-Joint-Innovation-Project

140 See http://www.telecomtv.com/articles/5g/china-telecom-deploys-5g-oriented-c-ran-fronthaul-network-15974/

141 See https://asia.nikkei.com/Business/AC/China-Telecom-s-5G-service-may-not-cover-whole-country. See also https://www.rcrwireless.com/20170824/5g/china-telecom-trial-5g-tag23

142 See https://5g-ppp.eu/wp-content/uploads/2016/11/03_9-Nov_Session-2_Chang-Ruoting-1.pdf

143 *Ibid*. The MIIT is also conducting LTE-V2X trials in the 5.9GHz band in Shanghai, Chongqing and other locations.

144 See https://5g-ppp.eu/wp-content/uploads/2016/11/Opening-1_Qian-Hang.pdf. See also news releases from the CAICT.

Industry plans and government commitments

Figure B.7 outlines 5G commercial deployment plans announced by the major MNOs in China:

Figure B.7: Announcements of 5G deployment plans by major MNOs in China [Source: company press releases]

MNO	Details of 5G activity
China Mobile	• On March 1, 2017, news reports stated that China Mobile would commercially launch 5G in 2020 (see above) • On February 12, 2018, news reports stated[145] that China Mobile, in partnership with vendor VIAVI, were aiming to introduce 5G services by the end of 2019 • Further details[146] are available from a China Mobile presentation on 5G commercial launch, delivered at MWC 2017
China Unicom	• A number of news reports,[147] citing Unicom's Deputy General Manager of Network Construction speaking at the MWC Shanghai event in June 2017, quoted the official as saying that 'we are not [currently] in a position to have a clear timeline towards the deployment of 5G'. However, Unicom's July 10, 2017, 5G NR trial announcement[148] stated that 'following the start of 5G field testing in 2017, China Unicom is intensifying efforts on verification, with a goal of pre-commercial 5G network deployment in 2019 and large-scale deployment in 2020'
China Telecom	• China Telecom plans to 'run laboratory and networks tests' until the end of [2018], before commencing pre-commercialization of 5G technology in 2019. Commercial launch is targeted for 2020 (see above)

In August 2017, China Unicom announced[149] a 'mixed-ownership reform', in which a consortium of 14 privately owned businesses and funds[150] would take a 35.2% stake for RMB78 billion (USD12 billion). Unicom stated that the proceeds raised by the new equity would allow it 'to enhance 4G capability, conduct 5G technical network trials and related business functions, build pre-commercial trial networks, and invest in innovative businesses'.

Most recently, on January 25, 2018, Qualcomm announced[151] that it had signed new agreements with Chinese smartphone makers to co-operate on 5G development.

145 See http://markets.businessinsider.com/news/stocks/china-mobile-research-institute-enlists-viavi-to-support-introduction-of-5g-service-1002078175

146 See https://www.youtube.com/watch?v=W2dZ0YRvL6w

147 See, for example, https://www.rcrwireless.com/20170703/5g/china-unicom-5g-timeline-tag23

148 See http://www.zte.com.cn/global/about/press-center/news/201707ma/0710ma1

149 See http://www.chinaunicom.com.hk/en/ir/presentations/pre170816.pdf

150 The consortium includes large Internet/ecommerce companies (Alibaba, Baidu, JD, Suning and Tencent), companies from other verticals (ride-hailing business Didi Chuxing, datacenter provider Wangsu Science & Technology, railway stock manufacturer CRRC, business software provider Yonyou, network services business Guangdong Eastone Century and technology conglomerate Kuang-Chi), financial institution China Life Insurance and two other specialized funds.

151 See https://www.qualcomm.com/news/releases/2018/01/24/qualcomm-and-leading-chinese-manufacturers-announce-5g-pioneer-initiative

Outlook

Our 5G outlook/assessment for China is summarized in Figure B.8 below.

Figure B.8: 5G outlook for China [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	3.3–3.6GHz, 4.8–5.0GHz (confirmed), 24.75–27.5GHz, 37–42.5GHz (approved for testing). The MIIT has said it aims to release 100MHz per MNO in the 'medium' range (i.e. 3.3–3.6GHz and/or 4.8–5GHz), plus 2GHz per MNO in 24.25–43.5GHz range	3/4
5G spectrum roadmap published	'13th Five Year Plan' aims for commercial 5G launch by 2020. The MIIT published a 'consideration of spectrum for 5G' document in 2016, with a '5G promotion plan' from 2013–2020	3/4
Government commitments and infrastructure policy	Range of government policies and support for R&D, as outlined in the roadmap documentation described above	4/4
Industry trials	China Mobile and China Unicom have completed trials. MIIT has conducted compatibility tests in a number of bands	4/4
Industry commitment and accelerated 5G launch	China Mobile, China Unicom, and China Telecom: 2020	4/4

B.3 France

ARCEP is the telecommunications regulator in France, with responsibility for spectrum policy and management. ARCEP has announced plans to release 300MHz of contiguous C-band spectrum for 5G by 2020, and 340MHz (3460–3800MHz) by 2026, with allocation to begin as early as 2018. Having already released 2×30MHz of paired spectrum in the European 700MHz band, the regulator has consulted on allocating a further 700MHz unpaired block, 2.3GHz and 26GHz spectrum for 5G. Orange, Bouygues Telecom and SFR have conducted a number of 5G trials, with Bouygues explicitly stating that it expects to roll out commercial services in 2020.

[Note: as a Member State of the EU, 5G policy in France is influenced by the relevant EU frameworks and initiatives. See separate EU case study.]

Overview and current spectrum holdings

ARCEP's recent consultation (see below) noted that mobile data traffic in France almost doubled between Q3 2015 and Q3 2016.

Current mobile spectrum allocations in France are shown in Figure B.9 below.

Figure B.9: Current spectrum holdings of MNOs in France, MHz [Source: ARCEP[152]]

MNO	700	800	900	1400	1800	2100	2300	2600	3400	Total
Orange	10	20	20	–	40	44.2	–	40	–	184.2
SFR	10	20	20	–	40	44.6	–	30	–	164.6
Bouygues	10	20	19.6	–	40	34.6	–	30	–	154.2
Free	20	–	10	–	30	10	–	40	–	110
Total	**60**	**60**	**69.6**	**–**	**150**	**133.4**	**–**	**140**	**–**	**613**

On January 22, 2017, ARCEP announced[153] plans for the extension of licenses in the 900MHz, 1800MHz and 2100MHz bands ahead of their expiry between 2021 and 2024.

Main 5G spectrum proposals

ARCEP ran a public consultation[154] on new spectrum for 5G from January to March 2017, focusing on the 2.6GHz and 3.4GHz bands, but also discussing the 400MHz, 700MHz SDL, 1400MHz,

152 See https://www.arcep.fr/uploads/tx_gspublication/consult-frequences-terr-entreprises-5G-innov_01.pdf

153 See https://www.arcep.fr/uploads/tx_gspublication/description-dispositif-couverture-mobile-ENG-220118.pdf

154 See https://www.arcep.fr/uploads/tx_gspublication/consult-frequences-terr-entreprises-5G-innov.pdf

2.3GHz and 26GHz bands.[155] On June 22, 2017, ARCEP published responses to the consultation[156] and preliminary decisions[157] regarding the future allocation of spectrum. The NRA confirmed its intention to allocate:

- 40MHz of 2.6GHz spectrum (2570–2620MHz) to private mobile networks
- 40MHz of 3.4GHz spectrum (3420–3460MHz) to FWA in currently underserved areas[158] (with an additional 10MHz (3410–3420MHz) in certain areas, depending on 'coexistence constraints')
- 300MHz of contiguous C-band spectrum for 5G by 2020, and 340MHz[159] (3460–3800MHz) by 2026.

ARCEP stated that it welcomed requests from interested partied to conduct 5G pilots (see below), and that it would be possible, on the basis of those pilots, to start the 5G spectrum allocation in 2018. ARCEP also published a report[160] on 5G in March 2017, overviewing work that is currently underway on the future generation of mobile networks.

155 Section 3.3 notes that the central 40MHz portion of the L-band (1452–1492MHz) is more readily accessible than the remaining 51MHz (1427–1452MHz and 1492–1518MHz), which is currently used by the MoD and infrastructure links. ARCEP consults on its intention to only award spectrum when the entire 91MHz is available.

Section 3.4 consults on the demand for the 2.3GHz band, but notes that the 'assignment in this band depends on the needs of the MoD, and to date appears unlikely'. Between 2014 and 2016, ARCEP allowed the Telecom Platform Association and the Red company permission to use the 2.3GHz band experimentally.

Section 3.5 considers the 700MHz SDL band. 700MHz FDD spectrum (703–733MHz and 758–788MHz) was auctioned by ARCEP in December 2015. The consultation asks whether there is demand for the unallocated spectrum in the 700MHz band, in particular four 5MHz blocks at 738–753MHz. The consultation states that ARCEP has no plans to assign this spectrum before 01/07/19 (which is when PMSE should have released the band).

Section 3.6 consults on the 400MHz band (380–399.9MHz, 406.1–430MHz and 440–470MHz). The consultation notes that, in accordance with CEPT discussions 'work is well underway to assess the possibility of assigning authorizations for use of wider frequency bands, which [would] allow the introduction of the LTE in the 400MHz band.'

Section 3.7 of the consultation consults on the usage of the 26GHz mm-wave band for 5G services. This band was identified by the RSPG for 5G in its opinion piece on 09/11/16. We understand that this band would require extensive refarming, but that geographical coexistence can be envisioned.

156 See https://www.arcep.fr/uploads/tx_gspublication/synth-consult-frequences-5g-entreprises-juin2017.pdf

157 See https://www.arcep.fr/index.php?id=8571&no_cache=0&L=0&no_cache=0&tx_gsactualite_pi1[uid]=2063&tx_gsactualite_pi1[annee]=&tx_gsactualite_pi1[theme]=&tx_gsactualite_pi1[motscle]=&tx_gsactualite_pi1[backID]=26&cHash=0b883993e79c11e684d43c456e864432

158 A consultation on FWA spectrum was published on July 13, 2017, and a document outlining the assignment approach on December 11, 2017. As of March 2018, players are able to request regional FWA licenses from the regulator. See:
https://www.arcep.fr/uploads/tx_gspublication/consult-attribution-THD_radio-juil2017.pdf
https://www.arcep.fr/uploads/tx_gspublication/modalites_attribution_THD_radio-dec2017.pdf
https://www.arcep.fr/index.php?id=13756

159 390MHz in areas where 3410–3460MHz has not been allocated for FWA. ARCEP will reorganize the current 3.4–3.6GHz users towards the bottom of the band to achieve this. ARCEP states that it will contact existing licensees in the 3.4–3.6GHz band 'without delay', aiming to complete the required reorganization by YE 2017.

160 See https://www.arcep.fr/uploads/tx_gspublication/Report-5G-issues-challenges-march2017.pdf. The report 'reflects the views of the stakeholders who were interviewed, but in no way represents ARCEP's positions on or roadmap for 5G'.

Most recently, on December 13, 2017, the Ministry of Economy and Finance launched[161] a consultation on establishing a 5G roadmap. Responses are due by February 16, 2018, and the finalized 5G roadmap is scheduled to be published in the first half of 2018.[162]

Research, test beds and trials

Figure B.10 outlines 5G trials announced by the major MNOs in France:

Figure B.10: Announcements of 5G trials by major MNOs in France [Source: company press releases]

MNO	Details of 5G activity
Orange	• On February 7, 2018, Orange announced[163] plans to launch an 'end-to-end' 5G test in Lille and Douai between mid-2018 and mid-2019, using Ericsson equipment • On February 27, 2017, Orange Group, Qualcomm, PSA and Ericsson announced[164] 'a significant step towards the realization of 5G technology for connected vehicles' after conducting field trials in France, using the 2.6GHz band. V2V, V2P and V2X trials are part of their 'Towards 5G' initiative • On February 16, 2017, Orange Group and Huawei announced[165] that they had signed a partnership to co-operate in '5G & cloudification' and would co-operate on technologies such as massive MIMO, cloudification of the mobile network, network slicing and 4G and 5G power and channel sharing within spectrum bands • On January 30, 2017, Orange Group and Nokia announced[166] that they would 'collaborate to shape the future of 5G services', leveraging Nokia's Flexi Base Station and 5G-ready AirScale radio access portfolio, its AirFrame data center platform, telco cloud and cybersecurity technologies • On January 25, 2017, Orange and Ericsson announced[167] they had successfully demonstrated peak rates of 10Gbps in alive 5G field trial. Orange announced[168] a partnership with the vendor to develop 5G technology in October 2016 • On September 30, 2015, ARCEP announced[169] that it has authorized Orange France to conduct 5G trials in Belford until the end of 2016 in three bands: 3600–3800MHz, 10.500–10.625GHz and 17.300–17.425GHz
SFR[170]	• We are not aware of any explicit 5G trials conducted by SFR, though the MNO has announced[171] 'pre-5G' (i.e. 4.5G) trials, such as a 'pre-commercial field verification

161 See https://www.entreprises.gouv.fr/numerique/feuille-de-route-sur-la-5g-consultation-des-acteurs-du-marche

162 See https://www.entreprises.gouv.fr/files/files/directions_services/numerique/consultation-publique-sur-la-5G.pdf

163 See https://www.orange.com/en/Press-Room/press-releases/press-releases-2018/Orange-prepares-for-the-arrival-of-5G-with-three-new-tests

164 See https://www.orange.com/en/Press-Room/press-releases/press-releases-2017/Towards-5G-Initiative-Welcomes-Qualcomm-Shows-Fast-Results

165 See http://www.huawei.com/en/news/2017/2/ORANGE-HUAWEI-PARTNERSHIP-5G-CLOUDIFICATION

166 See https://www.nokia.com/en_int/news/releases/2017/01/30/nokia-and-orange-group-collaborate-to-shape-the-future-of-5g-services

167 See https://www.ericsson.com/en/news/2017/1/ericsson-and-orange-demonstrate-speeds-beyond-10gbps-in-live-5g-field-trial

168 See https://www.ericsson.com/en/press-releases/2016/10/orange-and-ericsson-partner-for-5g

169 See https://www.arcep.fr/uploads/tx_gsavis/15-1117.pdf

170 The GSA's January 2018 5G Market Trial report states that SFR and Free Mobile are both MNOs 'that have demonstrated, or are understood to be testing or trialing, pre-standards 5G technologies, or have been licensed to begin trials'.

171 See http://www.huawei.com/en/news/2017/6/Huawei-SFR-French-4x4-MIMO

MNO	Details of 5G activity
	[with Huawei] of 4×4 MIMO, achieving a downlink throughput of 628.31Mbps using a commercially available phone on SFR's 4.5G network' on June 26, 2017
Bouygues Telecom	• On February 27, 2018, Bouygues and Huawei announced[172] joint innovation program to develop 5G in France • On March 16, 2017, Bouygues announced[173] it had achieved download speeds of over 25.2Gbps in a 5G test with Ericsson. The test was conducted using two prototype mobile devices, which were simultaneously connected to an Ericsson radio base station equipped with active 5G antennas
Free Mobile[174]	• We are not aware of any explicit 5G trials publicly announced by Free Mobile. However, on October 5, 2017, ARCEP authorized[175] Free to conduct 5G testing in the 3.6–3.7GHz bands

ARCEP has actively encouraged industry players to conduct 5G (and LTE) testing. After awarding licenses for use of the 700MHz band in 2015, the regulator has invited[176] stakeholders to request spectrum for experimentation in the 2.6GHz and 3.4–3.6GHz bands. In ARCEP's June 2017 announcement (see above), the regulator encouraged industry players to conduct 5G pilots. It nominated 80MHz (3600–3680MHz) of spectrum for that purpose, and identified six cities where pilot projects could be carried out (Lyon, Nantes, Lille, Le Havre, Saint-Etienne and Grenoble).

On January 16, 2018, ARCEP formally opened a '5G pilot window',[177] inviting industry players to apply for trial licenses with the objectives of:

- Engaging all players across the 5G value chain in cooperation (new verticals as well as MNOs)
- Assigning spectrum for 5G pilots, particularly in the 3.4–3.8GHz and 26GHz bands. (The announcement notes that 3.4–3.8GHz spectrum is already available for 5G pilots in the six cities mentioned above, but that those cities are 'not exhaustive and may change'.[178] Players interested in deploying networks in other frequency ranges/areas are invited to contact ARCEP)
- Receiving initial feedback on the deployment of 5G networks. This feedback will help ARCEP to prepare the procedure for awarding future 5G licenses.

172 See http://www.huawei.com/en/press-events/news/2018/2/Huawei-Bouygues-Telecom-5G-Agreement

173 See https://www.bouygues.com/wp-content/uploads/2017/03/bouygues-telecom-5g-demo-with-ericsson.pdf

174 The GSA's January 2018 5G Market Trial report states that SFR and Free Mobile are both MNOs 'that have demonstrated, or are understood to be testing or trialing, pre-standards 5G technologies, or have been licensed to begin trials'.

175 See https://www.arcep.fr/uploads/tx_gsavis/17-1198.pdf

176 See https://www.arcep.fr/index.php?id=8571&no_cache=1&tx_gsactualite_pi1%5buid%5d=1843&tx_gsactualite_pi1%5bbackID%5d=26&cHash=4b0291e929f616fc99ac087b8f3e18c6

177 See https://www.arcep.fr/index.php?id=8571&no_cache=0&tx_gsactualite_pi1[uid]=2119&tx_gsactualite_pi1[annee]=&tx_gsactualite_pi1[theme]=&tx_gsactualite_pi1[motscle]=&tx_gsactualite_pi1[backID]=26&cHash=7a322a2c0239bb9c53b8f95be9d7e7e2

178 The interview with ARCEP's president (link below) states that there are nine pilot cities – Bordeaux, Douai and Montpellier, in addition to the six mentioned above.

We understand[179] that the pilot licenses will last 18–24 months, and that pilot sites will consist of 'a few tens of towers representing a modest investment of a few million euros'. The first pilot licenses were issued by ARCEP (in the 3.4-3.8GHz band) to Orange and Bouygues in February 2018[180].

In parallel with inviting requests for 5G pilot licenses, ARCEP launched work on the 'deployment conditions for 5G', stating that it would organize a workshop on the subject 'in the course of 2018'.

Industry plans and government commitments

Figure B.11 outlines 5G commercial deployment plans announced by the major MNOs in France:

Figure B.11: Announcements of 5G deployment plans by major MNOs in France [Source: company press releases]

MNO	Details of 5G activity
Orange	• No explicit 5G commercial deployment plans publicly announced • However, we understand[181] that 'Orange expects capital expenditure to peak in 2018 or 2019, as [it] prepares for the introduction of 5G'. The company produced[182] a 5G position paper in May 2017 which anticipates that European MNOs will launch 5G commercial networks 'from 2020'
SFR	• No explicit 5G commercial deployment plans publicly announced • After its 4.5G trial with Huawei in June 2017 (see above), SFR stated that its ambition is to 'build the best and fastest 4.5G network in France' and thereby 'pave the way for the future, since a successful transition to 5G will depend first on 4.5G successes' • An article published on the MNO's website in July 2017 states[183] that 'pending the first deployments of the 5G planned for 2020, SFR is evolving its network to offer its customers growing speeds in the short and medium term'
Bouygues	• Bouygues' March 2017 press release (see above) states that it plans to roll out 5G in 2020
Free Mobile	• No explicit 5G commercial deployment plans publicly announced

We are not aware of any specific government funding designed to directly accelerate 5G technological development.

Outlook

Our 5G outlook/assessment for France is summarized in Figure B.12 below.

179 See interview with ARCEP's president reported at: https://www.usinenouvelle.com/article/neuf-sites-pilotes-pour-la-5g-en-2018-2019-annonce-sebastien-soriano-president-de-l-arcep.N638013

180 See https://www.telegeography.com/products/commsupdate/articles/2018/03/02/arcep-issues-two-5g-trial-licences-assigns-3-5ghz-spectrum-in-saint-martin

181 See http://www.lightreading.com/mobile/5g/orange-sees-peak-capex-in-2018-19-ups-2017-guidance/d/d-id/733295

182 See https://www.orange.com/en/news/2017/Juillet/5G-a-mobile-revolution-of-the-future

183 See http://www.sfr.com/reseau/tres-haut-debit/07062017-1446-en-route-vers-la-5g and http://www.sfr.com/sites/default/files/20170512_pr_sfr_networks_march2017.pdf

Figure B.12: 5G outlook for France [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	300MHz of 3.4GHz by 2020, 340MHz of 3.4GHz by 2026 Spectrum to be auctioned as early as 2018. Plans for other bands (700MHz SDL, 26GHz etc. less clear)	2/4
5G spectrum roadmap published	3.4GHz licensing decision announced, with other bands at consultation stage. French government has launched a consultation on a 5G roadmap which is expected to be finalized in H1 2018	2/4
Government commitments and infrastructure policy	ARCEP has been encouraging trials through offering test licenses, and recently opened a pilot 'window'	2/4
Industry trials	Orange and Bouygues have completed 5G trials. ARCEP is encouraging trials in the 3.6/26GHz bands	2/4
Industry commitment and accelerated 5G launch	Bouygues: 2020, Orange, SFR, Free: N/d	1/4

B.4 Germany

The Federal Network Agency (Bundesnetzagentur or BNetzA) is the regulatory authority for a number of markets in Germany including telecommunications, with oversight of managing and licensing radio spectrum. The market has a large amount of spectrum currently assigned for mobile use, including the European 700MHz band, and L-band, as well as spectrum in the 3.4–3.6GHz range, which might be suited for 5G use. The regulator has announced plans to allocate the entire 3.4–3.8GHz range to 5G in 2018, and is also considering action in the 700MHz unpaired block not awarded along with the paired blocks, as well as 26GHz, 28GHz and possibly other mm-wave bands. As well as MNO trials, a number of initiatives are stimulating the development of 5G technology, including Germany's '5G Lab' and the '5G Berlin' initiative.

[Note: as a Member State of the EU, 5G policy in Germany is influenced by the relevant EU frameworks and initiatives. See separate EU case study.]

Overview and current spectrum holdings

The Federal Ministry for Economic Affairs and Energy, in its Digital Strategy 2025, aims to 'create a viable digital infrastructure that can support the triple requirements of high capacity, broad availability and low latency'.[184] Elsewhere, the Ministry has noted that the increasing convergence of fixed and mobile applications has led to 'stringent requirements regarding the appropriate provision of spectrum, especially for 5G'.[185] Most recently, on September 14, 2017, the government published[186] its '5G Strategy for Germany', stating its aspiration to be a leading market for 5G applications, and roll out the technology in 2020.

Current mobile spectrum assignments in Germany are shown in Figure B.13 below.[187]

Figure B.13: Current spectrum holdings of MNOs in Germany, MHz [Source: BNetzA[188,189]]

MNO	700	800	900	1400	1800	2100	2300	2600	3400	Total
Telefónica	20	20	20	–	40	93.5	–	80	42	**357.5**
Vodafone	20	20	20	20	50	34.7	–	65	42	**229.7**
DT	20	20	30	20	60	24.8	–	45	42	**261.8**

184 Federal Ministry for Economic Affairs and Energy, Digital Strategy 2025, p.13.

185 Federal Ministry of Transport and Digital Infrastructure, Kursbuch Netzausbau 2016, Area of action, Frequencies, p.37.

186 See https://www.bmvi.de/SharedDocs/EN/publications/5g-strategy-for-germany.pdf?__blob=publicationFile

187 BNetzA claims that over 1GHz us currently allocated to MBB. However, the allocation table provided by the same source implied a total of 849MHz; see https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/DrahtloserNetzzugang/Projekt2016/Frequenzen700bis1800_pdf.pdf?__blob=publicationFile&v=3

188 *Ibid*.

189 On February 21, 2018, Telefonica announced that it had sold half of its spectrum in the 3.5GHz band (42MHz) to Vodafone. See https://www.telefonica.de/fixed/news/6094/more-high-speed-for-germany-vodafone-and-telefonica-deutschland-to-cooperate-over-fast-fibre-optic-connections-for-mobile-networks.html

MNO	700	800	900	1400	1800	2100	2300	2600	3400	Total
Total	**60**	**60**	**70**	**40**	**150**	**153**	**–**	**190**	**126**	**849**

Upcoming allocation plans in existing and new bands are discussed below.

Main 5G spectrum proposals

BNetzA's 'framework' document issued[190,191] on June 27, 2017, identifies the following spectrum[192] for 5G, which the NRA aims to assign in 2018:

- 2×60MHz in the 2.1GHz band, to be assigned in 2×5MHz blocks, which will become available in either 2020 or 2025 (based on expiry dates for current UMTS licenses).
- 400MHz in the 3.4–3.8GHz range, to be assigned in 10MHz unpaired blocks, most of which will become available in 2022 when current licenses expire. The 3.4–3.7GHz range will be available for national use, while the 3.7–3.8GHz range will be awarded on a regional basis

On January 31, 2018, BNetzA published a draft decision[193] regarding these bands, confirming its intention to auction 2×60MHz in the 2.1GHz band and 300MHz in the 3400–3700MHz (3.5GHz) band (for nationwide use) in 2018. Comments on the draft decision are due by February 28, 2018.

The framework document also identifies other spectrum ranges that could be used for 5G, including:

- 738–753MHz. This was not part of the 2016 700MHz auction, and is currently used for PMSE services. The range is unpaired and could be used for time division duplex (TDD) or supplementary downlink (SDL) technology and will be considered for auction at a later date.
- mm-wave spectrum. The regulator considers the 26GHz (24.25–27.5GHz), 28GHz (27.5–29.5GHz) and 32GHz (31.8–33.4GHz) ranges, with 26GHz being the most important having been designated a RSPG pioneer band for 5G. BNetzA aims develop an approach to release these bands for 5G (starting with 26GHz) 'as early as possible so that usage can start in 2020'.[194]

190 See https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2017/27062017_Frequenzen.html?nn=26577. The '5G Strategy in Germany' paper was published in September, but reiterates previous BNetzA documentation.

191 This follows the 'Frequency Compass' and 'Points of Orientation' documents published in 2016; see https://www.bundesnetzagentur.de/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OeffentlicheNetze/Mobilfunknetze/mobilfunknetze-node.html

192 Both the 2.1GHz and C-band spectrum will be awarded technology-neutral, with licenses expiring on December 31, 2040.

193 See https://www.bundesnetzagentur.de/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OeffentlicheNetze/Mobilfunknetze/mobilfunknetze-node.html

194 See https://www.bmvi.de/SharedDocs/EN/publications/5g-strategy-for-germany.pdf?__blob=publicationFile

Research, test beds and trials

Figure B.14 outlines 5G trials announced by the major MNOs in Germany:

Figure B.14: Announcements of 5G trials by major MNOs in Germany [Source: company press releases]

MNO	Details of 5G activity
Telefónica	• On October 19, 2017, Telefónica and Huawei announced[195] that they had launched a '5G-oriented antenna deployment solution' at the 2017 Global Antenna Technology & Industry Forum held in Munich. The solution includes a 14-port multi-band antenna and a TDD 3.5GHz Massive MIMO antenna. This follows a TD-LTE 3.5GHz massive MIMO trial in February 2017[196] as part of its Munich 'TechCity' project with Huawei
Vodafone	• On January 16, 2018, Vodafone and HERE announced[197] signing an agreement to develop a 5G 'real-time atlas' for connected cars • On October 13, 2016, Vodafone Germany and Huawei announced[198] the successful demonstration of '1.5km cell coverage' using the lower C-band', and peak speeds of 5Gbps using the 'high band' • On July 1, 2016, Vodafone Germany and Ericsson announced[199] they had demonstrated 'a new 5G Proof of Concept' following joint commitment to 5G innovation announced at Mobile World Congress 2016
Deutsche Telekom (DT)	• On January 25, 2018, DT, Intel and Huawei announced[200] that they had achieved 5G interoperability and development testing (IODT) based on the 3GPP R15 Standard with a commercial base station using the C-band • On December 14, 2017, Ericsson announced[201] that it had been selected by DT to supply one out of two of the MNO's market areas with a '5G-ready' network • On October 12, 2017, DT announced[202] demonstrating 'Europe's first' live 5G connection in a real-world setting, claiming it had demonstrated a throughput of over 2Gbps to a single customer device in Berlin using 3.7GHz spectrum over pre-standard 5G NR. The technology (powered by Huawei) was first announced[203] on September 1, 2017 • On February 15, 2017, DT announced[204] that it had 'built and demonstrated the world's first intercontinental 5G trial network' with SK Telecom and Ericsson. This

195 See http://www.huawei.com/en/news/2017/10/First-5G-oriented-Antenna-Deployment-Solution

196 See https://www.telefonica.de/home-corporate-en/company-news/news/6015/tech-city-munich-reaches-next-milestone-on-its-way-to-5-g-telefonica-germany-launches-the-worlds-first-3-5-g-hz-massive-mimo-field-trial.html?page=2

197 See https://www.telecompaper.com/news/vodafone-and-here-to-develop-5g-atlas-for-connected-cars--1227349

198 See http://www.huawei.com/en/news/2016/10/Test-Frequency-Bands-Urban%20City

199 See https://www.ericsson.com/en/press-releases/2016/7/vodafone-and-ericsson-demonstrate-new-5g-proof-of-concept

200 See http://www.huawei.com/en/news/2018/1/dt-intel-huawei-worlds-first-5g-nr-interoperability https://www.telekom.com/en/media/media-information/archive/dt-and-partners-achieve-5g-nr-interoperability-515364

201 See https://www.ericsson.com/en/press-releases/2017/12/deutsche-telekom-selects-ericsson-for-5g-ready-network

202 See https://www.telekom.com/en/media/media-information/archive/europes-first-5g-antennas-are-transmitting-in-berlin-505686

203 See https://www.telekom.com/en/media/media-information/archive/dt-and-huawei-go-live-with-europes-first-5g-connection-501660

204 See https://www.telekom.com/en/media/media-information/archive/world-s-first-5g-federated-network-slicing-grants-global-reach-485658

MNO	Details of 5G activity
	follows the joint announcement by the three companies at MWC Shanghai 2016 of their partnership to develop 5G technology • On December 1, 2016, DT and Huawei announced[205] they had successfully demonstrated 5G with 'end-to-end autonomous […] network slicing' • On March 9, 2016, DT and Nokia announced[206] the successful demonstration of 5G MBB in Berlin's Olympic stadium • On March 24, 2015, DT announced[207] the launch of its '5G:haus' lab, naming Ericsson, Nokia, Samsung, ZTE, Qualcomm and Huawei as some of its partners

In addition to the above, the MNOs participate in a number of 5G development schemes:

- Germany's '5G Lab' at Technische Universität Dresden (TUD), is an interdisciplinary team from a variety of different research areas at the University which aims to 'deliver key technologies for enabling 5G'. The research collaboration opened[208] on September 24, 2014, and, as of November 2017, has more than 50 connected partners, including each of the major MNOs in Germany.

- On November 17, 2016, the '5G-Connected Mobility' project was initiated,[209] formed from a cross-industry consortium including each of the three MNOs, Ericsson, BMW Group, Deutsche Bahn, the TUD 5G Lab, the Federal Highway Research Institute (BASt) and BNetzA. The project researches vehicle-to-vehicle and vehicle-to-infrastructure 5G technology, and involves a 'dedicated test network' in the 700MHz band along the A9 motorway and the high-speed rail track between Nuremberg and Greding.

- The '5G Berlin' initiative was formed[210] in 2014 by Fraunhofer HHI and FOKUS. The initiative consists of a set of 'technology tool kits' and interconnected laboratories within Berlin, representing a testbed environment which allows partners (including Vodafone and DT) to develop 5G technology.

Other 5G development schemes based in Germany include Huawei's 5G Vertical Industry Accelerator (5G VIA), a large experimental system for 'testing promising 5G communication concepts'[211]. The 5G VIA testbed is based in Munich, where Huawei is partnering with the local government, Technische Universität München (TUM) and ISP M-Net.

205 See http://www.huawei.com/en/news/2016/12/world-first-5G-E2E-autonomous

206 See https://www.telekom.com/en/media/media-information/consumer-products/future-of-digital-5g-entertainment-unveiled-in-berlin-435936

207 See https://www.telekom.com/en/media/media-information/archive/deutsche-telekom-launches-innovation-laboratory-5g-haus-361962

208 See http://5glab.de/wp-content/uploads/Press_Release_TUD_Dresden5GLab_01_2014_opening.pdf

209 See https://eth.org.hu/5G-ConnectedMobility/en

210 See http://www.5g-berlin.org/

211 See https://www.huawei.eu/media-centre/press-releases/huawei-builds-large-scale-5g-testbed-real-life-environment-munich

The federal government outlines five action points as part of its '5G Strategy for Germany':

- step up network roll-out
- make available frequencies based on demand
- promote cooperation between telecommunications and user industries
- targeted and coordinated research
- initiate 5G for towns and cities.

Under the 'targeted and coordinated research' action point, the Federal government is funding research and development for 5G in its 'Industrial Communications of the Future' initiative. The focus is on three research priorities: 'reliable wireless communications in the industry', '5G: industrial internet' and '5G: tactile internet', for which up to EUR80 million will be made available.[212] Examples of projects funded include the A9 Digital Motorway Test Bed (see above), 'TACNET 4.0' and the 'PMSE-xG' initiative. The government support research activities with a focus on spectrum above 20GHz.

The 5G Strategy paper claims that 'almost all universities with IT faculties and numerous non-university research institutions are conducting research on issues with 5G relevance', and provides a map of selected 5G research centers in Germany.

Industry plans and government commitments

Figure B.15 outlines 5G commercial deployment plans announced by the major MNOs in Germany:

Figure B.15: Announcements of 5G deployment plans by MNOs in Germany [Source: company press releases]

MNO	Details of 5G activity
Telefónica	• No explicit 5G commercial deployment plans publicly announced
Vodafone	• No explicit 5G commercial deployment plans publicly announced
Deutsche Telekom (DT)	• In its October 2017 press release (see above), DT CTO stated that 'as soon as the [5G] standard is defined and is available, we will proceed in 2018 to lay the foundation for large-scale build-out' • A news report[213] in November 2017, citing DT's CTO, states that the MNO 'is aiming to have its 5G network go live post-2020'

Under the 'promote cooperation between telecommunications and user industries' action point of the 5G Strategy, the government describes the '5G Dialog Forum', which was set up in September 2016 to support 'the active exchange and networking between the telecommunications sector and vertical industries'. The first sector-specific dialogue forum on 5G prospects for the automotive industry was held in February 2017, followed by an exchange on health issues in March. Other

212 Moreover, the Federal government is funding 'further R&D activities within the framework of different programs with regard to applications where 5G is an important driver in the realization process'. For example, the combination of a driving simulator, test vehicles and the 'CERMcity' urban test field in Aldenhoven that has been developed by the RWTH Aachen; see '5G Strategy for Germany' (p.19).

213 See http://www.zdnet.com/article/deutsche-telekom-we-are-ready-for-5g/

events are planned for the areas of logistics, cultural and creative industries, Industry 4.0, energy and agriculture.

Regarding financial investment, on March 7, 2017, the Federal Minister of Transport and Digital Infrastructure and the members of the Network Alliance for a Digital Germany adopted[214] the 'Gigabit Germany Initiative for the Future'. The objective of the joint strategy is to invest EUR100 billion to create a high-performance broadband network in Germany by 2025. In a statement,[215] the Minister said that using the 'most sophisticated technologies available' such as 'fiber optics and […] 5G'. We are not aware of details regarding the specific amount to be allocated to 5G.

Most recently, BNetzA launched[216] an 'exchange platform' to 'support user companies and industries in their standardization activities for 5G'.

Outlook

Our 5G outlook/assessment for Germany is summarized in Figure B.16 below.

Figure B.16: 5G outlook for Germany [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	300MHz (3.4–3.7GHz) to be allocated in 2018 (for use from 2022) on national basis, 700MHz SDL to be considered at a later date, mm-wave bands (starting with 26GHz) as soon as possible: 26GHz (24.25–27.5GHz), 28GHz (27.5–29.5GHz) and 32GHz (31.8–33.4GHz)	2/4
5G spectrum roadmap published	'5G Strategy for Germany' paper published in September 2017. 3.4–3.8GHz to be allocated in 2018, and BNetzA has published a 'framework document' considering other bands (see below)	3/4
Government commitments and infrastructure policy	5G Strategy indicates EUR80 million for 'targeted and coordinated research'. Broader 'Gigabit Germany Initiative for the Future' (which encompasses 5G technology) aims to invest EUR100 billion by 2025	2/4
Industry trials	All operators have conducted trials. 5G R&D schemes include the TUD 5G Lab, the 5G-Connected Mobility project and the 5G Berlin project	3/4
Industry commitment and accelerated 5G launch	DT: Testing virtual reality and autonomous cars, Vodafone – 5G 'proof of concept' tests with Ericsson	1/4

214 See https://www.bmvi.de/SharedDocs/EN/PressRelease/2017/029-network-alliance.html

215 *Ibid*.

216 See https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2017/24102017_5G.html

B.5 Japan

The Ministry of Internal Affairs and Communications (MIC) regulates the Japanese telecom market. In 2016, the MIC published its 'Policy to realize 5G in 2020' (in time for the Tokyo 2020 Olympics). Policy includes promoting the work of the 5G Mobile Forum (5GMF), 5G R&D and standardization activities. The regulator has outlined plans to release/share spectrum in several bands (both below and above 6GHz), and aim to release spectrum in the 3.6–4.2GHz, 4.4–4.9GHz and 27.5–29.5GHz ranges by March 2019. Japan's MNOs have all conducted extensive 5G trials, and plan to launch commercial services in 2019/20.

Overview and current spectrum holdings

According[217] to the MIC, average monthly mobile data traffic in Japan increased by a factor of ~13 between March 2011 and March 2016, demonstrating the strong demand for mobile spectrum in the Japanese market.

The spectrum currently assigned for mobile use in Japan is shown in Figure B.17 below:

Figure B.17: Current spectrum holdings of MNOs in Japan, MHz [Source: MIC[218]]

MNO	700	800	900	1500	1800	2100	2600*	3500	Total
NTT DOCOMO	20	30	–	30	40***	40	–	40	**200**
KDDI	20	30	–	20	–	40	50	40	**200**
Softbank	20	–	30	20	30	71.2**	30	40	**241.2**
Total	**60**	**60**	**30**	**70**	**70**	**151.2**	**80**	**120**	**641.2**

* Excludes regional WiMAX (20MHz TDD)

** Includes 31.2MHz of PHS TDD spectrum

*** Some areas only

Historically, mobile licenses in Japan have been assigned via beauty contest rather than auctioned. However, an article published[219] by the Asia Nikkei review on November 28, 2017, stated that the MIC is planning to conduct a competitive auction process in an upcoming mobile spectrum award for spectrum in the 1.8GHz and 3.4GHz bands.

Main 5G spectrum proposals

The MIC published a 5G roadmap[220] on June 28, 2016, which outlines its aim 'to realize 5G in 2020' in time for the Tokyo Olympics. As part of its policy, the MIC has indicated that it expects to

217 See https://www.gsma.com/spectrum/wp-content/uploads/2016/08/MIC_Spectrum-for-5G-MIC-Kuniko-OGAWA.pdf

218 *Ibid*. See also http://www.tele.soumu.go.jp/e/adm/freq/search/myuse/0002/index.htm

219 See https://asia.nikkei.com/Politics-Economy/Policy-Politics/Japan-to-invite-new-faces-to-5G-party. See also https://www.mckinsey.com/industries/telecommunications/our-insights/japan-at-a-crossroads-the-4g-to-5g-revolution

220 See https://www.gsma.com/spectrum/wp-content/uploads/2016/08/MIC_Spectrum-for-5G-MIC-Kuniko-OGAWA.pdf. The MIC has since published a number of similar iterations of the presentation; see https://5g-ppp.eu/wp-content/uploads/2016/11/Opening-1_Yuji-Nakamura.pdf (November 9, 2016), https://5g-ppp.eu/wp-

promote use of spectrum sharing in a range of frequency bands. The roadmap states that frequency sharing with other services should ensure a total bandwidth of 2700MHz (including bandwidth for wireless LAN) below 6GHz by 2020. Above 6GHz, the MIC is targeting a total bandwidth[221] of around 23GHz 'looking ahead to the 2020s'.

A 5G consultation[222] was subsequently published by the MIC in July 2017, providing further details on the expected bands and timeline for assignments.

In order to address the current mobile spectrum shortage, the MIC will:

- 1.7GHz: promote frequency sharing/reallocation in the 1710–1750/1810–1850MHz range
- 2.3GHz: promote frequency sharing/reallocation in the 2300–2330/2370–2400MHz range
- 2.6GHz: consider frequency sharing with mobile satellite in the 2500–2545/2645–2690MHz range
- 3.4–3.48GHz:[223] consider early migration of existing users (incumbent licenses expire in November 2022), aiming to allocate to mobile by March 2018.

Another consultation[224] released by the MIC in December 2017 proposes draft rules for releasing both the 1.7GHz and 3.4–3.48GHz bands to mobile by March 2018.

In order to realize 5G launch in 2020, the MIC is proposing to authorize 5G use in several bands, as follows:[225]

- 3.6–4.2GHz and 4.4–4.9GHz: aim to allocate to mobile by March 2019, sharing with existing systems. Given sharing constraints, a maximum of 500MHz is expected to be allocated to mobile
- 27.5–29.5GHz: aim to allocate up to 2GHz to mobile by March 2019, sharing with existing systems, with a particular view to 'accordance with [the] US, Korea etc.'
- ITU mm-wave bands (24.25–86GHz):[226] conduct sharing studies in all 11 mm-wave ITU bands to be considered in the context of ITU-R WRC-19 (agenda item 1.13); particular focus on bands below 43.5GHz.

content/uploads/2016/11/04_9-Nov_Session-2_Yuji-Nakamura.pdf (November 9, 2016) and http://5gmf.jp/wp/wp-content/uploads/2017/06/02-Opening-Session-1_Isao-Sugino.pdf (May 24, 2017).

221 The MIC states that it is targeting the following frequency bands: 8.4/14/28/40/48/70/80GHz.

222 'Draft report from New generation mobile communication system committee', July 28, 2017 (in Japanese); see http://www.soumu.go.jp/main_content/000499652.pdf. See also section 9 of the 5GMF white paper version 1.1.

223 Note that 3.48–3.6GHz is already allocated to mobile.

224 See http://www.soumu.go.jp/main_content/000517622.pdf. The MIC will also allocate all of the 1765–1785/1860–1880MHz range (which is currently shared) to mobile on an exclusive basis.

225 The June 2016 roadmap indicated that the MIC also aimed to share the 5.15–5.35GHz band with 5G; however, this band is not mentioned in subsequent documentation.

226 The 5G Americas Whitepaper 'Spectrum landscape for mobile services', published in November 2017, states that the following mm-wave bands have priority for 5G in Japan: 24.25–29.5GHz, 37.0–40GHz and 40.5–43.5GHz, with 27.5–29.5GHz receiving 'priority attention'.

On September 29, 2017, the 5GMF (see below) published[227] a white paper which assesses a large range of bands (from 6–100GHz) for 5G, based on their suitability for sharing with incumbent users, and level of harmonization with other key markets.

Research, test beds and trials

Figure B.18 outlines 5G trials announced by the major MNOs in Japan:

Figure B.18: Announcements of 5G trials by major MNOs in Japan [Source: company press releases]

MNO	Details of 5G activity
NTT DOCOMO	DOCOMO has conducted a large number of 5G trials,[228] claiming to have been 'engaged in studies' on 5G since 2010. The company published[229] a 5G white paper and announced[230] plans to conduct 5G trials with six vendors in 2014. Below we highlight some of the most recent trial announcements: • On February 25, 2018, DOCOMO and Intel announced[231] plans to collaborate to provide 5G technologies at the Tokyo Olympics. DOCOMO also announced[232] 5G initiatives to accelerate its commercial launch plans with Fujitsu and NEC • On February 6, 2018, news reports emerged[233] stating DOCOMO had launched an 'open partner program' to enable local organizations to develop 5G use cases • On December 18, 2017, DOCOMO and Huawei announced[234] they had successfully completed a 5G trial in the 39GHz band in Yokohama • On December 7, 2017, DOCOMO and Huawei announced[235] a 'milestone' in their joint trials, by transmitting data a distance of 2km using the 28GHz band • On November 6, 2017, DOCOMO announced[236] the 'world's first' URLLC field trial using a macro base station on the 4.5GHz band with a new radio interface similar to the 3GPP 5G NR air interface • On November 2, 2017, DOCOMO announced[237] a joint trial conducted with MediaTek Inc. which had successfully developed a chipset to increase the spectral efficiency of mobile devices using NOMA and MUC technology

227 Version 1.1; see http://5gmf.jp/wp/wp-content/uploads/2017/10/5GMF-White-Paper-v1_1-All.pdf (section 9).

228 See https://www.nttdocomo.co.jp/english/corporate/technology/rd/tech/5g/5g_trial/. Previous trials have also included the 15GHz and 70GHz band, see for example: https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/rd/tech/5g/5g_MWC2016_docomo.pdf and https://www.nttdocomo.co.jp/english/info/media_center/pr/2015/1126_00.html

229 See https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/whitepaper_5g/DOCOMO_5G_White_Paper.pdf. See also 5G presentations delivered by DOCOMO at MWC (https://www.nttdocomo.co.jp/english/corporate/technology/rd/tech/5g/5g-exhibitions/)

230 See https://www.nttdocomo.co.jp/english/info/media_center/pr/2014/0508_00.html

231 See https://newsroom.intel.com/editorials/intel-5g-technology-olympic-games-tokyo-2020-play-role-transforming-everything-sports-transportation/

232 See http://www.fujitsu.com/global/about/resources/news/press-releases/2018/0226-01.html and http://www.nec.com/en/press/201802/global_20180223_03.html

233 See https://www.telecomasia.net/content/docomo-kicks-partner-program-5g-use-cases

234 See http://www.huawei.com/en/news/2017/12/NTT-DOCOMO-5G-mmWave-Trial

235 See http://www.huawei.com/en/news/2017/12/NTT-DOCOMO-5G-mmWave-Field-Trial-Tokyo

236 See http://www.huawei.com/en/news/2017/11/Huawei-DOCOMO-First-5G-URLLC-Field-Trial-C-Band

237 See https://www.nttdocomo.co.jp/english/info/media_center/pr/2017/1102_02.html

MNO	Details of 5G activity
	• On June 27, 2017, DOCOMO and Huawei announced[238] a successful demonstration of 39GHz mm-wave technology based on 3GPP 5G NR standards
KDDI	• On November 30, 2017, KDDI and Samsung announced[239] the completion of a 5G test on a high-speed train in Saitama (near Tokyo), achieving speeds of 1.7Gbps • On September 11, 2017, Ericsson and KDDI announced[240] they had signed a collaborative agreement for a 5G proof of concept test in several cities across Japan. The test will use the 4.5GHz and 28GHz bands, and be completed by 2018 • On May 16, 2017, NEC announced[241] that it will conduct a trial of remote construction technologies with KDDI and Obayashi, with the aim of achieving smart civil engineering using 5G • On May 12, 2017, KDDI and Nokia announced[242] a trial achieving speeds of more than 1Gbps over 5G with 'Nokia AirScale radio access on the 28GHz band'. The companies said this would be the first in a series of collaborations • On February 22, 2017, KDDI and Samsung announced[243] they had successfully completed a 5G handover trial using the 28GHz band on a City Highway in Tokyo
Softbank	• On September 29, 2017, Softbank and ZTE announced[244] the successful test of '24-stream space division multiplexing technology using pre-5G TDD Massive MIMO 2.0' in Nagasaki. The test achieved a peak data rate of 1Gbps using a 20MHz carrier. This follows an announcement[245] by the pair on June 13, 2017 of an agreement to conduct a 4.5GHz 5G trial across metropolitan areas in Tokyo. The companies first announced plans to conduct 5G trials in July 2015 • On September 8, 2017, Softbank and Huawei announced[246] they had jointly demonstrated a 5G transmission of over 800Mbps with a latency of less than 2ms • On August 31, 2017, Softbank and Ericsson announced[247] plans to run a pre-commercial end-to-end 5G trial including two 5G New Radios, virtual RAN, virtual EPC, beamforming and Massive MIMO in urban areas of Japan. Separately, on June 24, 2017, the pair announced[248] the next phase of their Tokyo trial, using Ericsson's 28GHz 5G test-bed which supports Massive MIMO, massive beamforming, distributed MIMO, multi-user MIMO and beam tracking. This follows the successful completion of Tokyo trials conducted by the two companies using the 4.5GHz and 15GHz, which began in August 2016 (initially announced in July 2015) • On May 10, 2017, Softbank Qualcomm and US MNO Sprint announced[249] they had jointly agreed to develop 5G NR technology in Band 41 (2.5GHz)

238 See http://www.huawei.com/en/news/2017/6/NTT-DOCOMO-5G-Live-Demo-39GHzmm-wave

239 See https://news.samsung.com/us/kddi-samsung-complete-5g-demonstration/

240 See https://www.ericsson.com/en/press-releases/2017/9/ericsson-and-kddi-to-test-5g-on-4.5ghz

241 See http://uk.nec.com/en_GB/press/201705/global_20170516_01.html

242 See https://www.nokia.com/en_int/news/releases/2017/05/12/nokia-and-kddi-trial-5g-with-airscale-radio-for-wireless-ultra-broadband-in-megacities

243 See http://www.samsung.com/global/business/networks/insights/news/kddi-and-samsung-successfully-demonstrate-5g-handover-using-28ghz-spectrum

244 See http://www.zte.com.cn/global/about/press-center/news/201709ma/0929ma1

245 See http://www.zte.com.cn/global/about/press-center/news/201706ma/0613ma1

246 See https://www.softbank.jp/en/corp/group/sbm/news/press/2017/20170908_02/

247 See https://www.ericsson.com/en/news/2017/8/ericsson-and-softbank-trial-5g-in-4.5ghz-band

248 See https://www.ericsson.com/en/press-releases/2017/3/softbank-and-ericsson-to-demonstrate-5g-28ghz

249 See https://www.softbank.jp/en/corp/group/sbm/news/press/2017/20170510_01/

In addition to the MNO activity outlined above, in May 2017 the MIC began[250] a 5G 'System Trial' in Tokyo and rural areas of Japan. The trial is being conducted in partnership with each of the country's MNOs as well as a number of equipment manufacturers (Panasonic, Sharp and Fujitsu), and is expected to continue until 2020. Extensive trialing is also being conducted by the 5GMF group (see below). A detailed white paper published[251] in September 2017 addresses the results of studies carried out by the 5GMF.

Most recently, on March 8, 2018, NTT DOCOMO, Huawei and Tobu Railway announced 5G testing in a dense urban area (Tokyo Skytree Town, the commercial center of the Sumida District of Tokyo) in the 28GHz band. The trial, which was part of the MIC's 5G System Trial, follows tests conducted in December 2017 (see above), and continues Japan's 5G development ahead of the Tokyo 2020 Olympics.

Industry plans and government commitments

Figure B.19 outlines 5G commercial deployment plans announced by the major MNOs in Japan:

Figure B.19: Announcements of 5G deployment plans MNOs in Japan [Source: company press releases]

MNO	Details of 5G activity
NTT DOCOMO	• DOCOMO has stated[252] that it aims to launch a commercial 5G service in 2020 in time for the Tokyo Olympics • On January 19, 2018, Nokia confirmed[253] that it had signed an agreement with DOCOMO to supply '5G baseband products for aiming to deploy in a 5G mobile network planned to be in commercial service by 2020' • A presentation[254] delivered by DOCOMO at the MWC in 2017 provided further details. Launch will take place in selected 'high performance' areas in 2020 (using the existing LTE EPC), before expanding nationwide by '202X' (eventually using separate 5G core equipment). DOCOMO has identified three bands for initial 5G launch: 3.4–3.8GHz, 4.4–5GHz and 27.5–29.5GHz
KDDI	• In the November 2017 press release (see above), KDDI's Senior Managing Executive Officer stated that the MNO's objective is to launch 5G by 2020
Softbank	• Softbank's September 2017 press release (see above) states that it is 'endeavoring to launch 5G commercial services around 2020'. Its May 2017 announcement (see above) said it was planning to 'provide commercial services and devices in late 2019'

In addition to the MNO activity outlined above, the MIC's policy paper (see above) commits to a package of a 'comprehensive promotion strategies for 5G' including:

250 See https://www.telecomstechnews.com/news/2017/may/31/japan-prepares-2020-olympic-games-5g-trial-system/

251 See http://5gmf.jp/wp/wp-content/uploads/2017/10/5GMF-White-Paper-v1_1-All.pdf

252 See https://www.nttdocomo.co.jp/english/corporate/technology/rd/tech/5g/

253 See https://www.nokia.com/en_int/news/releases/2018/01/19/nokia-to-supply-5g-equipment-to-ntt-docomo-in-support-of-launch-of-commercial-5g-service

254 See https://www.youtube.com/watch?v=yJdBYSWXmMs

- promoting three activities to support 5G realization for 2020 and beyond:
  - — activities of the 5G Mobile Forum (5GMF)
  - — 5G R&D through 'Industry-Academic-Government Cooperation'
  - — standardization activities at the ITU and 3GPP

- the 5G System Trial (see above).

The 5GMF[255] was founded on September 30, 2014 with the objective of developing 5G technology through conducting research and development relevant to global 5G standardization, liaising/coordinating with related organizations, and promoting 5G awareness. Membership includes a large number of industry players, institutions and universities. The 5GMF has published two significant white papers (referred to above).

Outlook

Our 5G outlook/assessment for Japan is summarized in the table below.

Figure B.20: 5G outlook for Japan [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	To address the current mobile spectrum shortage, the MIC will consider frequency sharing in the 1.7GHz, 2.3GHz and 2.6GHz bands, and aim to allocate 3.4–3.48GHz to mobile by March 2018. For 5G, the MIC will allocate up to 500MHz in the 3.6–4.2GHz and 4.4–4.9GHz bands, and up to 2GHz in the 27.5–29.5GHz band by March 2019	3/4
5G spectrum roadmap published	MIC launched its 'radio policy to realize 5G by 2020' in June 2016. The 5G implementation phase of its plan is scheduled for the 2020 Tokyo Olympics	2/4
Government commitments and infrastructure policy	The MIC's 5G roadmap commits to a package of 'comprehensive promotion strategies for 5G', including R&D and the 5GMF	3/4
Industry trials	NTT Docomo, KDDI and Softbank have all conducted trials	4/4
Industry commitment and accelerated 5G launch	NTT Docomo, KDDI and Softbank: 2020	3/4

255 See http://5gmf.jp/en for further details.
See also http://5gmf.jp/wp/wp-content/uploads/2015/11/CEATEC2015_5GWS_5GMF.pdf and the 5GMF White Papers. An overview of 5GMF and its IMT-2020 Evaluation Group published in October 2017 is available here: https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/S03–7_5GMF%20Japan.pdf

B.6 Russia

The Ministry of Communications (MinSvyaz) is the governmental agency of Russia responsible for telecommunications, mass media, IT and postal services. The State Commission for Radio Frequencies (SCRF) is the body, under MinSvyaz, with specific responsibility for radio spectrum management. The government's 5G roadmap aims for deployment to begin in 2020 and cover all large cities by 2024. A formal decision on spectrum award is scheduled for 2018, however the SCRF has released spectrum in the 3.4–3.8GHz and 25.25–29.5GHz bands (to certain players) for testing. The 2018 FIFA World Cup is a significant focus, with both MTS and MegaFon aiming to provide 5G services for the event.

Overview and current spectrum holdings

Current mobile spectrum allocations in Russia are shown in Figure B.21 below.

Figure B.21: Current spectrum holdings of MNOs in Russia, MHz [Source: www.spectrummonitoring.com[256]]

MNO	450	700	800	900*	1400	1800*	2100	2300	2600	3400	Total
MTS	–	15	15	50*	–	150*	30	–	45	–	**N/A**
MegaFon	–	15	15		–		30	–	105	–	**N/A**
Beeline	–	15	15		–		30	–	20	–	**N/A**
Tele2	9	15	15		–		30	–	20	–	**N/A**
Total	**9**	**60**	**60**	**50**	**–**	**150**	**120**	**–**	**190**	**–**	**639**

* 900MHz and 1800MHz bands were awarded on a regional basis.

An auction[257] of 450MHz spectrum in five Russian regions is scheduled to take place by Q2 2018.

Main 5G spectrum proposals

The government's 5G roadmap (see below) schedules a formal decision on 5G spectrum allocation[258] for 2018. As of February 2018, we understand that no decision has been announced.

However, on July 4, 2017, the SCRF announced[259] a decision to allocate 3.4–3.8GHz to MegaFon for 5G fixed network testing and 25.25–29.5GHz for the deployment of a 5G mobile network at the 2018 World Cup[260]. Fixed incumbent Rostelecom (3.4–3.8GHz) and the National Research Institute of Technology and Communications (25.25–27.5GHz, 31.8–33.4GHz, 40.5–42.5GHz and 66–

256 See also http://minsvyaz.ru/en/events/34050/ and http://rkn.gov.ru/news/rsoc/news35132.htm

257 See http://minsvyaz.ru/ru/events/37755/

258 Some sources claim that the Russian Digital Economy plan (see below) indicates 5G networks will be built in the 694–790MHz, 3.4–3.8GHz, 4.4–4.99GHz, 5.9GHz, 24.25–29, 5GHz, 30–55GHz, 66–76GHz and 81–86GHz bands. However, we are not aware of this explicitly stated in the public documentation; see http://www.tadviser.ru. An article published on TDaily.ru in March 2018 states that 5G spectrum will not be approved until 2019. See http://www.tdaily.ru/news/novosti-korotkoi-strokoi/44151

259 See http://minsvyaz.ru/ru/events/37119/

260 In March 2018 reports emerged that the Russian regulator had started issuing licenses for the 2018 FIFA World Cup. See https://www.telecompaper.com/news/russia-issues-spectrum-permits-for-world-cup--1235619

71GHz) have also received test licenses.[261] Beeline (3.4–3.8GHz, 25.25–29.5GHz) and MTS (27.5–28.35GHz) submitted requests for test spectrum to the SCRF, but these were declined on interference grounds.[262]

Research, test beds and trials

Figure B.22 outlines 5G trials announced by the major MNOs in Russia:

Figure B.22: Announcements of 5G trials by major MNOs in Russia [Source: company press releases]

MNO	Details of 5G activity
MTS	• On October 23, 2017, MTS and Ericsson announced[263] they had agreed a partnership to upgrade MTS's network in preparation for 5G, with 'software for Massive IoT solutions, including NB-IoT and Cat-M1 technologies'. The companies state that they will roll out '5G demo zones' during FIFA 2018 World Cup in Russia. This follows an announcement[264] from the pair on April 26, 2017, stating that they had built a prototype 5G network in Moscow and successfully completed a trial achieving peak data rates of 25Gbps achieved using massive and multi-user MIMO, beam tracking and dynamic TDD. On June 16, 2016, the companies announced[265] successfully testing 5G using CA across the 1800MHz and 5GHz (unlicensed) bands. The pair first announced[266] an MoU to develop 5G on December 21, 2015 • On February 8, 2017, MTS and its fixed network division MGTS announced[267] a joint strategy for development of fixed and mobile internet access in the Moscow region from 2017–2020. MTS plans to increase the number of base stations connected to GPON from 25% to 40–45%, while MGTS intends to launch mass adoption of XG-PON (10GPON) in its network in 2017, enabling the network to become a platform for transition to 5G services • On September 26, 2016, MTS and Samsung announced[268] a MoU to jointly collaborate on next-generation technologies, including 5G • On September 15, 2016, MTS and Nokia announced[269] achieving speeds of 4.5Gbps in 5G tests using the 4.65–4.85GHz range. On July 14, 2016, the pair stated[270] the

261 See https://www.kommersant.ru/doc/3521675. The link includes a list of regions covered by the licenses.

262 Beeline's request was postponed until the SCRF's next meeting, while MTS's request was rejected. For further details, see https://www.telegeography.com/products/commsupdate/articles/2017/09/22/beeline-mts-make-5g-frequency-applications/ and https://www.telegeography.com/products/commsupdate/articles/2018/01/04/scrf-declines-to-issue-spectrum-for-russian-5g-testing/

263 See https://www.ericsson.com/en/press-releases/2017/10/mts-selects-ericsson-to-prepare-network-for-5g-and-iot

264 See https://www.ericsson.com/en/press-releases/2017/4/ericsson-and-mts-test-new-5g-features. The EU's 5G PPP claims that the test used the 14.5–15.3GHz range; see https://5g-ppp.eu/5g-trials-2/#1512731007968-7c9b98d6-90eb

265 See http://www.mtsgsm.com/blog/post/2016/06/16/MTS-AND-ERICSSON-EXTEND-PARTNERSHIP-IN-5G-AND-IOT.aspx

266 Se https://www.ericsson.com/en/press-releases/2015/12/mts-and-ericsson-bring-5g-to-russia

267 See http://www.mtsgsm.com/news/2017-02-08-105223/

268 See http://www.samsung.com/global/business/networks/insights/news/samsung-and-mobile-telesystems-sign-mou-to-collaborate-on-next-generation-technologies/

269 See http://www.mtsgsm.com/blog/post/2016/09/15/MTS-AND-NOKIA-REACH-RECORD-BREAKING-INTERNET-SPEEDS-IN-RUSSIA-USING-5G.aspx

270 See https://www.nokia.com/en_int/news/releases/2016/07/14/nokia-and-mts-boost-4g-speeds-and-coverage-with-commercial-deployment-of-fdd-tdd-carrier-aggregation-in-moscow

MNO	Details of 5G activity
	companies were continuing to test LTE-A, LTE-A Pro and 5G technologies, following their 5G collaboration first announced[271] on May 18, 2016
MegaFon	• On March 23, 2018, reports stated[272] that MegaFon and Qualcomm had conducted 5G tests in the 24.25-27.5GHz range • On January 31, 2018, new reports[273] stated that 5G mobile network trials would start in Tatarstan in March 2018, conducted by Rostelecom, Tattelecom and MegaFon • On November 28, 2017, MegaFon and integrated digital services provider Rostelecom announced[274] an agreement to jointly develop 5G services using the 3.4–3.6GHz and 26GHz bands • On June 1, 2017, MegaFon and Huawei demonstrated[275] 5G speeds of 35Gbps at the St. Petersburg International Economic Forum (SPIEF) using 2GHz of 70GHz (E-band) TDD spectrum • On July 28, 2016, MegaFon and Nokia signed[276] a memorandum on the joint development of 5G networks in Russia, aiming to test services at the 2018 World Cup • On November 19, 2017, Megafon and Huawei announced a 5G MoU, aiming to provide services for the 2018 World Cup
Beeline	• On January 25, 2017, Beeline and Huawei announced[277] they had signed an agreement on research and testing of 5G technologies
Tele2	• In July 2017, Tele2 and Nokia announced[278] 5G mobile testing, including driverless cars and 'video-analytics'. The tests were based on Nokia AirFrame (Mobile Edge Computing solution) and AirScale hardware operating at 4.5GHz, using 8×8 MIMO. The test was part of the companies' 5G development framework signed on[279] September 5, 2016

Other key industry players are also testing 5G solutions in Russia. For example, fixed incumbent Rostelecom signed[280] an agreement with Skolkovo[281] and Nokia on October 17, 2017, to set up a 5G pilot zone in the territory of the Skolkovo innovations center. Rostelecom also signed an agreement with Tattelecom and Huawei in November 2017, according to which the companies will build a 5G testing zone in Innopolis.

271 See https://www.nokia.com/fi_fi/node/41

272 See http://www.tdaily.ru/news/top-novosti/44361

273 See http://www.tdaily.ru/news/novosti-korotkoi-strokoi/43565

274 See https://corp.megafon.com/investors/news/capital_market_releases/20171128-1330.html

275 See https://corp.megafon.ru/press/news/tags/20170601-1251.html

276 See https://corp.megafon.ru/press/news/tags/20160728-1620.html

277 See https://www.telecompaper.com/news/beeline-huawei-sign-agreement-on-5g--1180766

278 See https://www.telecompaper.com/news/tele2-russia-nokia-demonstrate-5g-capabilities--1203060

279 See https://www.nokia.com/en_int/news/releases/2016/09/05/nokia-and-tele2-russia-collaborate-on-developing-5g-technologies

280 See https://www.rostelecom.ru/en/ir/news/d441808/. Reports indicate that this launched in March 2018, see: https://www.telegeography.com/products/commsupdate/articles/2018/03/23/rostelecom-launches-5g-open-pilot-zone

281 The Skolkovo Foundation is a non-commercial organization set up in September 2010 to 'mobilize Russia's resources for advanced applied research by establishing a favorable environment for R&D in five top priority technological areas'.

Industry plans and government commitments

Figure B.23 outlines 5G commercial deployment plans announced by the major MNOs in Russia:

Figure B.23: Announcements of 5G deployment plans MNOs in Russia [Source: company press releases]

MNO	Details of 5G activity
MTS	• Ericsson and MTS's October announcement (see above) states that the MNO will 'deploy first solutions based on 5G technologies starting 2020'.
MegaFon	• We are not aware of any explicit 5G commercial deployment plans publicly announced by MegaFon. However, the operator is aiming to provide 5G services for the Russian FIFA World Cup in 2018 (see above)
Beeline	• No explicit 5G commercial deployment plans publicly announced
Tele2	• No explicit 5G commercial deployment plans publicly announced

News reports[282] have indicated that the Russian government is discussing ways to encourage MNOs to work together to develop 5G, with authorities ready to 'ease administrative barriers' for the technology's deployment. However, we are not aware of any specific government-level initiatives in Russia to support the industry with 5G trials or commercial launch.

On July 11, 2017, Russia's Ministry of Communications indicated[283] that it expected the first 'major segments' of 5G networks to appear in Russia in 2019–2020. On July 28, 2017, the Russian government published[284] its 'Digital economy of the Russian Federation' plan, which includes a 5G roadmap. The plan states the aim to provide 'stable' 5G coverage in all large cities (>1 million people[285]) by 2024. The roll-out plan to large cities is as follows: 2018: 0, 2019: 0, 2020: 1, 2021: 2, 2022: 5, 2023: 10 and 2024: 15 (see pages 17, 63).

Outlook

Our 5G outlook/assessment for Russia is summarized in Figure B.24 below.

Figure B.24: 5G outlook for Russia [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	Spectrum decision scheduled for 2018, but 3.4–3.8GHz and 25.25–29.5GHz has been released for trials	1/4
5G spectrum roadmap published	'Digital economy' plan aims for first commercial networks in 2020, with coverage of all large cities (>1mn pop.) by 2024	0/4
Government commitments and infrastructure policy	Limited data, though some indication that government aims to 'ease administrative barriers' for 5G deployment	1/4
Industry trials	All operators have conducted trials. MTS/Ericsson and MegaFon/Huawei have been conducting tests in preparation for	3/4

282 See https://www.kommersant.ru/doc/3263421

283 See http://minsvyaz.ru/ru/events/37147/

284 See http://static.government.ru/media/files/9gFM4FHj4PsB79I5v7yLVuPgu4bvR7M0.pdf

285 Other sources indicate the aim for 5G in all cities with pop. >300 000 by 2024; see http://minsvyaz.ru/ru/events/37119/

Metric	Description	Score
	showcasing 5G services at the 2018 World Cup. Beeline/Huawei and Tele2/Nokia have also announced testing	
Industry commitment and accelerated 5G launch	MTS: 2018 World Cup, with first commercial deployments in 2020, MegaFon: 2018 World Cup, Beeline/Tele2: N/d	1/4

B.7 Singapore

The Infocomm Media Development Authority (IMDA) is a statutory board in the Singapore government which regulates the telecommunication and media sectors and has responsibility for spectrum management. The IMDA released a consultation in May 2017, which considers assigning mobile spectrum in the L-band, the 3.4–3.8GHz band, 28GHz band, and a number other mm-wave bands for 5G. Although no formal 5G roadmap has been released, the regulator appears to anticipate the launch of commercial 5G in 2022, with total mobile spectrum demand ~3.4GHz at that date. We are not aware of confirmed commercial launch dates from the Singaporean MNOs, though a number of 5G trials and demonstrations have been announced.

Overview and current spectrum holdings

Current mobile spectrum assignments in Singapore (including all the spectrum assigned in the 2016/2017 4G auctions) are shown in Figure B.25 below.

Figure B.25: Current spectrum holdings of MNOs in Singapore, MHz [Source: IMDA[286]]

MNO	700*	800	900	1400	1800	2100	2300	2600	3400	Total
Singtel	40	–	20	–	60	45	–	55	–	**220**
StarHub	30	–	10	–	50	45	–	60	–	**195**
M1	20	–	10	–	40	45	–	40	–	**155**
TPG	-	–	20	–	–	–	40	10	–	**70**
Total	**90**	**–**	**60**	**–**	**150**	**135**	**40**	**165**	**–**	**640**

* As of July 2017, the 700MHz was 'pending assignment' (see IMDA Spectrum Management Handbook).

Upcoming allocation plans in existing and new bands are discussed below.

Main 5G spectrum proposals

The IMDA ran a public consultation[287] '5G mobile services and networks' from May to July 2017 seeking comments on 'various aspects of 5G technology development and spectrum requirements'. The document considers potential spectrum for 5G in three categories:

286 See IMDA's Spectrum Management Handbook, Issue 1 Rev 2.9 – July 2017, pages 8 and 9, and auction results

287 See https://www.imda.gov.sg/regulations-licensing-and-consultations/consultations/consultation-papers/2017/public-consultation-on-5g-mobile-services-and-networks

- Sub-1GHz spectrum. The IMDA notes that a portion[288] of the 800MHz band is scheduled to be released for mobile telecom around 2021. It seeks comment on whether further sub-1GHz spectrum for mobile usage is needed in future.

- 1–6GHz spectrum. The IMDA is 'exploring the possibility' of allocating the 1427–1518MHz (L-band) and 3.4–3.6GHz (extended C-band) ranges for IMT services.

- >6GHz spectrum. The IMDA asks for general responses on the role of mm-wave bands, but focuses on the 28GHz band: 'considering that there are 11 candidate bands under consideration at WRC-19, how would making available the 28GHz band help in the deployment of 5G services in Singapore?'.[289]

The IMDA has modelled spectrum supply/demand from 2017 to 2025. The consultation states that 'spectrum demand is projected to increase to at least 3360MHz by 2022 [from 860MHz in 2017] once there is commercial deployment of 5G services and applications'. The increase in demand is expected be met by the release of spectrum in the identified 1–6GHz and mm-wave bands 'if harmonization is achieved globally and/or for the Asia Pacific region at WRC-19', bringing the projected spectrum supply to 3831MHz. This is composed of 640MHz of currently assigned spectrum, the L-band (91MHz), the extended C-band (200MHz), the 28GHz band (2000MHz) and 900MHz of other mm-wave spectrum.[290] The consultation seeks views on whether their demand forecasts are realistic, and whether mm-wave spectrum should be provided earlier than 2022 to enable commercial network deployment.

Research, test beds and trials

Figure B.26 outlines 5G trials announced by the major MNOs in Singapore:

Figure B.26: Announcements of 5G trials by major MNOs in Singapore [Source: company press releases]

MNO	Details of 5G activity
Singtel	• On October 11, 2017, Singtel and Ericsson announced[291] they would establish a 'Centre of Excellence' to facilitate 5G development and deployment in Singapore, co-fund the venture with an initial investment of SGD2m over the next three years. The pair said they would deploy a mobile 5G test bed in 2018, to carry out live 5G field trials with key enterprise customers • On February 23, 2017, Singtel and Ericsson announced[292] they were working together to pilot Massive MIMO and Cloud RAN on Singtel's 4G LTE network. The

288 The proposed band plan in the most recent consultation proposes an allocation of 2×10MHz (824–834/869–879MHz) to mobile; see https://www.imda.gov.sg/-/media/imda/files/inner/pcdg/consultations/20150707_secondpublicconsultation/consultation.pdf?la=en

289 Figure 4 of the consultation indicates that 24.25–24.45GHz, 25.05–25.25GHz and 42–42.5GHz are 'potential bands for harmonization' in Singapore.

290 That is, 24.25–24.45GHz, 25.05–25.25GHz, 42–42.5GHz, which the IMDA says are the most likely to be globally harmonized.

291 See https://www.singtel.com/about-Us/news-releases/singtel-and-ericson-to-launch-singapores-first-5g-centre-of-excelence

292 See https://www.singtel.com/about-Us/news-releases

MNO	Details of 5G activity
	pair first signed a 5G MOU in January 2015 and demonstrated downlink 5G speeds of 27.5Gbps in August 2016. On January 11, 2017, they announced achieving 1Gbps LTE downlink speeds using 256QAM, 4×4 MIMO and triple CA technologies • Singtel has also made a series of 'journey to 5G' press releases. On August 3, 2017 the MNO announced[293] it (with Ericsson/Huawei/ZTE) would combine recently acquired 2.5GHz spectrum with massive MIMO technology as a 'precursor to 5G' • On November 19, 2014, Singtel and Huawei announced[294] plans to launch a 5G 'Joint Innovation Program' at the 2014 Global Mobile Broadband Forum in Shanghai
StarHub	• On January 20, 2017, sources[295] indicate that StarHub and Huawei achieved speeds of 35Gbps during a 5G trial, using 2GHz of E-band spectrum (60–90GHz) with 64QAM • On November 2, 2016, StarHub and Nokia said[296] they had used Nokia's AirScale platform to demonstrate 5G speeds of 4.3Gbps using spectrum in the 3–30GHz range
M1	• On January 18, 2017, M1 and Huawei announced[297] a 5G trial achieving speeds of 35Gbps using E-band spectrum (73GHz) in Jurong. This follows a trial conducted in January 2016 by the pair which achieved a combined DL/UL speeds of >1Gbps using 3 component CA, 4×4 MIMO and 256QAM on existing commercial hardware
TPG	None[298]

In May 2017, the IMDA announced that it would waive the frequency fees associated with 5G trials until December 2019, intending to encourage 5G R&D within the industry. The IMDA's 5G consultation (see above) states that there are currently no incumbent users in any of the frequency bands identified for 5G studies at the WRC-19, 'so these bands could be made available for 5G trials and IMT at any time'. Separately, the consultation notes that the IMDA 'has also received industry interest in the use of the E-band, 71–76GHz paired with 81–86GHz, for commercial applications in Singapore which include fixed-wireless backhaul, inter-building fixed-wireless network and mobile fronthaul/backhaul.'

Industry plans and government commitments

Figure B.27 outlines 5G commercial deployment plans announced by the major MNOs in Singapore:

293 *Ibid*.

294 See http://pr.huawei.com/en/news/hw-397408-5g.htm#.Wifdskpl99M

295 See http://www.zdnet.com/article/starhub-clocks-35gbps-speeds-in-5g-trial-with-huawei/

296 See http://www.starhub.com/about-us/newsroom/2016/november/nokia-and-starhub-achieve-4-3gbps-speeds-in-5g-showcase-in-singa.html

297 See https://www.m1.com.sg/AboutM1/NewsReleases/2017/M1%20and%20Huawei%20achieves%2035Gbps%20in%205G%20trial.aspx

298 TPG became Singapore's fourth MNO in 2016, after winning 2×10MHz of 900MHz and 40MHz of 2.3GHz TDD at the new-entrant spectrum auction (NESA). It went on to win an additional 10MHz of 2.6GHz TDD spectrum in the general spectrum auction. Sources indicate that its outdoor network is set to be complete by YE 2018; see http://www.zdnet.com/article/tpg-to-complete-singapore-outdoor-mobile-network-by-end-of-2018/

Figure B.27: Announcements of 5G deployment plans MNOs in Russia [Source: company press releases]

MNO	Details of 5G activity
Singtel	• In February 2015, Singtel said[299] that the MNO is 'working towards being one of the first in the world to roll out 5G in the year 2020'. We are not aware of more recent announcements regarding commercial deployment timelines
StarHub	• No explicit 5G commercial deployment plans publicly announced
M1	• No explicit 5G commercial deployment plans publicly announced
TPG	• No explicit 5G commercial deployment plans publicly announced

We are not aware of any specific government investment directly designed to accelerate 5G development.

Outlook

Figure B.28: 5G outlook for Singapore [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	IMDA notes spectrum demand forecast for 2022 could be met by releasing the L-band (91MHz), the extended C-band (200MHz), the 28GHz band (2000MHz) and 900MHz of other mm-wave spectrum	1/4
5G spectrum roadmap published	Initial consultation completed in July 2017	1/4
Government commitments and infrastructure policy	N/d	0/4
Industry trials	Singtel, StarHub and M1 have conducted trials. IMDA is waiving 5G frequency fees for trials until YE 2019	2/4
Industry commitment and accelerated 5G launch	Singtel: 2020, StarHub, M1, TPG: N/d	1/4

299 See https://www.enterpriseinnovation.net/article/singtel-pushes-5g-eyes-2020-rollout-1161669997

B.8 South Korea

The Ministry of Science and ICT (MSIT, formerly MSIP), is the government ministry of South Korea with responsibility for radio policy and spectrum allocation. South Korea used the 2018 Winter Olympics (held in PyeongChang in February 2018) as an opportunity to showcase 5G technologies, and the government is supporting the necessary research and trials, as well as making a commitment to invest USD1.5 billion in 5G by 2020. The MSIT's 'K-ICT' plan commits 1300MHz to 5G by 2018 across the 3.5GHz and 28GHz bands, with a potential further 2GHz to be released in the 28GHz band. South Korea's MNOs have all announced extensive 5G testing, and aim to be among the first operators in the world to commercialize 5G, with SKT and KT Corporation planning to launch services in 2019.

Overview and current spectrum holdings

Current mobile spectrum allocations in South Korea are shown in Figure B.29 below.

Figure B.29: Current spectrum holdings of MNOs in South Korea, MHz [Source: APT[300]]

MNO	700	850	900	1400	1800	2100	2300	2600	3400	Total
SKT	–	20	–	–	35	40	30	60	–	**185**
KT Corp	–	10	20	–	55	40	30	–	–	**155**
LG Uplus	–	20	–	–	20	40	–	40	–	**120**
Total	**–**	**50**	**20**	**–**	**110**	**120**	**60**	**100**	**–**	**460**

We are not aware of upcoming allocation plans beyond the 5G spectrum discussions outlined below. However, in South Korea's most recent auction (May 2016), spectrum in the 700MHz band (2×20MHz) remained unsold; MSIT may choose to re-auction this block in the future. Furthermore, the majority of existing licenses expire in 2021, indicating an auction/renewal process may be expected within the next few years (following previous auctions in 2011, 2013 and 2016).

Main 5G spectrum proposals

Specific details regarding 5G spectrum allocation in South Korea have been limited. In early 2017, MSIT released[301,302] a national broadband/spectrum plan ('K-ICT'), indicating that it planned to allocate a minimum of 1300MHz for 5G by 2018, consisting of 300MHz in the 3.5GHz band (3.4–3.7GHz[303]) and 1GHz in the 28GHz band (27.5–28.5GHz, with a possible 2GHz extension).[304] On

300 Data from APT report APT/AWG/REP-15(Rev.4) and 2016 auction results; see http://www.apt.int/AWG-RECS-REPS

301 See https://blog.naver.com/with_msip/220917986508. The plan aims to release a total of 40GHz of additional spectrum by 2026 across four service categories: IoT, public sector, private sector and broadcast/satellite.

302 See also a notice released by MSIT in July 2017 indicating that the government may be reserving 76–81GHz and 3.1–3.735GHz for 5G; see http://www.msit.go.kr/web/msipContents/contentsView.do?cateId=mssw352&artId=1364893

303 See https://www.ituaj.jp/wp-content/uploads/2017/05/nb29-2_web.pdf

304 That is, 26.5–29.5GHz; see http://5gmf.jp/wp/wp-content/uploads/2017/10/5GMF-White-Paper-v1_1-All.pdf (p.92–93). See also IMDA's 5G consultation (p.20), the MIC's July 28, 2017, Draft Report (p.22), and the 5G Americas Whitepaper 'Spectrum landscape for mobile services', November 2017 (p.31). Qualcomm's December 2017 report

November 29, 2017, the head of MSIT's information and communications policy department reportedly said[305] that frequency auctions would take place in March 2018. Statements issues by MSIT in January 2018 indicate that 5G commercialization is expected from March 2019.[306]

Research, test beds and trials

Figure B.30 outlines 5G trials announced by the major MNOs in South Korea:

Figure B.30: Announcements of 5G trials by major MNOs in South Korea [Source: company press releases]

MNO	Details of 5G activity
SK Telecom	SKT has announced[307] many 5G trials/plans, and has partnered with a number of large mobile vendors, including Nokia, Ericsson and Samsung. An announcement was made[308] to partner with Ericsson to develop 5G technology as early as July 2014. Below we outline some of the most recent announcements: • On December 28, 2017, SKT announced[309] that it had successfully deployed 5G infrastructure in K-City, the country's pilot city for self-driving vehicles • On December 1, 2017, SKT announced[310] it had developed 'new relay technologies' for 5G networks after a six-month-long collaboration with local partners • On November 21, 2017, SKT announced[311] that it had successfully deployed a 5G-PON for distribution networks that can deliver both LTE and 5G services. SKT said it would roll out the 5G-PON in 85 areas nationwide including Seoul, Busan, Daegu, Daejeon and Gwangju • On November 1, 2017, SKT announced[312] the successful demonstration of an in-building 5G relay repeater in its 5G trial network in Bundang, using both the 3.5GHz and 28GHz bands. SKT and Samsung also demonstrated a 360-degree VR 5G video call using a tablet-sized device
KT Corp	• On May 8, 2017, KT and Ericsson announced[313] steps to 'deploy and optimize a 5G trial network [in PyeongChang, host of the 2018 Winter Olympics] during 2017', which would use a 28GHz vRAN and virtualized 5G core. The companies also announced

'Spectrum for 4G and 5G' indicates that South Korea is adopting a three phase approach for spectrum allocation: 3.4–3.7GHz and 27.5–28.5GHz (Phase 1), 26.5–27.5GHz and 28.5–29.5GHz (Phase 2), a further 1GHz allocation (Phase 3).

305 See https://www.sktinsight.com/98809. See also page 27 of the GSMA/CAICT 2017 report referenced previously, and the June 2017 KISDI 5G report: http://www.msit.go.kr/web/msipContents/contentsView.do?cateId=mssw40b&artId=1348528.
Other sources have indicated that South Korea is working towards an auction by June or October 2018; see https://apps.fcc.gov/edocs_public/attachmatch/FCC-17-152A6.docx and http://www.srrc.org.cn/en/news3550.aspx https://www.koreatimes.co.kr/www/tech/2018/03/133_246024.html
On 25 March 2018, Yonhap News Agency reported that MSIT was 'in the process of setting details' of the upcoming 5G auction. See: http://english.yonhapnews.co.kr/news/2018/03/25/0200000000AEN20180325001500320.html

306 See http://www.msit.go.kr/web/msipContents/contentsView.do?cateId=mssw311&artId=1373121 and http://www.msit.go.kr/web/msipContents/contentsView.do?cateId=mssw311&artId=1372635

307 See https://www.sktinsight.com/category/tomorrow/5g-all and http://www.sktelecom.com/en/press/press.do

308 See http://www.sktelecom.com/en/press/press_detail.do?idx=1077

309 See http://www.sktelecom.com/en/press/press_detail.do?idx=1259

310 See http://www.sktelecom.com/en/press/press_detail.do?idx=1256

311 See http://www.sktelecom.com/en/press/press_detail.do?idx=1255

312 See http://www.sktelecom.com/en/press/press_detail.do?idx=1246

313 See https://www.ericsson.com/en/news/2017/5/5g-collaboration-in-lead-up-to-2018-winter-games

MNO	Details of 5G activity
	conducting 5G tests along the Incheon Airport Railway. The pair first signed[314] an MoU to collaborate on 5G technologies in March 2015 • On April 7, 2016, KT and Japanese vendor NEC announced[315] the successful completion of a 5G wireless backhaul Proof of Concept (PoC) in PyeongChang using E-Band spectrum (70–80GHz). The pair first announced[316] their partnership in August 2015 • We understand that KT announced[317] its intention to provide the world's first large 5G trial service during the 2018 Winter Olympics in March 2015
LG Uplus	• On November 24, 2017, LG Uplus and Huawei announced[318] a 'large-scale' 5G network test in a pre-commercial environment in Gangnam District, Seoul. The trial used both 3.5GHz and 28GHz bands to achieve an average data rate of 5Gbps. This follows an announcement[319] by the pair on October 19, 2017, using the same 'Dual-Connectivity' technology in a field test in Seoul • On September 12, 2017, LG Uplus and Huawei announced they had completed the first phase of their 5G 'intensive urban field test' in the Sangam area of Seoul. The test an 'end-to-end' 5G network with 5G gNodeB, Ng Core and a 5G mobile bearer network. 28GHz spectrum was used • On November 30, 2016, LG Uplus and Huawei announced[320] the completion of a series of 5G tests, covering eMBB, uRLLC and mMTC. The pair first signed and MoU to partner on 5G R&D in July 2015, aiming to prepare pre-commercial 5G by 2018 • On September 21, 2015, LG Uplus and Ericsson signed[321] an MoU to collaborate on 5G and IoT technology

There was a strong focus for the South Korean industry on the Winter Olympics (held in PyeongChang in February 2018) as an opportunity to showcase 5G technologies, and the government also supported research and trials. The Olympics was used to demonstrate a variety of next-generation use cases, which the South Korean government/MSIT extensively marketed,[322] classified into five categories: 5G, IoT, VR, AI and UHD. KT[323] was an official partner of the Olympics and provided 5G services, but SKT and LG UPlus also conducted 5G demonstrations at the event (see below).

314 See https://www.ericsson.com/en/press-releases/2015/3/ericsson-embarks-on-joint-5g-research-with-kt

315 See http://www.nec.com/en/press/201604/global_20160407_01.html

316 See http://www.nec.com/en/press/201508/global_20150806_02.html

317 See http://koreatimes.co.kr/www/news/tech/2018/01/129_243388.html

318 See http://www.huawei.com/en/news/2017/11/Huawei-LGU-World-First-Commercial-5G

319 See http://www.huawei.com/en/news/2017/10/LG-U-5G-frequency3dot5GHz-28GHz-coupling-tec

320 See http://www.huawei.com/en/news/2016/11/Huawei-LG-U-5G-Full-Scenario-Test

321 See https://www.ericsson.com/en/press-releases/2015/9/ericsson-and-lg-uplus-to-partner-on-5g-and-iot

322 See https://blog.naver.com/with_msip/220979864407

323 See https://www.fiercewireless.com/5g/kt-s-millimeter-wave-5g-network-transmitted-3-800-tb-data-during-winter-olympics

Industry plans and government commitments

Figure B.31 outlines 5G commercial deployment plans announced by the major MNOs in South Korea:

Figure B.31: Announcements of 5G deployment plans MNOs in South Korea [Source: company press releases]

MNO	Details of 5G activity
SK Telecom	• A post by the MNO on October 10, 2017, states[324] that the company aims to commercialize 5G in H2 2019 • On January 21, 2018, the Korea Times reported that SKT had a 200-member taskforce aiming to launch 5G services 'as soon as possible' • We understand[325] that SKT is aiming to demonstrate trial 5G services at the 2018 Winter Olympics
KT Corp	• On January 31, 2018, news reports stated[326] that KT had announced it was ready to provide 5G trial services at the Winter Olympics in February 2018. KT, an official partner of the PyeongChang Olympics, unveiled a 5G exhibition hall in the Olympic Park • News reports[327] indicate the company is aiming to commercialize 5G services by March 2019, earlier than previously scheduled
LG Uplus	• In the November 2016 announcement (see above), LG Uplus stated that it hoped to provide 5G services by 2018; other comments in the announcement indicate these may be pre-commercial services. We are not aware of more recent plans • We understand[328] that LG Uplus is aiming to demonstrate trial 5G services at the 2018 Winter Olympics

In January 2014, MSIT announced[329] plans to invest KRW1.6 trillion (USD1.5 billion) by 2020 to enable local firms to build 5G networks. In January 2018, MSIT announced[330] R&D funding for a range science/ICT projects, covering: mobile communications and broadcasting (KRW70 billion), 'SW computing' (KRW146.6 billion), broadcasting (KRW65.7 billion), next-generation security (KRW61.8 billion) and 'devices' (KRW43.5 billion). Details regarding to what extent funding would be directly allocated to 5G related projects were not provided. We understand that MSIT has explicitly said[331] that it hopes to co-operate with the major telecom providers in order to build 5G infrastructure.

It is understood that some of the Korean research on 5G is being part financed in collaboration with the EU, through a collaboration between the Korean government and the EU on 5G technologies. The University of Oulu's research unit – The Centre for Wireless Communications – in Finland has

324 See https://www.sktinsight.com/97233

325 See https://spectrum.ieee.org/telecom/wireless/5gs-olympic-debut

326 See http://koreatimes.co.kr/www/news/tech/2018/01/129_243388.html

327 See https://www.telegeography.com/products/commsupdate/articles/2016/11/09/kt-aims-to-commercialise-5g-by-2019/ and https://www.koreatimes.co.kr/www/tech/2018/03/133_246024.html

328 See https://spectrum.ieee.org/telecom/wireless/5gs-olympic-debut

329 See http://english.yonhapnews.co.kr/business/2014/01/22/0504000000AEN20140122001200320.html

330 See http://www.msit.go.kr/web/msipContents/contentsView.do?cateId=mssw311&artId=1371962

331 See http://koreabizwire.com/5g-infrastructure-at-the-forefront-of-technology-investment-in-south-korea/106298

been tasked with developing the required 5G radio solutions and integrating them into a functioning mobile network, in time for the Winter Olympics. Other partners include operators, vendors and research institutes from Germany, France, Belgium and Korea.

Outlook

Our 5G outlook/assessment for South Korea is summarized in Figure B.32 below.

Figure B.32: 5G outlook for South Korea [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	1300MHz to be released for 5G by 2018 (300MHz in the 3.5GHz band and 1GHz in the 28GHz band), with a possible further 2GHz mm-wave extension. Spectrum awards expected to take place in March 2018	3/4
5G spectrum roadmap published	National broadband/spectrum plan ('K-ICT') published in early 2017	2/4
Government commitments and infrastructure policy	Government support for showcasing 5G technology at Winter Olympics in February 2018. MSIT has committed to investing USD1.5 billion in 5G by 2020	4/4
Industry trials	SK Telecom, KT Corp and LG Uplus have all completed trials.	4/4
Industry commitment and accelerated 5G launch	SKT and KT Corp: 2019 (and trial services at the 2018 Winter Olympics)	4/4

B.9 UK

The Department for Culture, Media and Sport (DCMS) is the government department responsible for telecom strategy and policy in the UK, and Ofcom is the communications regulator with responsibility for spectrum management. The UK government has stated that it is aiming for the UK market to be a global leader in 5G, and has committed to investing GBP740 million in full fiber and 5G technology by 2020–21. Ofcom has put in place specific plans to release each of the bands identified by the RSPG for 5G in Europe (700MHz, 3.4–3.8GHz and 24.25–27.5GHz), with the first auction scheduled to take place in 2018. Two major UK operators – BT/EE and Vodafone – have announced 5G trials, with BT/EE indicating that it aims to offer commercial services around 2020.

[Note: as a Member State of the EU,[332] 5G policy in the UK is influenced by the relevant EU frameworks and initiatives. See separate EU case study.]

Overview and current spectrum holdings

In March 2017, the UK government released a 5G strategy paper[333], setting out its ambition that 'the UK should be a global leader in 5G so that we can take early advantage of its potential and help to create a world-leading digital economy'.

Current mobile spectrum allocations in the UK are shown in Figure B.33 below. In early 2017, Three UK announced[334] that it had reached an agreement to acquire UK Broadband Limited, giving the operator 40MHz of spectrum in 3.4GHz band (as shown) as well as 168MHz in the 3.6–4.0GHz range.

Figure B.33: Current spectrum holdings of MNOs in the UK, MHz [Source: Ofcom[335]]

MNO	700	800	900	1400	1800	2100	2300	2600	3400	Total
O2	–	20	35	–	12	20	–	–	–	86
BT/EE	–	10	–	–	90	40	–	115	–	255
Vodafone	–	20	35	20	12	30	–	60	–	176
Three UK	–	10	–	20	30	30	–	–	40	130
Total	**–**	**60**	**70**	**40**	**143**	**119**	**–**	**175**	**40**	**647**

Upcoming allocation plans in existing and new bands are discussed below.

332 The future partnership between the UK and the EU is under debate at the time of producing this report.

333 See https://www.gov.uk/government/publications/next-generation-mobile-technologies-a-5g-strategy-for-the-uk

334 See http://www.threemediacentre.co.uk/news/2016/ukbroadband-news.aspx. UK Broadband has a UK-wide wireless broadband license to access 84MHz between 3605–3689MHz and 84MHz at 3925–4009MHz

335 See https://www.arcep.fr/uploads/tx_gspublication/consult-frequences-terr-entreprises-5G-innov_01.pdf

Main 5G spectrum proposals

Ofcom has plans to release spectrum in three further mobile band over the next few years:

- **2.3/3.4GHz**. On July 11, 2017, Ofcom announced[336] the final rules for the joint auction of spectrum in these bands. 190MHz of spectrum will be made available across two bands: 40MHz in the 2.3GHz TDD band and 150MHz in the 3.4GHz TDD band. The announcement anticipated an auction by the end of 2017, however judicial reviews filed[337] by Three UK and BT/EE in September 2017 (subsequently overturned[338] by expedited High Court of Justice rulings on December 20, 2017, and February 13, 2018[339]) delayed the expected timetable. With the final Court of Appeal ruling issued, Ofcom published[340] a list of qualified bidders at the end of February 2018 and began the auction on 20 March 2018[341].

- **700MHz**. In November 2014, Ofcom announced[342] plans to release the 700MHz FDD band (2×30MHz) for mobile. In December 2016, it was announced[343] that 1×20MHz of 700MHz SDL spectrum would also be allocated. Ofcom's proposed annual plan for 2018/19, published[344] in December 2017, stated that 'our current objective is to make the 700MHz band available for mobile services by Q2 2020', with the auction itself expected in 2018/19. Ofcom launched a consultation[345] in March 2018 on coverage requirements for the 700MHz spectrum.

In addition to the above, Ofcom is also consulting on a number of other 5G bands:

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336 See https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2017/ofcom-sets-rules-for-mobile-spectrum-auction ("Ofcom Media Release, 11/07/17") and links to accompanying Information Memorandum (IM). The auction will sell four 10MHz blocks in the 2350–2390MHz range, at a reserve price of GBP10million per 10MHz block and twenty 5MHz blocks in the 3410–3480MHz and 3500–3580MHz ranges, at a reserve price of GBP1 million per 5MHz block. The spectrum licenses are national (excluding the Isle of Man, Channel Isles and certain zones negotiated with the MOD), technology-neutral and come without coverage obligations; the auction will follow the SMRA format.

337 See https://www.ispreview.co.uk/index.php/2017/09/three-uk-formally-file-judicial-review-ofcoms-spectrum-auction.html. EE has also legally challenged Ofcom's proposed auction rules. The dispute regards the rules around spectrum caps. The spectrum was originally intended to be auctioned in 2015/16. The merger of BT and EE (approved by the CMA in January 2016), the failed merger of Three and O2 (blocked by the EC in May 2016), and significant lobbying from operators regarding spectrum caps (notably from Three), have all contributed to delays.

338 See https://www.judiciary.gov.uk/wp-content/uploads/2017/12/H3G-v-OFCOM-full-judgment.pdf

339 Three appealed the December 20, 2017, ruling, and the Court of Appeal expedited Three's (final) appeal, which was heard on February 13, 2018. The final appeal was also rejected, meaning that Ofcom may now proceed with the auction. On January 17, 2018 (between the two courts rulings), Ofcom published an updated timetable for the auction, indicating a number of steps it would take (publishing regulations, accepting auction applications) prior to Three's final appeal hearing. The timetable aimed to enable an auction to take place as soon as possible after Three's appeal hearing. See https://www.ispreview.co.uk/index.php/2018/02/5g-mobile-auction-proceed-appeal-three-uk-fails.html

340 See https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2018/qualified-companies-spectrum-auction

341 See https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2018/start-spectrum-auction

342 See https://www.ofcom.org.uk/consultations-and-statements/category-1/maximising-benefits-700mhz-clearance

343 See https://www.ofcom.org.uk/__data/assets/pdf_file/0031/92659/Maximising-the-benefits-of-700-MHz-clearance-Statement.pdf

344 See https://www.ofcom.org.uk/__data/assets/pdf_file/0018/108324/Proposed-Annual-Plan-2018.pdf. An announcement from Ofcom on January 30, 2018 confirmed that the clearance program is currently scheduled to finish in April 2020; see https://www.ofcom.org.uk/__data/assets/pdf_file/0019/110395/700-MHz-update.pdf

345 See https://www.ofcom.org.uk/consultations-and-statements/category-2/700-mhz-coverage-obligations?utm_source=updates&utm_medium=email&utm_campaign=mobile-coverage

- **3.6–3.8GHz**. Ofcom released[346] a consultation on October 6, 2016, to examine whether 3.6–3.8GHz spectrum could be allocated to future 5G eMBB services. On October 26, 2017, the NRA released[347] a statement confirming the release of this band and beginning the process of vacating existing users. Ofcom stated that it expects the spectrum to be 'be deployed in many areas from around 2020, and nationwide by 2022'. This timeline was confirmed in an announcement[348] made on February 2, 2018. Ofcom's proposed annual plan for 2018/19 (see above) states that a consultation for the band is due to be published in Q3 2018/19.

- **3.8-4.2GHz**. In 2016, Ofcom ran a 'Call for Input' on the 3.8–4.2GHz range as 'a candidate band for enhanced spectrum sharing', and for 'potential new innovative applications'[349]. Most recently, Ofcom's 'Enabling 5G in the UK' paper, published in March 2018, confirmed its intention to consider the band for the possibility of shared use. A consultation is expected to be released later in 2018[350].

- **mm-wave spectrum**. On September 22, 2017, Ofcom concluded[351] its 'Call for Inputs on the 26GHz spectrum band'. The document states that Ofcom is undertaking work to make the 26GHz band (24.25–27.5GHz) available for 5G, and also provides a 5G roadmap for further mm-wave bands. In particular, Ofcom believes that 'the bands with significant potential are 66–71GHz, and bands around 40GHz (37–43.5GHz)' [352]. Although the 32GHz band was initially considered to be 'a promising band for 5G in Europe', because of the potential for global equipment harmonization around 40GHz, Ofcom 'consider 40GHz is a higher priority'.

Ofcom has thereby put in place specific plans to release each of the bands identified[353] by the RSPG for 5G in Europe: 700MHz, 3.4–3.8GHz and 24.25–27.5GHz. On 9 March 2018, Ofcom published[354] a discussion document entitled 'Enabling 5G in the UK', confirming their 5G spectrum release plans. The UK government has also announced a number of plans to invest in 5G development and infrastructure (see below).

346 See https://www.ofcom.org.uk/consultations-and-statements/category-1/future-use-at-3.6-3.8-ghz

347 *Ibid*.

348 See https://www.ofcom.org.uk/__data/assets/pdf_file/0018/110718/3.6GHz-3.8GHz-update-timing-spectrum-availability.pdf

349 See https://www.ofcom.org.uk/__data/assets/pdf_file/0031/79564/3.8-GHz-to-4.2-GHz-band-Opportunities-for-Innovation.pdf.

350 Ofcom's 'Fixed Wireless Spectrum Strategy' and 'Review of the authorization regime for spectrum access' published on December 7, 2017, both stated that the regulator will publish a consultation on further sharing of the 3.8–4.2GHz band in 2018.

351 See https://www.ofcom.org.uk/__data/assets/pdf_file/0014/104702/5G-spectrum-access-at-26-GHz.pdf

352 We note that only the 26GHz and 66-71GHz bands are referenced in Ofcom's March 2018 'Enabling 5G in the UK' paper.

353 See http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf

354 See https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf

Research, test beds and trials

Figure B.34 outlines 5G trials announced by the major MNOs in the UK:

Figure B.34: Announcements of 5G trials by major MNOs in the UK [Source: company press releases]

MNO[355]	Details of 5G activity
Telefónica (O2)	• On February 22, 2018, O2 announced[356] plans to launch a 5G test bed at an arena in London in 2018. Network installation is scheduled for March, with visitors able to use the technology from H2 2018. • The MNO has commented[357] that it is investing over GBP600 million per year in 'innovations like massive MIMO and 5G'
BT/EE	• On February 28, 2018, at the MWC in Spain, BT/EE and Huawei signed[358] an agreement to extend their 5G development partnership • On January 29, 2018, Nokia announced[359] the launch of its 'ReefShark' chipset, which BT/EE said it would use in its 5G network • On November 28, 2017, BT, Nokia and the University of Bristol announced[360] a joint research program to test a 5G network in Bristol city center • On November 15, 2017, EE and Huawei announced[361] achieving a 2.8Gbps DL speed on an end-to-end 5G NR network in a UK test lab. The trial used a fully virtualized core network and 64×64 massive MIMO over 3.5GHz spectrum. • On May 23, 2017, BT and Huawei announced[362] new research into 5G network slicing. The pair first announced[363] a partnership to conduct 5G research at labs in Ipswich and other locations around the UK on December 8, 2016 • On August 18, 2016, BT and Nokia announced[364] they had signed a research collaboration agreement on 5G technologies
Vodafone	• On February 19, 2018, Vodafone and Huawei announced[365] that they had completed tests which confirmed the 'applicability of IP microwave backhaul for 5G' • On December 20, 2017, Vodafone and Ericsson (in partnership with King's College London) announced[366] the successful test of standalone pre-standard 5G in central London using 3.5GHz spectrum. It was claimed to be the first such test in the UK

355 See https://5g.co.uk/ for a summary of the 5G status of each of the UK's MNOs.

356 See https://news.o2.co.uk/press-release/o2-launch-5g-test-bed-o2/

357 See https://www.o2.co.uk/enterprise/services/connectivity/mobile-networks. See also https://5g.co.uk/o2/

358 See http://www.huawei.com/en/press-events/news/2018/2/Huawei-BT-Group-UK-5G-Leadership

359 See https://www.nokia.com/en_int/news/releases/2018/01/29/nokia-launches-reefshark-chipsets-that-deliver-massive-performance-gain-in-5g-networks

360 See http://www.bris.ac.uk/news/2017/november/5g-mobile-networks.html

361 See http://newsroom.ee.co.uk/ee-showcases-end-to-end-5g-network-architecture-with-28gbps-speeds/

362 See http://home.bt.com/tech-gadgets/future-tech/bt-and-huawei-research-5g-network-slicing-11364158147163

363 See http://home.bt.com/tech-gadgets/future-tech/bt-huawei-5g-mobile-technology-partnership-11364119667641

364 See http://home.bt.com/tech-gadgets/future-tech/bt-and-nokia-to-collaborate-on-development-of-5g-11364080303221

365 See http://www.vodafone.com/content/index/what/technology-blog/vodafone-and-huawei-test-applicability-of-ip-microwave-backhaul-for-5g.html

366 See https://www.ericsson.com/en/news/2017/12/first-live-uk-pre-standard-5g-test

MNO[355]	Details of 5G activity
	• On June 26, 2017, Vodafone announced[367] that it had selected Ericsson to provide massive MIMO and CA technology to help the MNO evolve its 4G network in the South of England, as well as to provide 5G NR technology to prepare for 'the introduction of 5G' in the region • On July 21, 2016, Vodafone and Huawei announced[368] they had completed an E-band 5G test in Newbury, using SU-MIMO with a strong reflection path to achieve peak speeds of 20Gbps, and MU-MIMO for long range UE to achieved peak speeds of 10Gbps. The pair signed a MoU on 5G in 2015 and a '5G acceleration MoU' in July 2016 • On February 17, 2016 Vodafone announced[369] that it was partnering with Huawei, Nokia, Ericsson, Intel and Qualcomm Technologies to develop 5G technologies. On February 27, 2017, Vodafone, Ericsson and Qualcomm Technologies further announced[370] that they were working on 5G interoperability testing and conducting an over-the-air 5G NR field trial in the UK, include various technologies (massive MIMO, beamforming, etc.)
Three UK	• We are not aware of any 5G trials announced by Three, though the MNO is planning[371] a 'multibillion pound overhaul of its network as […] it prepares for the introduction of 5G'

In addition to MNOs, a number of other players have conducted trials (see below). In July 2017, telecommunications infrastructure company Arqiva announced[372] that it had launched Europe's first 5G FWA trial in central London with vendor Samsung, using the 28GHz band.

Industry plans and government commitments

Figure B.35 outlines 5G commercial deployment plans announced by the major MNOs in the UK:

Figure B.35: Announcements of 5G deployment plans MNOs in the UK [Source: company press releases]

MNO	Details of 5G activity
Telefónica (O2)	• No explicit 5G commercial deployment plans publicly announced • A company post in July 2016 states[373] that 5G technology is 'about four years off'. Some sources[374] indicate the company could launch commercial services as early as 2019

367 See https://www.ericsson.com/en/press-releases/2017/6/vodafone-uk-selects-ericsson-technology-to-evolve-london-network

368 See http://www.huawei.com/en/news/2016/7/huawei-vodafone-5g-test

369 See http://www.vodafone.com/content/index/what/technology-blog/vodafone-group-partners-technology-companies.html

370 See https://www.ericsson.com/en/news/2017/2/ericsson-qualcomm-and-vodafone-trial-5g-new-radio-for-unified-5g

371 See http://www.telegraph.co.uk/business/2017/08/01/three-set-formultibillion-pound-network-overhaul-race-5g/#comments

372 See https://www.arqiva.com/news/press-releases/arqiva-and-samsung-kick-off-uks-first-5g-fixed-wireless-access-trial/. Plans for the trial were announced in February 2017: https://www.arqiva.com/news/press-releases/arqiva-and-samsung-to-undertake-first-5g-fixed-wireless-access-trial-in-the-uk/. In July 2017, Arqiva announced the acquisition of a 2×112MHz license in the 28GHz band for Central and Greater London.

373 See http://businessblog.o2.co.uk/5g-means-business/

374 See http://www.lightreading.com/mobile/5g/vodafone-uk-turns-mobile-network-guns-on-bt-ee/d/d-id/734095

MNO	Details of 5G activity
BT/EE	• News sources[375] quote BT/EE as saying that the company is aiming for a commercially available 5G service 'around 2020'. Other sources[376] indicate the company could launch as early as 2019
Vodafone	• No explicit 5G commercial deployment plans publicly announced • A company post in February 2016 (see above) states that Vodafone will 'prioritize the benefits of 5G that can be brought to market by 2020'
Three UK	• No explicit 5G commercial deployment plans publicly announced

Ofcom's 'Update on 5G' document published[377] in February 2017 states that 'the first wave of commercial [5G] products is expected to be available in 2020, but 'initial pre-commercial deployments are already expected to start from 2018'. However, it not clear if this is a generic statement or whether it reflects what Ofcom anticipates for the UK market.

In addition to the MNO activity outlined above, the UK government had made a number of commitments to invest in 5G technology:

- The 2016 Autumn Statement announced[378] that the government would invest over GBP1 billion by 2020–21 in digital communications, including GBP740 million through the NPIF (National Productivity Investment Fund) targeted at supporting the roll out full fiber and 5G.

- The 2017 Budget confirmed[379] plans to allocate funding to its '5G testbeds and trials' program:
  - On July 6, 2017, DCMS announced[380] GBP16 million for three UK universities (King's College London and the Universities of Surrey and Bristol) to develop a 5G test network
  - GBP25 million to be assigned through competitive tender in Phase 1 of funding (see below).

- The 2017 budget also announced a further[381] GBP160 million government seeded funding to invest in 5G infrastructure. Initial projects to benefit from the investment include:

  - GBP10 million to create facilities for 5G network security testing (announced in the budget)
  - GBP5 million for an initial trial, starting in 2018, to test 5G applications and deployment on roads, including testing benefits of self-driving cars (announced in the budget)
  - GBP35 million to enable trials to improve mobile communications for rail passengers.[382]

375 See https://5g.co.uk/ee/

376 See https://www.globaltelecomsbusiness.com/article/b13rpr1knjqrlg/exclusive-ee-eyes-2019-launch-uk-of-commercial-5g-services

377 See https://www.ofcom.org.uk/__data/assets/pdf_file/0021/97023/5G-update-08022017.pdf

378 See https://www.gov.uk/government/publications/autumn-statement-2016-documents/autumn-statement-2016

379 See https://www.gov.uk/government/publications/autumn-budget-2017-documents/autumn-budget-2017

380 See https://www.gov.uk/government/news/three-universities-to-develop-16m-5g-test-network

381 Despite the wording, it is not entirely clear that this is in addition to the GBP740 million previously pledged. The 2017 Budget also states that it 'commits GBP385 million to projects to develop next generation 5G mobile and full-fiber broadband networks, both funded from the NPIF'. See also the 'Industrial Strategy: building a Britain fit for the future' policy paper published on November 27, 2017.

382 Specifically, the funding will be used to: upgrade a portion of the Network Rail test track, install trackside infrastructure along a portion of the Trans-Pennine route, and support the roll-out of full-fiber and 5G networks.

- On March 8, 2017, DCMS published[383] a strategy paper for 5G in the UK. The strategy outlined a number of 'key themes that will determine our progress towards 5G'.[384]

- From October 23, 2017, to December 6, 2017, DCMS ran a competition[385] to allocate its first phase of funding (GBP25 million from the NPIF) to 'encourage technology and deployment, testbeds and trials to stimulate the development of 5G use cases and business models'. The grants are for initial projects across the UK that will run from April 1, 2018, until March 31, 2019. Recipients of the grants were announced[386] by the government in March 2018. Details of future funding for additional testbeds and trials will be available 'as the program progresses'.

- On November 28, 2017, DCMS launched[387] a review of the UK telecom markets, to investigate 'how it can support investment in the world-class connectivity of the future [full fiber and 5G]'.

Outlook

Our 5G outlook/assessment for the UK is summarized in Figure B.36 below.

Figure B.36: 5G outlook for the UK [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	190MHz in the 2.3/3.4GHz bands (2018), 2×30MHz and 1×20MHz of 700MHz (2018/19), 3.6–3.8GHz (2020–22) Work being undertaken to make spectrum from within the 26GHz band (parts of 24.25–27.5GHz) available. 66–71GHz and bands around 40GHz (37–43.5GHz) have also been identified by Ofcom as a priority for further study for 5G use	2/4
5G spectrum roadmap published	'Update on 5G spectrum in the UK' in February 2017 and a consultation/roadmap on mm-wave bands in July 2017. DCMS also published a 5G strategy paper in March 2017, and launched a 5G test beds and trials program in December 2017	3/4
Government commitments and infrastructure policy	GBP740 million committed to 5G and 'full fiber' in 2016 autumn statement, with 2017 budget adding GBP160 million for 5G infrastructure. DCMS published 5G strategy paper in March 2017 and 'Future Telecoms Infrastructure Review' in November 2017	3/4
Industry trials	BT/EE and Vodafone have announced trials. Three, O2: N/d	2/4

383 See https://www.gov.uk/government/publications/next-generation-mobile-technologies-a-5g-strategy-for-the-uk. This was informed by two major reports commissioned by the government: (1) in December 2016, the National Infrastructure Commission (NIC) set out its recommendations on steps that the UK should take to become a world leader in the deployment of 5G telecommunications networks. the Government (2) in January 2017, the Future Communications Challenge Group (FCCG), established by DCMS, provided advice on how the UK could become a world leader in the development of 5G telecommunication networks.

384 In particular, 'building the economic case', fit-for-purpose regulations, local areas – governance and capability, coverage and capacity – convergence and the road to 5G, ensuring a safe and secure deployment of 5G, spectrum and technology and standards.

385 See https://apply-for-innovation-funding.service.gov.uk/competition/46/overview

386 See https://www.gov.uk/government/news/25m-for-5g-projects-on-the-anniversary-of-the-uks-digital-strategy, and https://www.totaltele.com/499595/UK-government-awards-25m-in-funding-to-six-5G-projects

387 See https://www.gov.uk/government/news/government-launches-review-into-future-telecoms-infrastructure-investment

Metric	Description	Score
Industry commitment and accelerated 5G launch	BT/EE: 2019/2020 O2, Vodafone, Three UK: N/d	1/4

B.10 US

The Federal Communications Commission (FCC) regulates interstate and international communications in the US, and has responsibility for spectrum allocation and management. An independent US government agency overseen by Congress, the FCC is the federal agency responsible for implementing and enforcing America's communications law and regulations. In July 2016, the FCC adopted new rules that authorize around 11GHz of high-range spectrum for flexible, mobile and fixed use: 27.5–28.3, 37–38.6, 38.6–40GHz (licensed) and 64–71GHz (unlicensed). The FCC has since confirmed a further 1700MHz of high-band spectrum for 5G. The FCC recently awarded 600MHz spectrum for mobile, is in the process of releasing the CBRS band (3550–3700MHz) for shared wireless broadband use, and is exploring other mid-range bands. All the major MNOs have conducted 5G trials and announced ambitious commercial deployment plans, with services aiming to be phased in between 2018 and 2020.

Overview and current spectrum holdings

The FCC describes 5G as 'a virtual cornerstone for critical 21st century opportunities related to economic growth, education, employment, transportation, and more'. The regulator states that future 5G networks will rely on three key areas – spectrum, infrastructure and backhaul – and is taking steps in each area to establish global leadership in the deployment of next-generation wireless technologies.

The current mobile spectrum holdings of the major US operators (as well as DISH and US Cellular[388]) are shown in Figure B.37 below.

Figure B.37: Current mobile spectrum holdings[389] of the major US operators, MHz [Source: FCC's Twentieth Mobile Wireless Competition Report (Table II.E.3[390]), September 2017[391]]

MNO	600	700	Cell.	SMR	PCS	H-blk.	AWS1	AWS3	AWS4	WCS	BRS	EBS	Tot.
AT&T	2.6	29.2	23.6	-	38.1	-	14.6	20.3	-	20	-	-	**148**
Sprint	-	-	-	13.9	37.3	-	-	-	-	-	58.6	78.5	**188**
T-Mobile	30.8	9.9	-	-	28.7	-	36.9	3.4	-	-	-	-	**110**

388 DISH Network, a satellite broadcaster, own a significant amount of mobile spectrum, however they do not currently offer mobile services. US Cellular is the fifth largest MNO in the US market, currently operating in 23 states (see https://www.uscellular.com/uscellular/support/faq/faqDetails.jsp?topic=press-room.html)

389 Abbreviations for spectrum bands: Cell. (Cellular), SMR (Specialized Mobile Radio Service), PCS (Personal Communications Service), AWS (Advanced Wireless Service) WCS (Wireless Communications Service), BRS (Broadband Radio Service), and EBS (Educational Broadband Service)

390 Values shown are from Table II.E.3 (i.e. include a full 112.5MHz in the EBS band, which the FCC Spectrum Screen discounts to 89MHz); individual operators' holdings are as reported from this table. Sums for EBS and Total columns indicate both discounted spectrum holdings per the FCC, and as nominally available.

391 The source has not been adjusted for recent spectrum transactions (e.g. https://www.fiercewireless.com/wireless/at-t-looks-to-sell-600-mhz-spectrum-to-lb-license-co-for-nearly-1b). Note: slight discrepancy with other sources, e.g. Macquarie Research report 'A Global View of Spectrum' (June 8, 2017) (see https://www.scribd.com/document/358684577/2017-Jun-Macquiare-Bank-Global-View-on-Spectrum), Sprint (see http://newsroom.sprint.com/in-land-wireless-spectrum-is-king.htm), and Allnet Insights & Analytics (see https://www.fiercewireless.com/wireless/2017-how-much-low-mid-and-high-band-spectrum-do-verizon-at-t-t-mobile-sprint-and-dish-own).

MNO	600	700	Cell.	SMR	PCS	H-blk.	AWS1	AWS3	AWS4	WCS	BRS	EBS	Tot.
Verizon	-	21.7	25.2	-	21.4	-	35.2	11.4	-	-	-	-	**115**
US Cell.	1.8	2.5	2.1	-	1.5	-	0.7	1.6	-	-	-	-	**10**
DISH	17.8	4.6	-	-	-	10	-	21.1	40	-	-	-	**94**
Other[392]	14.9	2.1	2	0.5	3.4	-	2.6	2.6	-	-	8.9	34	**71**
Total	**70**	**70**	**50**	**14**	**130**	**10**	**90**	**65**	**40**	**20**	**67.5**	**89/ 112.5**	**715.5/ 739**

Note**:** spectrum is allocated in the US on a regional basis. Holdings shown are population weighted averages.

Upcoming allocation plans in new bands are discussed below.

Main 5G spectrum proposals

The FCC states[393] that it is 'focused on a strategy that will make more low, mid, and especially high-band spectrum available for 5G services'.

- **Regarding high-band spectrum**, the FCC has issued[394] an NOI (October 2014), NPRM (October 2015) and R&O/FNPRM (July 2016) under the title 'Use of Spectrum Bands Above 24GHz For Mobile Radio Services' (also referred to as the 'Spectrum Frontiers' initiative).

  The R&O adopts new rules that aims to authorize ~11GHz of high-frequency spectrum for flexible, mobile and fixed use, including 3.85GHz of licensed spectrum (27.5–28.35, 37–38.6, 38.6–40GHz) and 7GHz of unlicensed spectrum (64–71GHz).[395] The FNPRM (among other things) seeks comment on applying the flexible use service and technical rules adopted in the R&O to another 18GHz of spectrum encompassing eight additional high-frequency bands.[396]

  Most recently, on November 16, 2017, the FCC voted[397] through a second R&O and second FNPRM that (among other things) makes 1700MHz of additional high-frequency spectrum available for flexible terrestrial wireless use (700MHz in the 24GHz band and 1GHz in the

392 Smaller MNOs include C Spire Wireless, Shentel and others. Cable player Comcast and a number of other non-mobile players also own mobile spectrum.

393 See https://www.fcc.gov/5G. In 2010, the US launched a program to make 500MHz of federal and non-federal spectrum available for commercial wireless broadband by 2020. Over 300MHz has been released through the WCS/H-block/AWS-3/AWS-4/CBRS/600 ranges; see https://www.ntia.doc.gov/blog/2015/nearly-halfway-meeting-spectrum-target

394 All documentation is available at https://www.fcc.gov/5G. NOI = Notice of Inquiry, NPRM = Notice of proposed rulemaking, R&O = Report and order, FNPRM = Further NPRM (see https://www.fcc.gov/general/rulemaking-fcc for full explanation).

395 The unlicensed 64–71GHz band is adjacent to the 57–64GHz band, which is already unlicensed, resulting in a continuous unlicensed band of 14GHz.

396 Namely: 24.25–24.45GHz together with 24.75–25.25GHz (24GHz band), 31.8–33GHz (32GHz band), 42–42.5GHz (42GHz band), 47.2–50.2GHz (47GHz band), 50.4–52.6GHz (50GHz band), 71–76GHz band together with the 81–86GHz bands (70/80GHz bands), and bands above 95GHz. As described above, the 24GHz band and a 1GHz portion of the 47GHz band have been identified for mobile. On February 22, 2018, the FCC issued an NPRM on spectrum above 95GHz for new services and technologies. See https://www.fcc.gov/document/fcc-proposes-open-spectrum-horizons-new-services-technologies

397 See https://www.fcc.gov/document/fcc-takes-next-steps-facilitate-spectrum-frontiers

47GHz band).[398] The FCC's chairman has stated[399] that he would like to hold a high-band auction in November 2018, but proceedings are contingent on certain action from Congress. MNOs and other industry players have encouraged[400] the FCC to auction the spectrum as soon as possible.

The required action from Congress took place just before the publication of this report, and on March 29, 2018, the FCC published an agenda for its Open Meeting in April including an item which will discuss exact procedures for auctioning the 28GHz and 24GHz bands[401]. We understand that the proposed date for the 28GHz auction is November 14, 2018, and the 24GHz auction will commence immediately afterwards[402].

- **Regarding mid-band spectrum**, the FCC is in the process of releasing the citizens broadband radio service (CBRS) band (3550–3700MHz) for shared wireless broadband use.[403] The band is governed by a three-tier authorization framework that allows commercial users to share spectrum with existing federal and non-federal users:
  - Tier 1 consists of incumbent users[404] (primarily the US military), which have top priority.
  - Tier 2 organizations can be granted priority access licenses (PALs) for a fee. A maximum of seven PALs, each 10MHz in size, will be licensed in any given geographical area. Use of these bands can be pre-empted by Tier 1 users. The exact structure of the PALs (license duration, geographical extent, etc.) has been the subject of significant debate, which was

398 That is, the 24.25–24.45 and 24.75–25.25GHz bands (24GHz band) and the 47.2–48.2GHz band.

399 See http://transition.fcc.gov/Daily_Releases/Daily_Business/2017/db1122/FCC-17-152A2.pdf. The FCC chairman states: 'I want to move forward with a high-band spectrum auction in 2018. But […] we can't hold any large spectrum auction unless and until Congress fixes the upfront-payments problem'. This was confirmed at the MWC in February 2018, when the FCC chairman stated that he would like to hold a (28GHz) mm-wave auction in November 2018, but Congressional action is required by May 23, 2018. We understand that the FCC chairman would like to auction 24GHz spectrum immediately afterwards. See https://www.fiercewireless.com/5g/fcc-chief-wants-to-auction-28-ghz-spectrum-november.

400 See https://www.fiercewireless.com/wireless/verizon-charter-and-more-applaud-fcc-s-move-to-release-more-high-band-spectrum. The Statement of Commissioner Jessica Rosenworcel released after the FCC's November vote stated her desire to auction the 28GHz band prior to October 2018. See also AT&T's filing to the FCC on December 12, 2017, which makes proposals/suggestions for how to auction spectrum in the 39GHz band. The following article provides links to relevant filings from AT&T, Verizon, T-Mobile, US Cellular and CTIA - https://www.fiercewireless.com/wireless/t-mobile-presses-for-millimeter-wave-auction-2018-says-major-carriers-already-acquiring. See also https://www.fiercewireless.com/wireless/rosenworcel-u-s-needs-to-plan-next-spectrum-auction-now-or-risk-ceding-5g-leadership-to and https://www.fiercewireless.com/wireless/nokia-urges-u-s-to-hurry-up-and-set-spectrum-auction-calendar-for-5g

401 See https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0327/DOC-349936A1.pdf

402 See https://www.fiercewireless.com/wireless/fcc-sets-nov-14-as-start-28-ghz-auction. We the 28GHz licences will be offered in two 425MHz blocks (by county) and the 24GHz licences will be offered in seven 100MHz blocks by Partial Economic Area (PEA)

403 See https://www.fcc.gov/rulemaking/12-354#block-menu-block-4 for an index of FCC CBRS documentation.

404 Tier 1 incumbent users mainly use these bands for naval radar applications in coastal areas, so this capacity remains largely unused in inland areas.

ongoing at the time of producing this report.[405] PALs are expected[406] to be auctioned in late 2018 or 2019.

– Tier 3 users have general authorized access (GAA) – opportunistic use of any available block of the 3550–3700MHz band without a defined license term. These users must accept interference from Tier 1 and 2 users. We understand that use of GAA spectrum can begin as soon as the necessary equipment has been certified,[407] which is expected in H2-2018.[408]

Furthermore, on August 3, 2017, the FCC issued[409] an NOI entitled '*Exploring Flexible Use in Mid-Band Spectrum Between 3.7 GHz and 24 GHz*'. The NOI consults on three specific mid-range bands (3.7–4.2GHz,[410] 5.925–6.425GHz and 6.425–7.125GHz) for 'expanded flexible use', and seeks comment on further bands between 3.7GHz and 24GHz which might also be suitable[411]. At the MWC in February 2018, the FCC's Chairman stated[412] that '[in the coming months], I intend to propose the next steps needed to make 3.7 to 4.2GHz spectrum available for commercial terrestrial use'.

Most recently, on February 26, 2018, the National Telecommunications and Information Administration (NTIA), in coordination with the Department of Defense (DOD) and other federal agencies, announced[413] that it had identified 100MHz (3450–3550MHz) for 'potential

405 See, for example, http://www.wispa.org/Wispa-News/ArtMID/13028/ArticleID/199/CategoryID/55/CategoryName/Top-Story/FCC-VOTE-IS-A-STEP-BACKWARD-FOR-RURAL-BROADBAND-WISPA-SAYS. For a more recent example, see https://www.fiercewireless.com/wireless/t-mobile-smaller-license-areas-cbrs-would-result-inefficient-use-spectrum

406 See, for example, https://www.cablelabs.com/meet-cablelabs-tech-policy-whisperer-rob-alderfer

407 Cloud-based Spectrum Access Systems (SASs) will actively manage users of the three CBRS tiers. The SAS will tell the CBRS base stations (called CBRS Devices, CBRDs) which channels to use in order to avoid interference with other users in a given geographical area. The main instance of incumbent use will come from US military shipborne radar. A radar detection network known as an ESC (Environmental Sensing Capacity) will detect the arrival of these ships on either the east or west coasts of the US. SAS and ESCs must be certified before the GAA tier of the CBRS can be used.

408 See, for example, Federated Wireless' response to the NPRM: https://ecfsapi.fcc.gov/file/122836319522/Federated%20Wireless%20Comments%20on%202017%20CBRS%20NPRM%20-%20FINAL%2012.28.17.pdf

409 See http://transition.fcc.gov/Daily_Releases/Daily_Business/2017/db0713/DOC-345789A1.pdf and https://commlawmonitor2.lexblogplatformthree.com/wp-content/uploads/sites/512/2017/08/Mid-Band-Spectum-NOI.pdf

410 A number of industry players have called for the FCC to open up the 3.7–4.2GHz band for terrestrial wireless applications; see https://www.fiercewireless.com/tech/google-fiber-nokia-throw-support-behind-3-7-4-2-ghz-efforts-for-fixed-wireless

411 Intelsat and Intel submitted a response to the NOI on October 2, 2017, urging the FCC to 'allow co-primary terrestrial mobile operations in the 3.7-4.2GHz band through commercial agreements between terrestrial mobile interests and primarily affected FSS satellite operators'. Building on this proposal, in February 2018 Intelsat and SES proposed a framework in which wireless operators would gain access to ~100MHz of nationwide 3.7-4.2GHz downlink spectrum. See: https://www.businesswire.com/news/home/20180208006562/en/Intelsat-SES-Propose-Joint-C-band-Satellite-Terrestrial https://ecfsapi.fcc.gov/file/1002726526846/Joint%20Comments%20of%20Intelsat%20License%20LLC%20and%20Intel%20Corporation.pdf. For MNO responses to the NOI, see for example comments made by T-Mobile (filed November 15, 2017). See also T-Mobile's concerns with the Intel/Intelsat proposal: https://ecfsapi.fcc.gov/file/10214044930219/T-Mobile%20Ex%20Parte%2002142018.pdf

412 See https://www.fiercewireless.com/5g/fcc-chief-wants-to-auction-28-ghz-spectrum-november

413 See https://www.ntia.doc.gov/blog/2018/ntia-identifies-3450-3550-mhz-study-potential-band-wireless-broadband-use. The 'DOD plans to submit a proposal under the Spectrum Pipeline Act to carry out a comprehensive radio-

repurposing to… commercial wireless'. The 'DOD plans to submit a proposal under the Spectrum Pipeline Act to carry out a comprehensive radio-frequency engineering study to determine the potential for introducing advanced wireless services in this band (which is currently used for military radar) without harming critical government operations'.

Both the 3.450-3.550GHz and 3.7-4.2GHz bands have promising characteristics for 5G, including advantageous propagation characteristics, sufficient spectrum to provide wider channels and more significant throughput, and adjacency to the 3.5GHz band with the potential to share equipment components and lower device costs.

- **Regarding low-band spectrum**, the FCC completed[414] the 600MHz auction in April 2017, repurposing 2×35MHz of spectrum for licensed mobile use.

  Furthermore, in August 2017, the US Congress introduced legislation identifying the 1300-1350MHz and 1780-1830MHz bands as candidates for reallocation from federal users to non-federal use, and directing the NTIA to submit a report to Congress on relocating incumbent federal users from those bands[415].

Research, test beds and trials

Figure B.38 outlines 5G trials announced by the major MNOs in the US:

Figure B.38: Announcements of 5G trials by major MNOs in the US [Source: company press releases]

MNO	Details of 5G activity
Verizon	• In March 2018, Verizon applied[416] for two test licenses to conduct CBRS trials in two locations in Florida • On February 13, 2018, Verizon, Qualcomm and Nokia reported[417] that they had made a 4K video call in the 28GHz band, compliant with the new 3GPP 5G-NR standards • On January 3, 2018, Samsung announced that it had been selected to supply Verizon with commercial 5G FWA network solutions (which will be used in its launch in Sacramento in H2 2018 – see below) • On October 17, 2017, Verizon, Qualcomm and Novatel announced[418] plans to collaborate, initially focusing on 5G NR operation in 28GHz and 39GHz mm-wave spectrum bands. The companies plan to deliver 'a common 5G NR mm-wave technology platform for mobile and home broadband wireless access, supporting a 5G NR migration path for Verizon's early 5G fixed wireless access deployments and trials'

frequency engineering study to determine the potential for introducing advanced wireless services in this band [which is currently used for military radar] without harming critical government operations'.

414 See https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions

415 See http://docs.house.gov/meetings/IF/IF16/20171116/106636/HHRG-115-IF16-20171116-SD005-U5.pdf

416 See https://apps.fcc.gov/oetcf/els/reports/STA_Print.cfm?mode=current&application_seq=83599&RequestTimeout=1000

417 See https://www.fiercewireless.com/wireless/verizon-boasts-first-5g-call-using-3gpp-based-standards

418 See https://www.qualcomm.com/news/releases/2017/10/17/verizon-qualcomm-and-novatel-wireless-announce-collaboration-expedite

MNO	Details of 5G activity
	• On August 28, 2017, Verizon, Ericsson, Qualcomm and Federated Wireless demonstrated[419] an end-to-end LTE CA test in band 48 (CBRS) • On May 10, 2017, Verizon, Samsung and Cisco announced[420] the successful deployment of an end-to-end 5G trial network in Detroit, Michigan • On February 22, 2017, Verizon and Samsung announced[421] they had 'completed deployment of 5G systems in five US cities in preparation to begin customer trials of 5G technology […] the trials involve the use of 28GHz mm-wave spectrum and advanced beam-forming antenna technology'. This is part of a wider 5G trial being conducted by Verizon in 11 cities across the US
AT&T	• On January 17, 2018, AT&T submitted[422] an application for licenses to test 5G technology in the 28GHz and 39GHz bands • In December 2017, AT&T applied[423] for a test license in the 3.5GHz band, to conduct 5G tests using Ericsson equipment • On December 18, 2017, AT&T announced[424] the start of its largest 5G FWA trial so far, in Waco (Texas). Earlier in December the MNO had applied[425] to the FCC for a license to expand existing trials in the 28GHz band to the 37GHz and 39GHz bands. Sources indicate[426] plans for further 5G MBB testing in 2018 • On August 30, 2017, AT&T announced[427] that its second trial had achieved speeds of 1Gbps (and <10ms latency), and that trials were being extended to other areas of the country (in partnership with previous collaborators as well as Samsung and Nokia) • On June 27, 2017, AT&T, Intel and Ericsson announced[428] a second mm-wave FWA 5G trial at further locations in Austin (Texas) • On February 22, 2017, AT&T and Nokia announced[429] they were collaborating on 5G technology in the 39GHz band, and had recently completed FWA 5G tests with AT&T's Internet TV streaming service DIRECTV NOW using a 39GHz system based on its commercially available AirScale radio access platform • On December 5, 2016, AT&T, Intel and Ericsson launched[430] a FWA 5G trial in Austin (Texas), claiming that it was the first 5G business customer trial in the US. The trial reached speeds of 'nearly' 14Gbps and used the 15GHz and 28GHz bands

419 See https://www.qualcomm.com/news/releases/2017/08/28/verizon-ericsson-qualcomm-and-federated-wireless-team-showcase-first-end

420 See https://newsroom.cisco.com/press-release-content?articleId=1844370&type=webcontent

421 See https://news.samsung.com/us/samsung-verizon-announce-first-5g-customer-trials-set-begin-q2-2017/

422 See https://apps.fcc.gov/oetcf/els/reports/STA_Print.cfm?mode=current&application_seq=82237&RequestTimeout=1000

423 See https://apps.fcc.gov/oetcf/els/reports/STA_Print.cfm?mode=current&application_seq=81836&RequestTimeout=1000 and https://apps.fcc.gov/els/GetAtt.html?id=202484&x=.

424 See http://markets.businessinsider.com/news/stocks/AT-T-Launches-5G-Trial-with-Magnolia-at-the-Silos-1011617642

425 See https://apps.fcc.gov/els/GetAtt.html?id=202032&x=.

426 See https://www.fiercewireless.com/wireless/at-t-prepares-for-more-5g-mobility-tests-2018

427 See http://about.att.com/story/att_expanding_fixed_wireless_5g_trials_to_additional_markets.html

428 See http://about.att.com/story/att_launches_5g_trial_with_directv_now_in_austin.html

429 See https://www.nokia.com/en_int/news/releases/2017/02/22/nokia-and-att-first-to-successfully-conduct-5g-streaming-tests-with-directv-now-over-39-ghz-mwc17

430 See http://about.att.com/story/att_launches_first_5g_business_customer_trial_with_intel_and_ericsson.html

MNO	Details of 5G activity
T-Mobile	• On January 3, 2018, T-Mobile, Nokia and Intel announced[431] 'bringing a 28GHz outdoor 5G commercial radio system on air' to Bellevue, Washington • In December 2017, T-Mobile applied[432] for a test license from the FCC to use spectrum in the E-band (71–76/81–86GHz) to test 5G • On September 20, 2017, T-Mobile filed an application[433] with the FCC to conduct 3550–3700MHz band tests using Ericsson/Nokia equipment in Nevada and Texas. An extension was sought[434] in March 2018. This follows a previous application[435] on September 19, 2017 • On September 20, 2016, Nokia and T-Mobile announced[436] 'recent achievements' around a pre-standards 5G test network. The 5G air interface lab test used T-Mobile's 28GHz spectrum and Nokia's commercial 5G-ready AirScale radio platform. This resulted in connection speeds and throughput rates of 'several gigabits per second and real-time latency of 1.8 milliseconds while streaming four simultaneous 4K videos'
Sprint	• On September 12, 2017, Sprint announced[437] it had conducted 2.5GHz massive MIMO field tests in Washington and Texas using 5G equipment from Ericsson • On September 5, 2017, Sprint announced[438] partnering with a number of players on its nationwide NFV 'OpenStack' cloud deployment • On June 3, 2016, Sprint and Nokia announced[439] they had demonstrated the wireless delivery of a 4K UHD video over using a 73GHz system that supports beam steering. A bandwidth of 1GHz was used to achieve speeds of 2.3Gbps and ~1ms latency

In addition to the trials of the major MNOs outlined above, a number of 5G tests have been conducted by other players. Recent examples include Charter Communications' 5G trials in the 3.5GHz band[440] and US Cellular's 5G testing[441] with Ericsson in the 28GHz band.

Several of the major MNOs have acquired companies holding high-frequency spectrum. Verizon acquired XO Communications in February 2017,[442] and then in May 2017 acquired Straight Path

431 See https://www.nokia.com/en_int/news/releases/2018/01/03/nokia-t-mobile-us-and-intel-collaborate-to-bring-t-mobiles-first-commercial-hardware-based-5g-28-ghz-cell-on-air

432 See https://apps.fcc.gov/oetcf/els/reports/STA_Print.cfm?mode=current&application_seq=81454&RequestTimeout=1000

433 See https://apps.fcc.gov/els/GetAtt.html?id=199854&x=.

434 See https://apps.fcc.gov/oetcf/els/reports/STA_Print.cfm?mode=current&application_seq=83533&RequestTimeout=1000

435 See https://apps.fcc.gov/oetcf/els/reports/STA_Print.cfm?mode=current&application_seq=80342&RequestTimeout=1000. A previous application was also made by T-Mobile in April 2017 to trial CBRS spectrum in Bellevue (Washington), but the application was rejected on the grounds that proposed areas fell within an exclusion zone which the Navy could not approve.

436 See https://www.nokia.com/en_int/news/releases/2016/09/20/nokia-and-t-mobile-showcase-the-real-potential-of-5g-through-network-testing-and-applications

437 See http://newsroom.sprint.com/sprint-and-ericsson-conduct-first-us-field-tests-for-25-ghz-massive-mimo.htm

438 See http://newsroom.sprint.com/the-sprint-nfv-journey.htm

439 See https://www.nokia.com/en_int/news/releases/2016/06/03/sprint-and-nokia-conduct-live-5g-demo-in-santa-clara

440 See http://policy.charter.com/blog/wireline-wireless-broadband-part-broadband-solution/

441 See https://www.ericsson.com/en/press-releases/2017/10/u.s.-cellular-expands-5g-tests-with-ericsson-to-28ghz

442 Permission from the FCC for the acquisition appears to have been granted in November 2016, and an article published on February 1, 2017 by PR Newswire confirmed the acquisition had taken place; see http://www.prnewswire.com/news-releases/verizon-completes-purchase-of-xo-communications-fiber-business-300400440.html

Communications in an all-stock deal worth USD3.1 billion.[443] AT&T acquired FiberTower in February 2017,[444] and most recently (on February 5, 2018), news emerged[445] that T-Mobile is applying for permission to buy around 1150MHz of LMDS spectrum (28–31GHz) in Ohio, which the MNO said it plans to use for 5G.

Industry plans and government commitments

Figure B.39 outlines 5G commercial deployment plans announced by the major MNOs in the US:

Figure B.39: Announcements of 5G deployment plans by major MNOs in the US [Source: company press releases]

MNO	Details of 5G activity
Verizon	• On November 29, 2017, Verizon announced[446] that it would launch 5G FWA residential services in five markets in 2018 (the first being Sacramento, CA in H2 2018). Verizon will use Ericsson equipment[447] • Verizon also indicated[448] that 5G mobile services would be commercially available by 2020. Sources indicate[449] that it will begin testing in 2018
AT&T	• On March 14, 2017, AT&T stated[450] that it would be 'able to launch standards-based mobile [FWA] 5G services to consumers starting as early as late 2018' • On April 25, 2017, AT&T unveiled[451] plans to launch a '5G Evolution' service in over 20 cities by the end of 2018, to 'pave the way to the next generation of faster speeds' • On January 4, 2018, AT&T announced[452] that it expected to launch a standards-based mobile 5G service in a dozen cities in the US by the end of 2018. This was reaffirmed[453] in a press release on February 21, 2018.

443 Straight Path holds an average of 620MHz in the top 30 US markets and covers the entire nation with 39GHz spectrum. It has retained all its 28GHz spectrum licenses. Straight Path had long been expected to sell its licenses to a wireless or cable network operator; see http://www.fiercewireless.com/wireless/verizon-to-acquire-straight-path-for-3-1b-ending-bidding-war-at-t

444 FiberTower, which was in bankruptcy, has spectrum in the 24GHz and 39GHz bands covering 30 billion MHz POPs, according to Wells Fargo Securities and AllNet Insights. FiberTower (First Avenue Networks, Inc.) acquired 24GHz spectrum in the FCC's auction 56 in 2004. See http://www.fiercewireless.com/wireless/at-t-quietly-acquires-fibertower-for-24-39-ghz-spectrum. On January 26, 2018, the FCC announced FiberTower must return hundreds of mm-wave spectrum licenses (in both the 24GHz and 39GHz bands) to the NRA. AT&T will acquire ~500 licenses in the 39GHz band, but none in the 24GHz band; see https://www.fcc.gov/document/fibertower-spectrum-holdings-llc

445 See https://www.fiercewireless.com/wireless/t-mobile-buys-1150-mhz-millimeter-wave-spectrum-covering-ohio-for-5g

446 See http://www.verizon.com/about/news/verizon-launch-5g-residential-broadband-services-5-markets-2018

447 See https://www.ericsson.com/en/press-releases/2017/12/verizon-awards-5g-contract-to-ericsson

448 See http://www.lightreading.com/mobile/5g/verizon-says-its-fixed-5g-will-arrive-in-2018-mobile-in-2020/d/d-id/730880

449 See https://www.fiercewireless.com/wireless/verizon-track-to-launch-5g-broadband-offering-2018-palmer

450 See http://about.att.com/innovationblog/standardized_5g

451 See http://about.att.com/story/5g_evolution_to_over_20_metros_in_2017.html. The announcement was criticized for deceptive branding, with T-Mobile stating that it had already been using the same technology (LTE with carrier aggregation, 4×4 MIMO, 256 QAM) since 2016 (see T-Mobile deployment announcement).

452 See http://about.att.com/story/att_to_launch_mobile_5g_in_2018.html

453 See http://about.att.com/story/multigigabit_mobile_5g.html

MNO	Details of 5G activity
T-Mobile	• T-Mobile has stated[454] that it expects to begin a 5G mobile roll-out using 600MHz spectrum in 2019 and is targeting a full nationwide network by 2020 • On February 27, 2018, at the MWC in Spain, T-Mobile announced[455] that it plans to build out its 5G network in 30 cities in 2018, though devices won't be available until (early) 2019
Sprint	• On May 10, 2017, Sprint, Softbank (its Japanese parent) and Qualcomm announced[456] that they would develop 5G NR technology in Band 41 (2.5GHz), and plan to 'provide commercial [mobile] services and devices in late 2019'. The company reaffirmed[457] this in a statement on December 21, 2017, after 3GPP announced the ratification of its NSA 5G NR specification (which includes the 2.5GHz band) • On February 2, 2018, Sprint held its fiscal 2017 Q3 results call.[458] The MNO is increasing its capex by at least USD1 billion in the coming fiscal year, and is now working with Qualcomm and vendors to deliver 5G by H1 2019. The accompanying press release[459] provides further details of its 5G plans • On February 27, 2018, Sprint announced[460] plans to install Massive MIMO technology in six cities in April 2018, with vendors Samsung, Ericsson and Nokia suppling the equipment. The plans are a key step in delivering 5G by H1 2019.

On July 15, 2016, the US government announced[461] the launch of the USD400 million Advanced Wireless Research Initiative (AWRI) led by the National Science Foundation (NSF). The AWRI includes:

- USD85 million investment in 'advanced wireless testing platforms' via a public-private partnership, including NSF and over 20 technology companies and associations.[462] This funding includes:
  - — USD50 million over the next five years to design and build four city-scale advanced wireless testing platforms, beginning in FY 2017
  - — USD5 million for a project office to manage the design, development, deployment, and operations of the testing platforms, in collaboration with NSF and industry players.

454 See https://newsroom.t-mobile.com/news-and-blogs/nationwide-5g-blog.htm. See also https://newsroom.t-mobile.com/news-and-blogs/nationwide-5g.htm

455 See https://newsroom.t-mobile.com/news-and-blogs/mwc-2018-5g.htm, and https://www.theverge.com/2018/2/27/17058368/tmobile-5g-first-30-cities-2018-new-york-la-dallas-las-vegas

456 See http://newsroom.sprint.com/qualcomm-softbank-and-sprint-announce-collaboration-on-25-ghz-5g.htm

457 See http://investors.sprint.com/news-and-events/press-releases/press-release-details/2017/Sprints-25-GHz-Spectrum-Included-in-Non-Standalone-3GPP-5G-NR-Specification/default.aspx

458 See http://www.lightreading.com/mobile/5g/sprint-promises-mobile-5g-in-h1-2019-signals-more-job-cuts/d/d-id/740273

459 See http://s21.q4cdn.com/487940486/files/doc_financials/quarterly/2017/q3/01_Fiscal-3Q17-Earnings-Release-FINAL.pdf

460 See http://newsroom.sprint.com/sprint-unveils-5g-ready-massive-mimo-markets.htm

461 See https://obamawhitehouse.archives.gov/the-press-office/2016/07/15/fact-sheet-administration-announces-advanced-wireless-research

462 These include all the main MNOs, key vendors, and a number of other key industry players, as well as associations such as CTIA. See announcement for full details.

- Plans by NSF to invest an additional USD350 million over the next seven years in academic research that can use these testing platforms:
  - The platforms and the research they support aim to 'allow academics, entrepreneurs, and the wireless industry to test and develop advanced wireless technology ideas, some of which may translate into key future innovations for 5G and beyond'.
- A number of complementary efforts by other federal agencies were also announced, including:
  - The NSF announced a number of further initiatives, e.g. funding for the 'Millimeter Wave Research Coordination Network' and USD4.7 million (joint with the Academy of Finland) to support joint US–Finland research projects
  - DARPA announcing plans to demonstrate the viability of the technologies being developed Spectrum Collaboration Challenge (SC2)
  - The National Institute of Standards and Technology (NIST) announced the creation of a multi-disciplinary working group the 'Future Generation Communications Roadmap' and a project with the 5G mmWave Channel Model Alliance
  - The National Telecommunications and Information Administration (NTIA) announced a number of actions that build on its spectrum test bed and other measurement program.

However, we note that the AWR initiative is not a 5G specific initiative. It is really a longer range National Science Foundation initiative with government sponsoring advanced wireless test beds for cutting edge wireless technologies and use cases.

The FCC's Wireless Infrastructure docket seeks to reform the rules applying to infrastructure deployment, to streamline the process of deploying next generation wireless facilities, addressing the types of deployment subject to National Historic Preservation Act (NHPA) and National Environmental Policy Act (NEPA) review, and establishing timeframes for the FCC to act upon Environmental Assessments. The deployment of small cells, in particular, will be subjected to streamlined review.[463]

Most recently, in December 2017 the White House published[464] a high-level 'National Security and Strategy' report, which included a government commitment to work with private industry to improve American infrastructure. In particular, the report stated that the government would 'improve America's digital infrastructure by deploying a secure 5G Internet capability nationwide.' No further details were provided.

[463] See https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0301/DOC-349528A1.pdf

[464] See https://www.fiercewireless.com/5g/white-house-report-calls-out-5g-as-part-infrastructure-push

Outlook

Our 5G outlook/assessment for the US is summarized in Figure B.40 below.

Figure B.40: 5G outlook for the US [Source: Analysys Mason, 2018]

Metric	Description	Score
Amount and timeline of spectrum to be released	In July 2016, the FCC confirmed that ~11GHz of mm-wave spectrum was to be released for flexible mobile/fixed use: 3.85GHz of licensed spectrum (27.5–28.3, 37–38.6 and 38.6–40GHz) and 7GHz of unlicensed spectrum (64–71GHz). In November 2017, the FCC decided to make a further 1700MHz available for mobile in the 24GHz and 47GHz bands. Auction dates pending (expected 2018/19) 150MHz (3550–3700MHz) to be released in the CBRS three-tier licensing structure, with second-tier auctions expected in 2018/19. Further mid-bands have been consulted on	3/4
5G spectrum roadmap published	NOI/NOPR/FNPR documentation	3/4
Government commitments and infrastructure policy	USD400 million Advanced Wireless Research Initiative (AWRI) announced in July 2016	2/4
Industry trials	Verizon, AT&T, T-Mobile and Sprint have all announced trials	4/4
Industry commitment and accelerated 5G launch	AT&T: 2018/19, Verizon: FWA in 2018, mobile in 2020, T-Mobile: initial 30 cities deployment in 2018, additional deployment (using 600MHz and mm-wave spectrum) in 2019, targeting nationwide roll-out by 2020, Sprint: H1 2019	4/4

B.11 EU

The EU is a supra-national organization consisting (as of January 2018) of 28 Member States. The European Commission (EC) is the EU's politically independent executive arm, responsible for drawing up proposals for new European legislation. Two further EU bodies have particular relevance to telecommunications and spectrum policy:

- The Radio Spectrum Policy Group (RSPG), which is a high-level advisory group that assists the EC with the development of radio spectrum policy.
- The Body of European Regulators for Electronic Communications (BEREC), which aims to promote the development and better functioning of the EU's internal market for electronic communications networks and services, by ensuring a consistent application of the EU regulatory framework across Member States.

The EU has identified three 'pioneer' bands for 5G (700MHz, 3400–3800MHz and 24.25–27.5GHz), and issued comprehensive 5G strategy/roadmap documentation. The 5GPPP initiative is investing over EUR4 billion to realize the roll-out of 5G infrastructure and services by 2020.

Overview

On September 14, 2016, the EC launched[465,466] a '5G action plan' to boost EU efforts for the deployment of 5G infrastructure and services across the Digital Single Market by 2020. The plan[467] consists of the following key elements:

- Align roadmaps and priorities for a coordinated 5G deployment across all EU Member States, targeting early network introduction by 2018, and moving towards commercial large-scale introduction by the end of 2020 at the latest.
- Make provisional spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference (WRC-19), to be complemented by additional bands as quickly as possible, and work towards a recommended approach for the authorization of the specific 5G spectrum bands above 6GHz.
- Promote early deployment in major urban areas and along major transport paths.
- Promote pan-European multi-stakeholder trials as catalysts to turn technological innovation into full business solutions.

465 See https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan

466 The other key strategy document issued by the EC regarding 5G is the '5G Manifesto for timely deployment of 5G in Europe', published on July 6, 2016; see http://ec.europa.eu/newsroom/dae/document.cfm?action=display&doc_id=16579. See also the EU's 'vision for 5G' as presented at MWC 2015 - https://ec.europa.eu/digital-single-market/en/news/5g-european-research-and-vision-showcased-blueprint-showcased-mobile-world-congress-2015

467 See https://ec.europa.eu/digital-single-market/en/news/communication-5g-europe-action-plan-and-accompanying-staff-working-document

- Facilitate the implementation of an industry-led venture fund in support of 5G-based innovation.
- Unite leading actors in working towards the promotion of global standards.

The plan provides further detail in eight 'Action' points under the heading 'Keeping Europe ahead in the 5G race: key areas for action'.

Main 5G spectrum proposals

Regarding spectrum, Actions 2 and 3 state that the EC will work with Member States to:

- Identify (by the end of 2016) a provisional list of pioneer spectrum bands for the initial launch of 5G services.
- Agree (by the end of 2017) on the full set of spectrum bands (below and above 6GHz) to be harmonized for the initial deployment of commercial 5G networks in Europe, based on a planned RSPG opinion on 5G spectrum.
- Work towards a recommended approach for the authorization of the specific 5G spectrum bands above 6GHz, with an early indication of technical options and feasibility available through CEPT studies by the end of 2017.

As scheduled, the RSPG issued[468] its (first) 'Opinion on spectrum related aspects for next generation wireless systems (5G)' on November 9, 2016, which identified the following three main 'pioneer' bands:

- 3400–3800MHz: the RSPG considers this to be the primary band suitable for the introduction of 5G based services in Europe even before 2020.[469]
- 700MHz: the RSPG is of the opinion that 5G will need to be deployed in sub-1GHz bands already harmonized, particularly the 700MHz band, to enable nationwide and indoor coverage.
- 24.25–27.5GHz (26GHz): the RSPG recommends this band as a mm-wave pioneer band.

The opinion also discussed the 31.8–33.4GHz (32GHz) and 40.5–43.5GHz (42GHz) bands, stressing that 'there are many frequency bands above 24GHz which are of potential interest for 5G in Europe'.

468 RSPG16-032 FINAL. See http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf. See http://rspg-spectrum.eu/wp-content/uploads/2013/05/RSPG16-007_rev_sept_2016.pdf for earlier documentation issued by RSPG relevant to 5G spectrum. We also note that, in May 2015, the EC adopted a decision to open up the 1452–1492 MHz band for wireless broadband under harmonized technical conditions. This spectrum has yet to be allocated to mobile in a number of European countries.

469 See also http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008D0411&from=EN

On November 21, 2017, the RSPG issued[470] its draft second 'Opinion on 5G networks'. The document is a 'further development of the roadmap to facilitate the launch of 5G on a large scale in Europe starting in 2020', and includes the following opinions on 5G spectrum:

- Member States should consider appropriate measures to defragment the 3.6GHz band, the primary 5G band, in time for authorizing sufficiently large blocks of spectrum by 2020.
- An individual license regime should be the focus for the 24.25–27.5GHz band. However, the possibility of a general authorization regime under sharing conditions is not excluded; Member States should make sufficiently large portions of this band (e.g. 1GHz) available by 2020.
- The 32GHz band is no longer considered as a priority for study,[471] however, a general authorization regime is foreseen in the 66–71GHz band, which could be a primary band for 5G in Europe.

The final second 'Opinion on 5G networks' was published[472] on January 30, 2018, which confirmed the above recommendations. The RSPG's second Opinion also adopted a number of further recommendations for policymakers on strategic issues related to 5G deployment (e.g. authorization flexibility, cross border service performance needs, coverage requirements etc.) Full details are available in the published documentation.

Research, test beds and trials

Regarding 5G trials, Action 6 calls on the industry to:

- Plan for key technological experiments to take place as early as 2017, including the testing of new terminals and applications through the 5G-PPP (see below), demonstrating the benefit of 5G connectivity for important industrial sectors.
- Present detailed roadmaps by March 2017 for the implementation of advanced pre-commercial trials to be promoted at EU level (trials in key sectors must be launched in 2018).

Accordingly, in May 2017, the 5G Infrastructure Association (the private side of the 5G PPP; see below) published[473] the '5G Pan-EU Trials Roadmap Version 1.0' shortly before the 3rd 5G Global Event in Tokyo. In November 2017, the Roadmap Version 2.0 was published at the 4th 5G Global

470 See https://circabc.europa.eu/sd/a/b7f85cbb-5155-4268-abbb-fa83113b3ed4/RSPG17-034final_2nd_draft_opinion_on_5G.pdf

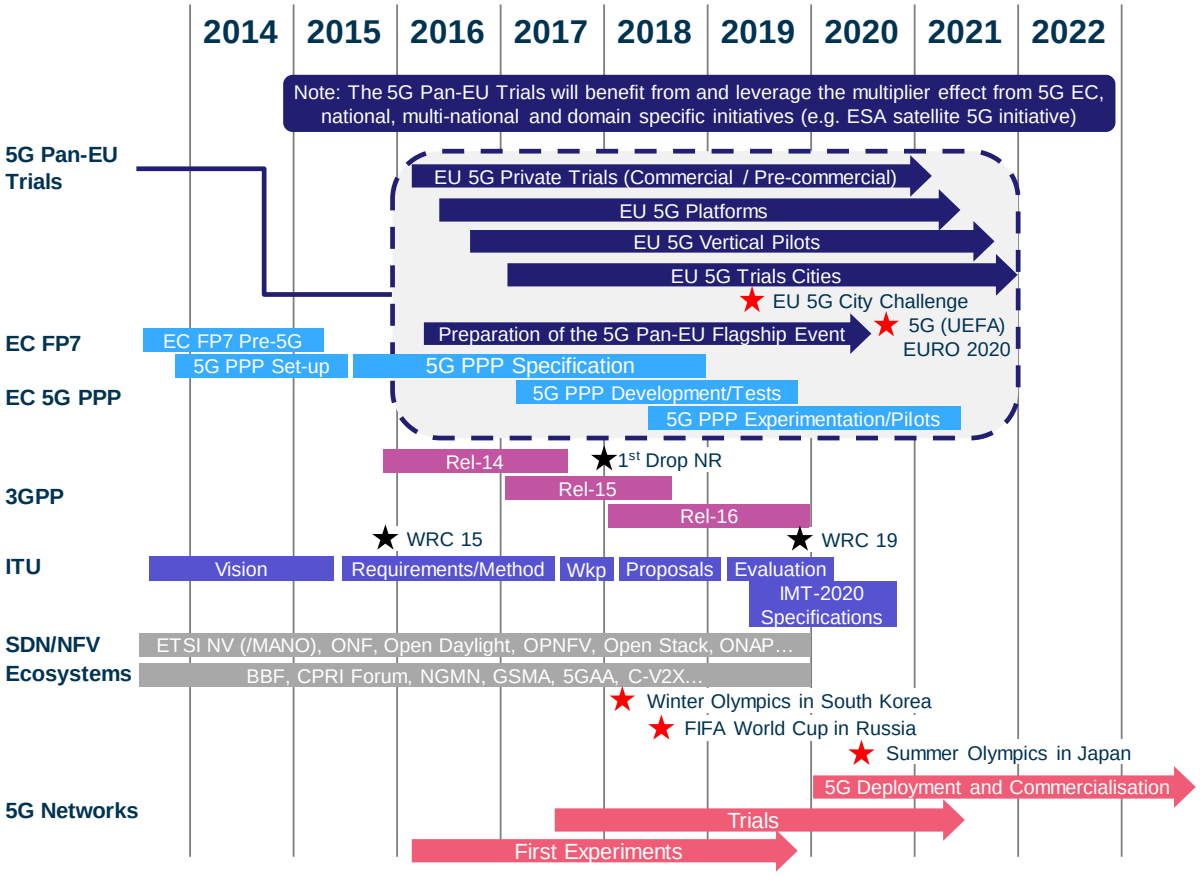
471 Regarding 31.8–33.4GHz, the RSPG notes that the preliminary results of sharing studies highlight some difficulties, and that the interest for this frequency band appears to be declining. Regarding 40.5–43.5GHz, RSPG notes that the industry has indicated that the band is expected to be part of a tuning range for equipment from 37–43.5GHz. The potential of this tuning range 'would be for different regions to be able to identify the most appropriate frequencies to be used for 5G'. The RSPG opinion also references a number of other mm-wave bands being studied as part of the preparation process for WRC-19.

472 See https://circabc.europa.eu/sd/a/fe1a3338-b751-43e3-9ed8-a5632f051d1f/RSPG18-005final-2nd_opinion_on_5G.pdf

473 See https://5g-ppp.eu/wp-content/uploads/2017/05/5GInfraPPP_TrialsWG_Roadmap_Version2.0.pdf. Roadmap Version 1.0 was publicly released shortly before the 3rd 5G Global Event in Tokyo (May 2017). See https://5g-ppp.eu/wp-content/uploads/2017/05/5GInfraPPP_TrialsWG_Roadmap_Version1.0.pdf

Event in Seoul. This Roadmap is summarized in Figure B.41 below, capturing the EC 5G Infrastructure PPP program phases and the high-level standardization time plan, as well as the 5G Pan-EU Trials.

Figure B.41: 5G Pan-EU Trials Roadmap [Source: 5G Pan-EU Trials Roadmap Version 2.0, November 2017]



The roadmap addresses the latest updates of the 5G Private Trials, the 5G Platforms, the 5G Vertical Pilots, the 5G Pan-EU Flagship event '5G for UEFA EURO 2020', and the 5G Trials Cities. A full discussion of each of these initiatives is beyond the scope of the present report; readers are referred to the publicly available documentation for further details. Release of Roadmap Version 3.0 is planned for May 2018 at the 5th 5G Global Event in Austin, Texas.

Furthermore, the EC has established a number of 'Joint Declarations' with other countries to partner in the development of 5G technologies. These are outlined in Figure B.42 below.

Figure B.42: 'Joint Declarations' between the EU and other nations to partner in 5G development [Source: EC[474]]

Partner nation (date)	Details
South Korea (June 16, 2014)	• A Joint Declaration[475] on 'Strategic Cooperation in Information Communications Technology (ICT) and 5G'

474 See https://ec.europa.eu/digital-single-market/en/5G-international-cooperation

475 See https://ec.europa.eu/digital-single-market/en/news/landmark-agreement-between-european-commission-and-south-korea-5g-mobile-technology

Partner nation (date)	Details
Japan (May 29, 2015)	• A Joint Declaration[476] on developing 5G. This followed the signing of a MoU between the EC's 5G PPP and Japan's Fifth Generation Mobile
China (September 28, 2015)	• A Joint Declaration[477] on developing 5G network technology
Brazil (February 23, 2016)	• A joint declaration[478] between on developing 5G was signed at the Mobile World Congress 2016 in Barcelona

The EC states[479] that co-operation agreements are also being discussed with India and the US.

Industry plans and government commitments

Regarding deployment plans, Action 1 states the following objectives:

- Promoting preliminary trials, under the 5G-PPP arrangement (see below), to take place from 2017 onwards, and pre-commercial trials with a clear EU cross-border dimension from 2018.
- Encouraging Member States to develop, by the end of 2017, national 5G deployment roadmaps as part of the national broadband plans.
- Ensuring that every Member State will identify at least one major city to be '5G enabled' by the end of 2020 and that all urban areas and major terrestrial transport paths have uninterrupted 5G coverage by 2025.

As part of the development of the 5G national roadmaps, Action 4 adds further objectives aimed at meeting the deployment targets outlines above (i.e. roll-out and quality objectives, and best practice for dense cell deployment).

Regarding 5G investment and funding, Action 8 states that the EC will 'work with the industry and the [European Investment Bank] EIB Group to identify the objectives, possible configuration, and modalities for a venture financing facility, possibly linked with other digital start-up actions. The feasibility should be assessed by the end of March 2017, taking into account the possibility to enhance private funding by adding several sources of public funding in particular from the European Fund for Strategic Investments (EFSI) and other EU financial instruments'.

The EC signed[480] an agreement with the 5G Infrastructure Association (5G-IA) on December 17, 2013, representing major European ICT industry players,[481] to establish a Public Private Partnership

476 See http://europa.eu/rapid/press-release_IP-15-5069_en.htm?locale=en

477 See http://europa.eu/rapid/press-release_IP-15-5715_en.htm

478 See http://europa.eu/rapid/press-release_IP-16-382_en.htm

479 See https://ec.europa.eu/digital-single-market/en/5G-international-cooperation

480 See http://ec.europa.eu/newsroom/dae/itemdetail.cfm?item_id=14764&newsletter=125

481 The 5G IA is committed to the advancement of 5G in Europe and to building global consensus on 5G. The Association brings together a global industry community of telecom and digital players, such as operators, manufacturers, research institutes, universities, verticals, and SMEs. The 5G IA carries out a wide range of activities in strategic areas including standardization, frequency spectrum, R&D projects, technology skills, collaboration with

on 5G (5G PPP).[482] 5G PPP is the EU's flagship initiative to accelerate research developments in 5G technology, backed[483] by EUR700 million of public funding set aside by the EC through the Horizon 2020 Programme.[484] EU industry is set to match this investment by up to five times, to more than EUR3 billion. 5G PPP states its main aims as:

- providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010
- saving up to 90% of energy per service provided. The main focus will be on mobile communication networks where the dominating energy consumption comes from the radio access network
- reducing the average service creation time cycle from 90 hours to 90 minutes
- creating a secure, reliable and dependable internet with a "zero perceived" downtime for services provision
- facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people
- ensuring for everyone and everywhere the access to a wider panel of services and applications at lower cost.

5G PPP's activities have been grouped into three phases of research and innovation projects:

- Phase 1 consisted of 19 projects (from 83 proposals), using EUR128 million of EC funding.[485] Most projects began in July 2015, and completed in 2017. Phase 1 projects focused on 'fundamental 5G research driving central 5G technical issues though pre-standardization consensus through to standardization submission'.

- Phase 2 is the current phase, consisting of 21 projects (from 101 proposals).[486] Most projects begin in June 2017, and are scheduled to be completed from 2019–20. Phase 2 projects are 'more focused on demonstrating and validating the developed technology and explicitly trying to integrate use cases from vertical industries beyond classical telecommunications'.

- Phase 3 documentation[487] was recently released (November 2017), with submissions due by January 2018.

key vertical industry sectors, notably for the development of trials, and international cooperation. See https://5g-ppp.eu/5g-infrastructure-association/

482 See https://5g-ppp.eu/

483 See http://ec.europa.eu/research/press/2013/pdf/ppp/5g_factsheet.pdf

484 See http://ec.europa.eu/programmes/horizon2020/

485 See https://5g-ppp.eu/wp-content/uploads/2015/10/5GPPP-brochure-final-web.pdf and https://5g-ppp.eu/5g-ppp-phase-1-projects/

486 See https://5g-ppp.eu/5g-ppp-phase-2-projects/ and https://5g-ppp.eu/wp-content/uploads/2017/11/5GPPP-brochure-phase2-final-web.pdf

487 See https://5g-ppp.eu/phase-3-pre-structuring-model/ and https://5g-ppp.eu/wp-content/uploads/2017/10/171107_5GInfraPPP_Phase3-Pre-StructuringModel_V2.0.pdf

A full discussion of the different 5G PPP projects (completed, ongoing and planned), and a detailed overview of the material published by the 5G PPP is beyond the scope of this project. Readers are directed to the 5G PPP website (https://5g-ppp.eu), which contains an extensive amount of relevant documentation, particularly the series[488] of 5G PPP and 5G-IA white papers published since 2015.

Outlook

Our 5G outlook/assessment for France, Germany and the UK (three individual Member States of the EU) is provided in the case studies for those countries.

[We note that our discussion above has excluded Actions 5 and 7 from the EC's 2016 '5G action plan'. Action 5 specifies the Commission's approach to standardization, which is an area not extensively covered in this study. Action 7 (and to some extent Action 4) is concerned with 5G infrastructure, and is discussed along with the Electronic Communications Code (ECC) in Section 5*]*

488 See https://5g-ppp.eu/white-papers/