IN-DEPTH ANALYSIS

Requested by the ITRE committee

European Parliament

5G Deployment

State of Play in Europe, USA and Asia

Policy Department for Economic, Scientific and Quality of Life Policies
Directorate-General for Internal Policies
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5G Deployment

State of Play in Europe, USA and Asia

Abstract

This in-depth analysis was prepared by Policy Department A at the request of the ITRE Committee. It compares 5G deployment in the EU with other leading economies – the USA, China, Japan, the Republic of Korea, Singapore and Taiwan. On a range of indicators, the EU compares well. However, this is not a short-term race. 5G is more complex than previous wireless technologies and should be considered as a long-term project to solve technical challenges and develop a clear business case.

This document was requested by the European Parliament's Committee on Industry, Research and Energy.

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LIST OF ABBREVIATIONS

5G	Fifth generation mobile communications system
CEPT	European Conference of Postal and Telecommunications Administrations
cMTC	Critical machine type communication
EECC	European Electronic Communications Code
eMBB	Enhanced or extreme mobile broadband
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FWA	Fixed wireless access
GSM	Global System for Mobile communications, digital cellular standard for mobile voice and data
ITU	International Telecommunication Union
IoT	Internet of Things
LTE	Long-Term Evolution, a standard for high-speed wireless communication
MIMO	Multiple-input and multiple-output
mMTC	Massive machine type communication
MNO	Mobile network operator
NRA	National regulatory authority
OTT	Over-the-top, delivery of services over the internet
RSPG	Radio Spectrum Policy Group
SDO	Standards development organization
SAWAP	Small area wireless access point
URLLC	Ultra-reliable low-latency communications
WRC	World Radiocommunication Conference

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EXECUTIVE SUMMARY

On a range of technical and other criteria, Europe compares well with other leading countries and economies in 5G development, such as the USA, China, Japan, the Republic of Korea, Singapore and Taiwan. In analysing the market and the positions of the various national players, it is helpful to classify countries and economies either as producers of 5G technology (e.g. Korea, Taiwan), consumers of 5G technologies (e.g. Singapore), or both. Europe falls in the latter category, along with the USA, China and Japan.

In fact, in many ways, European consortia are well placed, with an advanced programme in pilots, city trials and testing, and consensus on spectrum allocation and assignment. It also has some key strategic advantages compared to some other countries. For example, it is home to significant equipment suppliers (e.g. Nokia and Ericsson) as well as various key integrated circuit designers (e.g. ARM/Softbank) despite ownership by Japanese, US or Chinese enterprises. Furthermore, the key technical standards organization, ETSI/3GPP, is located in the EU and is at the centre of intelligence for the technologies, standards and the patents on which they are based.

It is becoming clear that 5G will cost much more to deploy than previous mobile technologies (perhaps three times as much) as it is more complex and requires a denser coverage of base stations to provide the expected capacity. The European Commission has estimated that it will cost €500 billion to meet its 2025 connectivity targets, which includes 5G coverage in all urban areas.

As 5G is driven by the telecoms supply industry, and its long tail of component manufacturers, a major campaign is under way to convince governments that the economy and jobs will be strongly stimulated by 5G deployment. However, we are yet to see significant "demand-pull" that could assure sales. These campaign efforts are also aimed at the MNOs but they have limited capacity to invest in the new technology and infrastructure as their returns from investment in 3G and 4G are still being recouped.

The notion of a "race" is part of the campaign but it is becoming clear that the technology will take much longer than earlier generations to perfect. China, for instance, sees 5G as at least a ten-year programme to become fully working and completely rolled out nationally. This is because the technologies involved with 5G are much more complex. One aspect, for example, that is not well understood today is the unpredictable propagation patterns that could result in unacceptable levels of human exposure to electromagnetic radiation.

The report makes four recommendations to improve the likely long-term success of 5G in the EU:

- Increasing long-term R&D efforts on 5G is essential to understand multiple propagation unknowns (e.g. measuring and controlling RF EMF exposure with MIMO at mmWave frequencies).
- More detailed study of business models is needed to better define the goals, scope and revenue sources for 5G.
- Policy for 5G networks should be based on encouraging infrastructure sharing and separation of infrastructure and services.
- Developing a lightweight regulatory framework for deployment of small area wireless access points (SAWAPs), key to the densified 5G networks envisaged, is essential for their easy rollout at the very large scale of base stations necessary.

1. THE 5G CHALLENGE

1.1. Introduction

The mobile industry's operators and suppliers promise a new wireless technology, referred to as 5G, which could bring a huge advance in speed and reliability to mobile devices. More importantly, 5G could enable a new wave of technologies and applications, based on its novel infrastructure for smart cities, advanced manufacturing, healthcare systems and connected cars.

The cost of meeting the European Union's connectivity goals for 2025, including 5G coverage in all urban areas, set out in its Communication on *Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society*, is estimated at €500 billion. Given the scale of the investment needed, the mobile industry needs to convince governments of the economic and social benefits that 5G might bring and, consequently, marketing hype is widespread. For example, it suits the industry if policy makers believe that there is a race between nations to be the first to launch 5G services – and that Europe is lagging behind. The telecommunications industry and mainstream media report daily on the latest development and who is ahead in this race while, more fundamentally, there are unanswered questions over what 5G actually is, what it is for, whether it is safe, whether it offers good value for money or whether anyone will be prepared to pay for it.

The most important lesson for Europe from analysing the strategies of the USA, China as well as other Asian countries is that developing and deploying new wireless technologies is a much longer project than this short-term race would imply (Jefferies, 2017).

Consequently, this report examines the business models proposed, the progress of technology, standards, pilot demonstrations and commercial rollout across the globe to compare progress in the EU with the USA, China and other Asian countries.

1.2. The 5G Business Model

One of the aims of 5G is to offer mobile and fixed Internet access at broadband speeds of the order of 10 Gbps, about a hundred times faster than theoretically possible with the current technology, LTE. The business drivers behind this advance are the need to:

- Transport much larger volumes of data more quickly, for video for entertainment content and live streaming on social networking.
- Reduce response time (or latency) across the mobile network for gaming and for certain vertical sector business applications, e.g. for Internet of Things (IoT) applications, such as real-time manufacturing and process control.

These two factors – data rates for a high volume of delivery, in minimal response time – support the business models mentioned above. The International Telecommunication Union (ITU) has classified 5G business models as three use cases, each having different communications needs:

- Enhanced or extreme mobile broadband (eMBB), aimed at entertainment, video social networking and multimedia communications with higher resolution video channels.
- Massive machine type communication (mMTC), designed for wide area coverage for hundreds of thousands of devices per square kilometre, typically to ensure ubiquitous connectivity for cheap, basic software and hardware units with minimal energy consumption, e.g. to monitor a city's air quality.

- Critical machine type communication (cMTC), for monitoring and control in real time, with very low end-to-end latency and high reliability. These may be termed ultra-reliable low-latency communications (URLLC) for industrial workflows such as the automation of energy distribution in a smart grid, in industrial process control and sensor networking where there are stringent requirements in terms of reliability and low latency.

Most importantly, the current mobile network operator (MNO) led business model may be challenged by industrial users. Such users are unwilling to pay for expensive 5G for connectivity, especially for their IoT requirements such as manufacturing, and so new models may emerge for alternative forms of network ownership and operations. In the vertical industrial sectors (e.g. aerospace and car manufacture, construction, health services, utilities, etc) the sector players may become the prevalent 5G network builders, owners and operators. In addition, there may be multi-operator "small cell" networks with separation of application services and basic networking infrastructure, especially where the general public needs connectivity.

1.3. 5G Augments Previous Generations but Brings New Challenges

With 5G, the technical approach to attain much higher data speeds and lower latency is complex compared to previous generations of mobile infrastructure, for the base stations, their antennae, the software and handsets. 5G attempts to revise the basic cellular radio technology model with:

- **Focused beams**: Rather than transmitting a wide area broadcast spread over a segment of the cell around a base station, an "active antenna" technique is used to form a set of steerable radio beams with power focused on a small area – the receiving handset.

- **Potentially much higher frequencies and greater bandwidth for higher data rates:** Although lower frequencies, many in the UHF range, are being proposed for the first phase of 5G networks, much higher radio frequencies are also projected in bands traditionally used for radars and microwave links. Whether this will transpire is still open to question. These frequencies are being commercially tested by some (e.g. by AT&T in the USA at 28 GHz). The new bands are well above the UHF ranges, being either in centimetric (3-30 GHz) or in millimetric bands (30-300 GHz) and popularly branded "mmWave", but present technical challenges that are expensive to solve. More spectrum remains unassigned in these upper bands, so broader swathes for wider bandwidth are vacant for more channels and also higher data rates per channel. Whether consumers as target users will value the higher data rates is unclear or whether they will need higher capacity, or will be able to afford the handsets and service tariffs (Webb, 2018). Bandwidths of the order of 100 MHz to 400 MHz are expected for operators, compared to 10 to 20 MHz for UHF channels (Bertenyi, 2017). This can serve more users at once and may be needed for the business models that expect much denser populations of human users, possibly at faster data rates, or, IoT machine users.

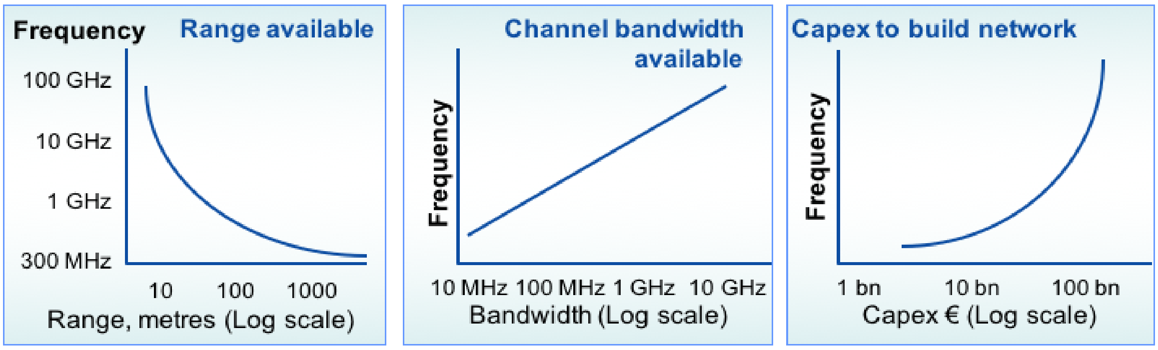
- **Shorter range, more interference and indoor penetration:** A radio signal's effective range reduces in proportion to the square of the frequency. That has major impacts on the capital cost of the cellular radio network. Although many 5G networks currently being piloted will use the much lower bands, those upper frequencies being proposed for the future may offer propagation ranges only in the order of hundreds or even tens of metres. Higher frequency signals are also subject to more interference from weather – rain, snow, fog – and obstacles - wet foliage or buildings and their walls. This means that, at higher frequencies, indoor use may be problematic if based on through-wall or window penetration. Consequently, re-use of the existing UHF bands and also those just above in the 3-10 GHz range ("mid-range") are emphasised today, to give 5G signals greater range with fewer technical challenges.

1.4. Implications of Network Densification

The implications of the trends above should be understood in terms of network economics, which are dictated by the signal propagation characteristics. A shorter range implies more base stations and higher cost as indicated in Box 1.

Box 1: Physics Controls the Economics of 5G

The diagrams indicate trends in terms of order of magnitude only – not exact figures.



Signal propagation range decreases as the frequency increases, with the square of the frequency. So more base stations are needed to cover a given area as the cell size shrinks. Consequently capital expenditure for the network goes up as cell radius decreases. However, at the higher frequencies, more spectrum is unused today and this wider channel bandwidth can give higher data speeds and serve many more users, be they people or machines such as connected cars in traffic flows.

With higher frequencies and shortened ranges, base stations will be more closely packed into a given area to give complete coverage that avoids "not-spots". Ranges of 20-150 metres may be typical, giving smaller coverage areas per "small cell". A cell radius of 20 metres would imply about 800 base stations per square kilometre (or small area wireless access points (SAWAPs), the term used in the European Electronic Communications Code (EECC)). That contrasts with 3G and 4G which use large or "macro" cells. Traditionally they offer ranges of 2-15 km or more and so can cover a larger area but with fewer simultaneous users as they have fewer individual channels. The concept of SAWAPs has been used with LTE for not-spot filling to some extent in cities such as Amsterdam and Singapore, but not on the scale envisaged for 5G.

This dense network rollout will be costly, not just in terms of installations, but, also in the costs and delays in obtaining planning permission and any authorisation. So, for urban coverage with 5G small cells, it would be sensible for the EU member states to simplify and harmonise their authorisation permits and planning permission processes, to enable a standard EU approach to densification:

- Small cell standards are needed to give the EU a way forward for high quality outdoor and indoor cellular connectivity to support a light-touch regulatory regime, essential to ensure rapid rollout of perhaps hundreds of small cells per square kilometre
- In practical terms, major efforts will include installer training and certification on a large scale
- Aesthetic objections solved via satisfactory designs and installation practices.

The EECC tries to address this with various measures (principally Article 57).

1.5. Denser Network Costs Might Drive Shared Infrastructure

In the current uncertain financial state of the global telecommunications industry, the calls for new and major investment are none too welcome, especially one with tentative business models – and thus unclear overall costs and returns. As a consequence, the mobile cellular industry is now grappling with different technical and commercial solutions for the arrival of small cells for 5G.

Thus, 5G may trigger alternative infrastructure ownership models, either sharing both physical networks and spectrum, or by separation of services and the network, so players may choose either the networking layer or services (Marti, 2019a). Such revised business models may introduce the concept of "neutral hosts" – third parties owning and operating networks and shared licensed spectrum as alternatives to the current models of infrastructure competition (Small Cell Forum, 2017). The concept of a specialised 5G network operator/owner, supporting all service providers in a neutral fashion has been entertained by the largest operators globally (Grijpink, Härlin, Lung, and Ménard, 2019). Whether the business model depends on such neutral hosts or a lesser form of that with an operator-owned shared network infrastructure is unclear.

1.6. 5G Standards are Still to be Finalised

While technical standards for the next generation of mobile radio services are not yet finalised, the EU, USA, China and other countries are still planning to be the first to deploy a working commercial network. Initial specifications for the 5G networking standard from the ETSI/3GPP SDO were released in 2017, but the rest of this first 5G standard, 3GPP Release 15, appeared in September 2018. It supports 28 GHz mmWave spectrum and MIMO antenna array technologies. Thus 2019 will be a key year for working standards, from ETSI/3GPP endorsed by the ITU, where 5G is termed International Mobile Telecommunications for 2020 (IMT-2020). Three spectrum ranges are under discussion:

Table 1: The Main Frequency Bands for 5G Standards Taken up Globally

Frequency Band	Frequency Range	Countries/Regions	Comments
Low Band	<1 GHz (UHF) usually 600/700 MHz	EU, USA, India	Current favourite as longer range, so less costly infrastructure and more familiar technology
Mid Band	3-5 GHz (above UHF)	EU, Korea, Rep., China, India with USA at 2 GHz; China and Japan in 2020	More spectrum available, with compromise on range and performance
High Band	20-100 GHz	EU, USA, Korea, Rep.; in 2020 - China, Japan, India	Short range (10-150m), high speed, low latency

Source: Bertenyi, 2017; authors.

Also, the major MNOs across the world are expecting complete versions of post-prototype equipment in 2020, including a range of handsets. However, the above ranges do not encompass all possibilities. China, for instance, is currently backing 2.6 GHz for 5G (Handford, 2019), which may influence other countries.

In the EU, the Radio Spectrum Policy Group (RSPG) favours the 3.6 GHz band (3.4-3.8 GHz), the 26 GHz band (24.25-27.5 GHz) and the existing EU harmonised UHF bands for mobile services, below 1 GHz, such as the 700 MHz band and above in the UHF range, in its third opinion (RSPG, 2018).

Agreement on standards for spectrum may be reached at the World Radiocommunication Conference (WRC-19) in October-November in Sharm El Sheikh). It should determine the use of particular spectrum bands for 5G in each of three global regions for the next four years and beyond. In preparation for WRC-19, formulation of regional positions is first carried out. The working groups under CEPT ECC PT-1 have the responsibility for the EU's spectrum proposals for the WRC. Current developments on spectrum harmonisation for 5G in Europe still require more effort, and proposed bands include the 3.6 GHz and 26 GHz bands. Across the EU there are also national strategies in view of preparations for WRC-19, with EU Member States focused on the 3.6 GHz band but also the 27.5-29.5 GHz bands.

3GPP Release 15 supports high speed video-enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC) and massive machine type communications (mMTC). It completes the end-to-end specification with definitions for working handsets. Those will be used by the likes of Apple, Samsung and others. Various versions of the processors and hardware will now be built and marketed, such as the radio modems and processor chipsets from ARM, Intel, Apple, Samsung Qualcomm, etc. The first small cell base stations, from suppliers such as Nokia, Ericsson and Cisco, will also be based on this norm.

Release 15 supports what is termed New Radio (NR), which is the radio air interface for two of the main frequency ranges that 5G will use. These are Frequency Range 1 (FR1) below 6 GHz and far higher frequencies in the centimetric and millimetric ranges, or Frequency Range 2 (FR2) in what is termed the mmWave range (Bertenyi, 2017). 5G NR also supports a configuration for the pilot trials, called the non-standalone mode. It is based on LTE for the Core Network, with a 5G RAN and a 5G handset. The standalone mode is the full 5G implementation, with the 5G Core Network and 5G handsets.

The next 3GPP 5G standards contribution, Release 16, is for the IoT applications in smart cities, massive machine communications and connected vehicles, etc., and is expected in December 2019 or early 2020 for handover to the ITU working groups for endorsement. 3GPP has approved the non-standalone (NSA) in December 2017 and the 5G standalone (SA) standard in January 2018 to complete Release 15.

From past experience, completion of the full 5G standards can be expected over the next decade, in several further releases. But the full extent of the radio technology will only be delivered if, and only if, the technology is taken up by the vertical sector industries that could use it and the business models employed are more than that of the mobile operators today.

1.7. 5G Electromagnetic Radiation and Safety

Significant concern is emerging over the possible impact on health and safety arising from potentially much higher exposure to radiofrequency electromagnetic radiation arising from 5G. Increased exposure may result not only from the use of much higher frequencies in 5G but also from the potential for the aggregation of different signals, their dynamic nature, and the complex interference effects that may result, especially in dense urban areas.

The 5G radio emission fields are quite different to those of previous generations because of their complex beamformed transmissions in both directions – from base station to handset and for the return. Although fields are highly focused by beams, they vary rapidly with time and movement and so are unpredictable, as the signal levels and patterns interact as a closed loop system. This has yet to be mapped reliably for real situations, outside the laboratory.

While the International Commission on Non-Ionizing Radiation Protection (ICNIRP) issues guidelines for limiting exposure to electric, magnetic and electromagnetic fields (EMF), and EU member states are subject to Council Recommendation 1999/519/EC which follows ICNIRP guidelines, the problem is that currently it is not possible to accurately simulate or measure 5G emissions in the real world.

2. 5G DEPLOYMENT IN LEADING COUNTRIES

This chapter reviews the status of 5G deployment in those countries and economies considered to be most advanced in their plans for 5G – the USA, China, Japan, the Republic of Korea, Singapore and Taiwan.

2.1. USA

The plans of the major four MNOs – AT&T and Verizon, as well as Sprint and T-Mobile – will determine the USA's progress in 5G for the next five years. They are quite diverse in terms of what they term "5G", their business models, rollout schedules, and which parts of the spectrum will be used. Only prototype handsets have been available but first consumer models are expected in 2019.

All MNOs have started trials of 5G technologies and equipment, with commercial launches planned by the end of 2019. The Federal Communications Commission (FCC) held a high-band spectrum auction (i.e. above 10 GHz) in November 2018, but it is unclear when mid-band spectrum (i.e. above the UHF band from 3 GHz - 6 GHz) will be made available. By early 2019, sixteen states had enacted legislation to enable small cells to be deployed more easily.

Verizon: In October 2018 Verizon launched "5G Home", claimed as the first commercial 5G service, over its proprietary 5GTF network standard. Speeds range from 300 Mbps to 1 Gbps, depending on location. It offers Fixed Wireless Access (FWA) broadband for home connectivity in parts of four large cities, with more in 2019. The service tariff is $70 per month or $50 per month for existing customers.

Independent field testing of the 5G network in Sacramento revealed 5G Home coverage of around 10% of the city (Dano, 2019). However, the FWA technology used is a pre-standard version, likely to be replaced when 3GPP standard equipment is available. Verizon's network is based on the 28 GHz spectrum for which it holds a licence. This band suits rapid data downloads but not coverage of large areas. Verizon claims a range of about 300 m from transmitter sites and potential customers' locations, but field tests showed it was about half this. Since 2017, Verizon has been testing mm-wave 5G service in 11 cities (in Ann Arbor, Atlanta, Bernardsville, Brockton, Dallas, Denver, Houston, Miami, Sacramento, Seattle, and Washington, DC). It demonstrated a 5G video call at the 2018 Super Bowl and a 5G NR data lab transmission with Nokia and Qualcomm in February 2018. In June 2018, Verizon tested two-way data transmission and multi-carrier aggregation and very high speeds outdoors. In August 2018, Verizon with Nokia succeeded in transmitting a 5G NR signal to a moving vehicle, using spectrum in the 28 GHz band in a New Jersey trial. Then in September 2018, it completed testing 5G transmissions to a test vehicle in Washington, at 28 GHz, using a 5G prototype core network with Nokia 5G radio equipment. It also transmitted 5G signals in commercial trials in Washington, DC and Minneapolis with the prototype user devices for its 5G NR network.

T-Mobile USA: In contrast, while T-Mobile is not ignoring high-band frequencies, it does not want to waste its vast 600 MHz spectrum investment. To demonstrate that mmWave bands are not a prerequisite for 5G, T-Mobile's latest 5G demo, opened in January 2019 operating at 600 MHz. It is targeting early 2019 for its commercial launch. The MNO expects the FWA (fixed-wireless access) coverage based 5G to offer 100 Mbps data rates for up to two-thirds of the US population in the next 5 years and cover 90% of the USA by 2024 (European 5G Observatory, 2019). The 600 MHz band will be the carrier for launch and first rollout, with 28 GHz and 39 GHz bands in a second stage. Their strategy is to demonstrate high speeds with a broad coverage early and corner the US market.

At the January 2019 Consumer Electronics Show in Las Vegas, it announced making the first data and video calls using the 600 MHz band. Using the latest 5G New Radio (NR) standard from 3GPP, running over an experimental 5G setup designed and created in collaboration with Intel and Ericsson (Bosnjak, 2019), integrated with the company's live commercial (LTE) network. T-Mobile also confirmed a successful tri-band video call leveraging its latest technologies, for three users connected via three different spectrum bands – 600 MHz, 28 GHz, and 39 GHz. Thus, T-Mobile is to expand capital expenditure for its 600 MHz 5G rollout in 2019, by 6%, from $5.8 billion in 2018 to $6.1 billion in 2019 (TelecomLead, 2019).

T-Mobile signed two $3.5 billion contracts with Ericsson and Nokia in August 2018 to support this nationwide 5G NR network deployment. Under the contract, Ericsson will provide T-Mobile with its 5G NR hardware and software, as well as Ericsson's digital services software for management. T-Mobile has also announced target cities for *mobile 5G* launch by 2020 in Dallas, Las Vegas, Los Angeles and New York City.

AT&T: on 21 December 2018, AT&T was the first in the USA to announce a 3GPP standards-based mobile 5G launch, for a commercial network. It planned to launch 5G services to 12 cities by the end of 2018. Interestingly, despite its pilots, AT&T remains reserved about 5G for fixed wireless access (FWA). Further rollout will be in 2019, for 19 additional cities. Its technology partners include Ericsson, Samsung, Nokia and Intel for its four city-wide trials performed since early 2017, on FWA and mobile 5G (European 5G Observatory, 2019), demonstrating its first mobile 5G device using mmWave spectrum as well as the "first mm-wave mobile 5G browsing session".

In addition, AT&T has been offering its own form of 5G that has caused some controversy, termed 5G+ but which is essentially an upgrade of LTE. AT&T proposes the Netgear Nighthawk 5G Mobile Hotspot device to run on AT&T's 5G+ network but over mmWave spectrum rather than UHF. Controversially, it has branded its LTE network as 5G Evolution or 5G E, a clear example of the hype surrounding 5G (Reardon, 2019).

AT&T is also proposing 5G hotspots for the dense urban areas of 12 cities and to extend to parts of seven other cities in 2019. In the home, the Netgear Nighthawk 5G Mobile Hotspot device (or "puck") will run on AT&T's 5G+ network over 28 GHz mmWave spectrum. Customers outside the 5G+ network coverage will be able to use the device for the best received local mobile network such as AT&T's 5G Evolution LTE network (with carrier aggregation). Note that the early 5G customer equipment and tariff plan is not cheap. The initial cost of a Nighthawk hotspot device is $499, with a15 GB data plan contract for 5G costing $70 a month.

Sprint: a much smaller MNO, it has planned a commercial launch in the first half of 2019. Customers for its mmWave network in nine target cities should have their first 5G smartphone from LG of Korea by mid-2019. It tested 5G in the 2.5 GHz range for the dense environment of the Atlanta Super Bowl in 2018, with a software upgrade for pilot smartphones. Sprint has the most 2.5 GHz spectrum of any MNO in the USA, and proposes to re-use it for both LTE and 5G, in city centres, via massive MIMO, so it can leverage its current macro cell sites and towers (Alleven, 2018). Sprint is still discussing a proposed merger with T-Mobile USA, hoping to combine its 2.5 GHz 5G network for city centres with T-Mobile's 600 MHz network for rural and suburban use, with future centimetric bands near 26 GHz, and higher, for dense urban settings in the future.

Conclusion

The USA is moving towards some form of rollout of mobile broadband as 5G but not necessarily in a holistic, well-orchestrated operation. It is more a set of ad hoc commercial manoeuvres. Some of these are simply rebranding existing LTE, rather than delivering novel networks. Re-use of the LTE spectrum in the UHF ranges (300 MHz to 3 GHz) is significant. The latter decision is probably warranted by its geography of large rural spaces and high density urban centres situated more on the coasts. Thus, the insistence for 5G on high centimetric bands (25–30 GHz and higher) is probably less justified than for the dense conurbations of Asia and the EU.

A significant challenge concerns the administrative local barriers to small cell rollout. The need for many small cells implies long delays and high costs. Local regulations continue to prevail despite the FCC's mandate on a light-touch regime and minimal permit costs. This has led to a wide divide between local and central government on the principles of having to obtain permission for rollout and the charges for that. Local administrations, especially in the larger municipalities, are at loggerheads with the FCC (Zima, 2018). Several court challenges are being made to the FCC mandate of August 2018 that overrides local objections to a "one-touch" regime.

2.2. China

China has invested in a 5G national action plan to orchestrate its industry R&D and deployment efforts through central government support. Its 5G investments have been organised since 2015 at national level through the three state-owned mobile operators – China Mobile, China Unicom and China Telecom. A broad commercial launch of 5G by 2020 is aimed at in the country's latest Five-Year Plan and China's telecoms operators are automatically committed to such targets. In December 2019, operating licences for 5G were issued to all three MNOs.

A spokesperson for China's industrial policy administrator and national regulatory authority (NRA), the Ministry of Industry and Information Technology (MIIT), has confirmed plans to accelerate the commercialisation of 5G technology, with work on further radio frequency plans for 5G licences. *China Daily* quotes Vice Minister of industry and IT, Chen Zhaoxiong, as saying that MIIT is stepping up its efforts to promote the maturity of 5G technologies and is aiming to create a complete industrial chain to create a strong foundation for the commercial exploitation of 5G.

Although the minister stopped short of providing a specific timetable for 5G licensing, MIIT has previously said that it expects to issue 5G licences in the second half of 2019 (TeleGeography, 2018). In June 2017, MIIT invited public comment on the planned use of the 3.4-3.6 GHz and 4.8-5.0 GHz spectrum bands for 5G technology. During this process, MIIT noted potential disruption of existing services, principally radio broadcasting, satellite earth stations and also radio astronomy. Simultaneously, it also opened a consultation on use of mmWave spectrum in the 24.75-27.5 GHz centimetric and 37-42.5 GHz millimetric ranges for 5G services. In March 2018. MIIT told local media that the government expected to issue commercial 5G licenses in the second half of 2019. Moreover, MIIT might distribute specific rights for the necessary spectrum early to facilitate a timely rollout of 5G networks (TeleGeography, 2018a). In January 2019, the MIIT announced temporary 5G licences in various cities for the first 5G networks using prototype equipment (Shen, 2019).

Thus, China's government is opening significant amounts of both mid-band and high-band spectrum, beginning with low centimetric bands (3-30 GHz) and millimetric (30-300 GHz). The key spectrum bands are most probably 3.4-3.6 GHz and 4.8-5.0 GHz, but in its latest deliberations, 2.6 GHz is also being assigned. China's regulatory authority has committed to release at least 100 MHz of mid-band spectrum in the 3.4-3.6 GHz range for each MNO but some 2 GHz of the higher-band spectrum for each MNO. MIIT has final allocation of frequencies planned for the second half of 2019. Under China's state planning, auction status is unclear, as the granting of licences to incumbents is more usual.

China's assignment of spectrum for 5G is also unique – in that different bands are being assigned to each of the three MNOs by MIIT. China Mobile (the current market leader) could benefit most, being awarded 2515-2675 MHz and also 4.8-4.9 GHz bands. This 2.6 GHz band is typically a 4G band and also could be for 5G, with longer range than the higher frequencies, lowering the cost of a new network.

China Telecom received 3.4-3.5 GHz and China Unicom was awarded 3.5-3.6 GHz (Handford, 2019). The latter bands are commonly being seen as leading frequencies for 5G, in the EU and elsewhere. Moreover, each MNO in China has a different date for its prospective commercial launch, with 2019 for China Mobile, but sometime in 2020 for China Unicom and China Telecom. However closer analysis reveals four other crucial influences on the 5G rollout programme:

- The research effort called for under the 5G initiative has a much longer timeframe –to 2025 and beyond to 2030 for the final developments – because the technical challenges are considered to be so significant. These may demand rethinking some basic premises of mobile technology theory. China Mobile's 2016 presentation of the reworking of the whole mobile model (Blackman and Forge, 2016) indicates a number of significant highly technical hurdles, ranging from rethinking antenna engineering for dynamic MIMO beamforming to the basic cellular model and Shannon's theory of communications capacity.
- The mobile operators do not control physical rollout for 5G. That is under the control of China Tower, the largest mobile base station site operator in the world with some 1.9 million transmitter sites already (currently UMTS and LTE macro cells). Migrating to 5G will involve deploying between 66 million and 164 million small cells in China (Wu Chao Zhe and Yu Hai Ning, 2017)) for the kind of short-range small cells envisaged for 5G.
- China has significant problems with indoor coverage, as a result of the relatively low national RF EMF limits it has set. RF EMF maxima are set low for health reasons. Thus, it needs 5G for better indoor coverage and not just the business models put forward as the conventional 5G applications (faster multimedia, connected vehicles and IoT applications). 5G could meet this need if densification increased considerably over the current levels for LTE/UMTS. There are other impediments for China. For example, there is a lack of trained personnel in consideration of the magnitude of the rollout task. Chinese authorities are thus preparing large-scale training courses for a new generation of technicians for the small area base stations.

Overall investments are expected to be high and for the long term, to 2030, with at least Y200 billion (about €26 billion) per year. China's Academy of Information and Communication Technologies, which is the research arm of the Ministry of Industry and Information Technology, expects investment between 2020 and 2030 in domestic 5G networks to reach Y2.8 trillion (about €370 billion) (Bien, 2017).

Political, Economic and Security Issues May Slow China's Advance

All of China's MNOs have conducted extensive 5G trials and committed to 5G commercial launches. Data from CCS Insight suggests the Chinese market is likely to be the biggest for 5G by 2022. However, there are other political and economic influences on the development of China's 5G technology that may tend to slow its advance considerably. They are related to the national status of the key equipment manufacturer and China's technical R&D lead in 5G, Huawei (Financial Times, 2019b). The lingering security concerns of the EU member states, principally France, Germany, the UK and Poland as well as the USA and Japan have stalled its endeavours to participate in the largest commercial rollouts for 2020. The USA seems mostly concerned about breaking of economic sanctions through sales of equipment to Iran and the Democratic People's Republic of Korea, as much as theft of intellectual property – and not just the security concerns over procurement. The EU member states are more worried about the insecurity aspects of its core network equipment, the radio access network, and any 5G smartphones. This export restriction may tend to slow its progress in 5G, so advances in terms of the technical know-how, component design, manufacturing economies of scale and practical rollout experience gathered globally will be restricted.

Conclusion

Taking the longer-term view of China's investment plans, Huawei's problems (and its main Chinese rival, ZTE which faces the same issue) and the internal situation of upgrading its indoor reception as the main role for 5G, China may lead the world eventually. But that could be between 2025 and 2030. Overall for the various reasons cited above, a slow rollout is expected, perhaps beginning later in 2019.

2.3. Japan

The government adopted a 5G roadmap in 2016, following pilot trials since 2014 and is committed to releasing more spectrum. The Ministry of Internal Affairs and Communications (MIC). Has committed about $300 million to promote 5G and future technologies, such as IoT, robotics, etc (European 5G Observatory, 2019). Concrete plans for auctions are yet to be announced, but commercial operations are proposed for 2020, with allocation of 5G spectrum in Japan expected in spring 2019 (European 5G Observatory, 2019). Key spectrum bands are yet to be confirmed but may include 4.5 GHz, 28 GHz, 39 GHz and 90 GHz (TeleGeography, 2018b). The MNOs are focused on widespread deployment ahead of the 2020 Olympics and so pilot trials have taken place. Hence, Japan expects its first commercial rollout in the second quarter of 2019 (Milne, 2019).

A trial by NTT DOCOMO with NEC employed beamforming coordinated between two base stations containing 128-element antennas was announced on 30 May 2018. They claimed the world's first successful 5G communications, and noted a 5.5 Gbps throughput, for the trial with eight users having prototype 5G handsets. The pilot demonstration in Kawasaki City used inter-base station coordination in the 4.5 GHz band to control the beamforming (TeleGeography, 2018b). Other NTT DOCOMO trials have used 28 GHz.

For future development, MIC plans to commercialise 5G services for the Tokyo Olympics and Paralympics in 2020, and is still deciding on which bands will be distributed to the country's mobile network operators. The three incumbent MNOs, NTT-DOCOMO, SoftBank and KDDI, have been using a range of spectrum bands to support their 5G tests, including the 4.5 GHz band (DOCOMO, SoftBank and KDDI), 28 GHz band (DOCOMO, SoftBank and KDDI), 39 GHz band (DOCOMO), and 90 GHz band (DOCOMO) (TeleGeography, 2018b).

Pragmatism on 5G is Now Evident as Challenges Become Apparent

However, more recently following its pilots, some of Japan's MNOs are taking a more pragmatic view of the technical challenges of 5G, publicly drawing attention to the various difficulties. At the European 5G Conference in Brussels in January 2019, Takehiro Nakamura, the VP of NTT DOCOMO and also general manager for the company's 5G laboratories, said, "We have provided the dreams of 5G but we need now to explain the reality" (Marti, 2019). He went on to say that many of the MNO's partners apparently seem to "have a misunderstanding of 5G" and so he emphasised the need for the mobile industry to offer a much more realistic view of early 5G deployments:

- Following the 5G trials that NTT DOCOMO has been involved in, he highlighted the two key misconceptions: coverage and performance. While some believe 5G will be available everywhere, he thought that most people know this will not be the case. The first rollout of 5G will only be in densely populated areas.
- To compensate for the lack of contiguous spectrum, all spectrum bands are needed, i.e. at low, medium and high frequencies.
- 5G network latency will vary, depending on the conditions of each network and the distance to the terminal – and it is it is vital to explain this to vertical industries.

- Most notably, these points highlight the essential role that LTE will continue to play.

Mr Nakamura emphasised a difference with some industry announcements which insist that there will be a 10 Gbps data rate everywhere with a one millisecond latency.

Conclusion

Japan began its experimental trials of 5G in 2014 and so has nearly five years of understanding of the practical challenges. Consequently, the recent attempt to reduce the hype is interesting and it also echoes the views from China – that the technology will take much longer to come to fruition than previously thought.

2.4. Korea

Korea's centrally planned industrial policy for ICTs demands an early adopter profile to support hi-tech exports, so its industry and government are now positioning to try to lead in commercial 5G offerings, for global sales. To support the early launch of 5G mobile services, spectrum bands in the 3.5 GHz and 28 GHz ranges were auctioned in June 2018 (TeleGeography, 2018c). Enabling this required direct government intervention, to open up the main spectrum bands needed. Moreover, the Ministry of Science and ICT (MSIT) promised "unlimited" tax benefits to MNOs if they worked together to launch 5G and shared a common network. Samsung had previously said it would have 5G hardware available for the carriers so they could begin initial 5G transmissions in December 2018, with full commercialization in March 2019 (Horwitz, 2018).

In February 2018, Korea's Winter Olympics pilot demo was a focal point for early 5G investment and trials by the MNOs, such as KT, which showed its network for 20 Gbps with latency under 1 msec and aiming for over a million devices per sq km. It was intended to serve the public and user sectors, such as Hyundai, with an autonomous vehicle, while chipset vendor Intel trialled its high resolution 8K video over the KT network. That introduced 5G base stations with active MIMO antennae, fibre-to-the-antenna to reduce latency in the base station, microwave line-of-site backhaul in mmWave bands with diverse routing for reliability, plus testing of mmWave operation.

The commercial 5G launch was originally planned for March 2019, with all the MNOs – SK Telecom, KT Corp and LG Uplus – participating in a single 5G rollout so all are equally at risk. The MNOs even agreed to launch on the same day (a date imaginatively called "Korea 5G Day"). However, Korea has now been practising with pilots for a year and has the experience from its LTE introduction of perfecting its offerings in the home market before successfully launching globally. In a somewhat surprising move, following that agreement on the shared rollout date, SK Telecom, LG Uplus and KT launched their 5G service in a number of cities much earlier, on 1 December 2018. But initially these offerings are only for large business customers in some cities. Thus, the operators appear to have accelerated rollout, or at least their marketing, based on their first limited initial test transmissions, to make a more serious impact – possibly guided by the administration, ensuring Korea could claim first place with a real 5G offering (not the non-standard 5G offering from Verizon or the renamed LTE offering from AT&T that the USA claims).

Prototype services are available in some parts of Seoul, Busan and five other cities. However, it should be noted that the 5G deployment in December 2018 was not for smartphones as the 5G-equipped mobile devices be released in April 2019. For the December launch, the three wireless carriers planned to deliver 5G services first by using routers – devices that enable connection to Wi-Fi devices. The 5G services for smartphones is due to be available in March 2019 (Mendoza, 2018).

Naturally the largest Korean company, Samsung, will also participate, with its large-scale integration (LSI) business to make the chipsets for 5G. Samsung would prefer that the 28 GHz spectrum, in which it is stronger than in 3.5 GHz, will be the basis of 5G standalone (SA) deployments early (in 2019 and 2020) to give it an advantage over Huawei. The conglomerate hopes to benefit from its new range of radio modem chips and IoT sensors for 5G (Cho, 2018), to sell in large volumes to industries that will be open to a next generation of 5G products.

Conclusion

In many ways, Korea's 5G motives are quite different to those of other countries. Its aim is to perfect its 5G equipment offering, especially in chipsets. Those LSI substrates for the software-defined radio modem, RF integrated circuits and MIMO antenna chips could be the foundation of every 5G base station and 5G smartphone, both for their own smartphone sales (Samsung, LG, etc) but also to sell to every other smartphone vendor, including the Chinese and Taiwanese. In some ways, the country acts as a laboratory for its export initiatives. For that reason, Korea is progressing rollout for the first quarter of 2019 (Milne, 2019).

2.5. Singapore

The Info-Communications Media Development Authority (IMDA) is orchestrating the 5G effort in Singapore in a specific direction – towards those vertical industry sectors that are the main drivers of its economy – high technology manufacturing (semiconductors and digital device manufacture and assembly), technical services such as aircraft maintenance and financial services. IMDA will regulate and facilitate 5G rollout in these areas. It is supporting 5G development with targeted pilots in laboratory conditions on campus sites such as factories and industrial zones, as the first step, in which the vertical sector, the equipment suppliers and the local operators participate. That began in 2017 with a public consultation to which stakeholders, such as the government-owned MNO Singtel, replied in detail. The stakeholders are asking for support in licence agreements, extra spectrum and availability of sites for small cells, all of which IMDA is engaged in supplying. Thus, Singapore has a centrally organised 5G initiative based on government backing with quite specific goals for 5G as an industrial support infrastructure. It does not expect completed standards and full commercialisation before 2020 and so is preparing for that.

The consumer segment is not considered in this plan. Instead various densification efforts using small cells are in hand, using existing technologies, with some extensions for sharing licensed and unlicensed spectrum oriented to the incumbent licensed carriers. Small cell infrastructure expansion of the existing mobile network for crowded urban locations is based on Wi-Fi and LTE technologies. It is being deployed in metro stations, shopping malls, pedestrian precincts, and so on. Essentially, Singapore is rehearsing for a future densification with 5G small cells.

A key partner is Singtel, the incumbent operator, majority owned by Temasek, Singapore's sovereign wealth fund. Singtel jointly established a centre of excellence (CoE) for 5G development with Ericsson in 2017. The CoE targets a wide 5G deployment in Singapore beyond 2020 focused on applications for smart cities, IoT, autonomous vehicles and sister projects. A modest cofunding by Singtel and Ericsson of S$2 million (about €1.3 million) over three years is the initial investment for a first pilot, part of Singapore's 5G mobile network infrastructure to support its future *Smart Nation* initiatives.

To encourage pilots, no permits are needed, if it facilitates 5G technology and service trials by industry in Singapore. Also, IMDA is waiving spectrum licence fees as the aim of such trials is to assist the industry to better understand how 5G will work in a real-world environment and the potential benefits for different sectors. 5G trials may utilise the existing IMDA Technical Trial ("TT") and Market Trial ("MT") framework. Generally, TTs may be conducted for the purpose of equipment testing and R&D for any telecommunication service, while MTs may be performed to assess the commercial potential of a new technology, service or product that is not commercially deployed or offered in Singapore. As such, TTs must be on a non-commercial basis.

Singtel, with Ericsson, were the first to showcase 5G in South East Asia, demonstrating the world's first end-to-end low latency networking in 2016. To enable this, IMDA made available some 15 spectrum bands from 1427 MHz up to 80 GHz specifically for 5G (the 800 MHz band is excluded). The aim of current experiments in the mmWave bands is to understand the propagation characteristics and performance of higher frequency ranges for 5G deployment. To facilitate trials, all of the bands in the frequency range above 6 GHz that will be potentially harmonised internationally for 5G are to be made available by IMDA.

Singapore's first 5G pilot was tested at the end of 2018 in an initiative driven by Singtel and Ericsson at the Singtel Comcentre. The pilot was demonstrated with drone and autonomous vehicle technologies tested, using Ericsson's 3GPP standards compliant 5G technology. The trial's spectrum was allocated by IMDA for the pilot network which can deliver 5G coverage with enhanced Mobile Broadband (eMBB) speeds and low latency. Currently Huawei is also present in Singapore for 5G network tests (Reichart, 2018), partnering with the MNO M1.

Conclusion

In many ways, Singapore, although a unique commercial and managed innovation environment, is a more useful yardstick for the EU than the USA or China. It is more relevant especially as the target of this technology is the dense urban centre. It balances existing UHF technology and 5G in a way that looks at business cases pragmatically, rather than in a hopeful "build it and they will come" syndrome.

2.6. Taiwan

Taiwan is investing in 5G with its own strategy for 5G and its rollout. It is driven by being a global centre for semiconductor manufacturing, so it must keep up with the demands of its integrated circuit design customers (such as Apple, MediaTek, Qualcomm, etc) for new types of digital signal processors for 5G plus 5G's high frequency radio modem circuits, as well as planning for its own improved national broadband network. Most importantly, that can be used as a proving ground for the prototype chipsets. The government has shut down both its 2G and 3G networks as its coverage of the island territory with LTE is complete. The market is not expecting 5G licences to be released until 2020, so a timetable for rollout is unclear.

The incumbent operator of mobile and fixed line communications, Chungwha Telecom (CHT) contracted with Nokia and Ericsson to partner in its trial 5G networks. The objectives of the trials are to gain a better understanding of real world capabilities, and so to contribute to the national strategy for 5G with an accelerated adoption. Two initial 5G pilot networks have been built to test different specific features of 5G. In the CHT-TL stadium project, with its high user density, massive MIMO antennae are being examined. In contrast, 5G's mobility is being evaluated on a high-speed railway, the Qingpu (Small Cell Forum, 2018). These pilots are using 5G NR in both the 3GPP non-standalone (i.e. with LTE core network) and standalone modes in the 3.5 GHz and 28 GHz bands, plus coexisting with LTE in the 1.8 GHz and 2.1 GHz bands.

Smart city 5G projects are being pursued by the Taipei City Government, in a public-private partnership (PPP) with the incumbent, CHT, in urban test beds at multiple locations such as the Taipei International Convention Center, the Taipei Music Center and the Xinyi District, with smart surveillance. These areas are where an initial pre-commercial 5G service may be deployed in the second half of 2020.

On the technology supply side, Taiwan's R&D efforts are directed at its semiconductor industry. Taiwan government funding will be aimed at R&D for products such as 5G chipsets, complete smartphones, small cell base stations, cloud self-organising networks, software-defined networking, edge computing, etc, destined for applications such as connected cars and smart cities. Vertical sector 5G projects, e.g. for factory automation systems, are being explored.

Conclusion

Taiwan depends on its major ICT suppliers for economic success and technical leadership, and so, like Korea, views 5G as a technology to be sold globally. Hence, Taiwan has to invest in its own 5G infrastructure so that it may use it as a learning tool. It is one part of its industrial strategy for leading in global exports. Taiwan may lag Japan and China in field testing but its prowess in the latest semiconductor manufacturing will assure its presence in supplying several of the key components for base stations and handsets. Its industrial strategy is often to subsidise key industries in promising fields to catch up and overtake, but to delay making major investment until demand is more certain. TSMC is already producing the first 5G radio modems and the Qualcomm 5G system on chip processor. This may be the preparation stage for global export drive, in expectation of significant global demand from 2020.

3. COMPARING THE EU WITH OTHER LEADING COUNTRIES

3.1. Summary of EU Progress

With the adoption of the EECC in December 2018, a connectivity objective has been added to the regulatory framework, which includes the availability of uninterrupted 5G coverage for urban areas and major terrestrial transport paths. All member states must now clear the 5G "pioneer" frequency bands (700 MHz, 3.5 GHz and 26 GHz) and reassign them by the end of 2020. However, it is unlikely that all countries will meet this target. Currently, nine member states have published their 5G actions plans – Austria, France, Finland, Netherlands, Spain, Sweden, Germany, Luxembourg and the UK (European 5G Observatory, 2019). Europe has been prominent in the number of 5G trials that have taken place, with some 138 trials across all 28 member states recorded by early 2019. However, according to the European 5G Observatory, only 7% of 5G pioneer spectrum has been assigned. The Observatory's scoreboard notes that 82% of the 700 MHz band, 87% of the 3.5 GHz band and over 96% of the 26 GHz band remains unassigned.

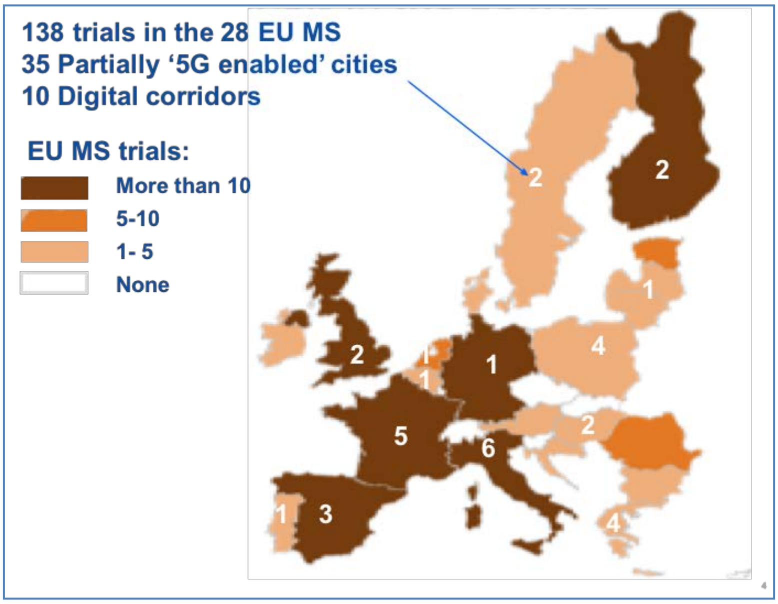
3.1.1. 5G Trials Cities

The 5G Action Plan prepared in September 2016 was finally confirmed by the EU Council in December 2017. This aims for a trial commercial 5G rollout by 2020 in one major city in each member state – termed the 5G Trials Cities. Candidate cities were requested to announce their own plans for 5G trials and pilots. By the end of August 2018, a non-exhaustive list of at least 35 Trials Cities was made, which included Amsterdam, Aveiro, Barcelona, Bari, Berlin, Bristol, Espoo, Ghent, L'Aquila, London, Madrid, Malaga, Matera, Milan, Oulu, Patras, Prato, Stockholm, Tallinn and Turin, with, in France, nine major regional cities: Belfort, Bordeaux, Douai, Grenoble, Lannion, Lille, Lyon, Marseille, Nantes, Sophia-Antipolis et Toulouse. Three additional cities joined in August 2018: Aveiro, Bristol and Ghent. A total of at least 45 Trials Cities is expected, as future expansion will include Paris and perhaps 10 cities in the Paris suburbs including Châtillon, Linas-Monthléry and Saclay. The role of 5G Trial Cities is to host the technology and demonstrate the service, gathering vertical sector use cases. Cities, as public entities, usually have different interests even in similar use cases, compared to the private sector. Cities will focus more on e-health, energy, transport, smart buildings and digital service portals with overall focus being on the smart city concept. Such trials should take in the impacts of the real user environments of cities. Maximum involvement of local ecosystems and residents are key priorities.

3.1.2. Digital Cross-Border Corridors

For live testing of real-time 5G connectivity in Cooperative Connected and Automated Mobility projects, ten "digital cross-border corridors" have been established. As a flagship use case within the European 5G vertical strategy, Connected and Automated Driving (CAD) is now being considered for 5G deployment along European transport routes. The long-term aim is to create complete ecosystems around vehicles, going beyond the safety services currently targeted by the Cooperative-Intelligent Transport System (CITS) roadmap of Europe. The EU's overall readiness is summarised in Figure 1.

Figure 1: The 5G Trials and Initial City Pilot Rollouts



Source: European 5G Observatory, 2019.

3.2. Ranking of EU against Other Countries

In comparing national or regional progress in 5G, in terms of technology, deployment and acceptance by investors and by the public, a pragmatic assessment depends upon whether the objective of the country or region is to be a user, producer or both:

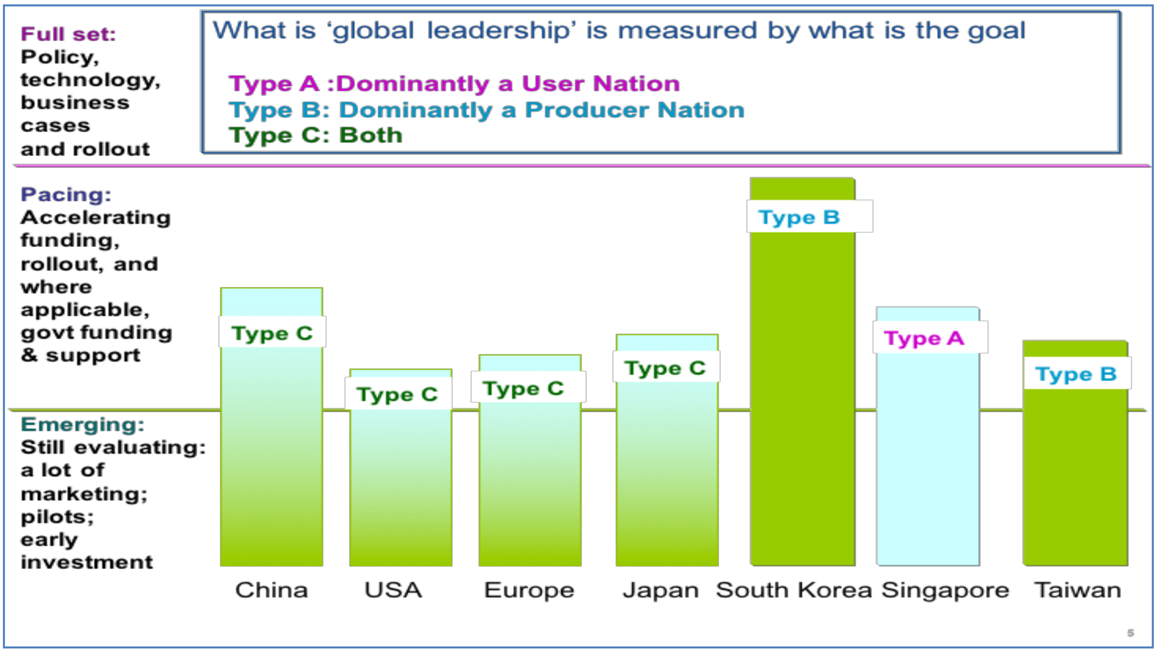
Type A: The User Nation. These countries are consumers of technology, largely from elsewhere, and so the focus is on broadband services at low cost. The driving force may be the government in applying 5G for other industries, under its industrial policy, or the commercial drive of the national operators.

Type B: The Producer Nation. Success is measured in terms of global sales of key 5G products: semiconductor components, equipment, and software. Rollout of a national 5G network is directed by national industrial policy as an early proving ground to test products against global competition.

Type C: Both. The aim is to both develop networking equipment and chipsets for sale globally and also to rollout the technology internally for local broadband services. There may be different degrees of each capability and government intervention and role may vary considerably**.**

On this measure, the EU is performing quite well, for reasons of its economic structure, although it is still early days for what promises to be a ten-year rollout for 5G. First, Europe has two of the major network equipment producers in Nokia and Ericsson, who hold about 50% of the global telecoms equipment market as well as some core patents. Some important semiconductor suppliers (e.g. ARM, NXP) are located in the EU, even if owned now by Japanese, US or Chinese investors. Also, the EU hosts the key institution for 5G international standards, ETSI/3GPP, which means that Sophia Antipolis is at the centre of intelligence for the technologies, standards and patents behind them. Consequently, in Figure 2, Europe ranks near Japan but below China. The reasons for the pattern shown are also partly the result of four market forces, which are examined below.

Figure 2: Ranking 5G Development across the Globe Based on Multiple Criteria



Source: Authors.

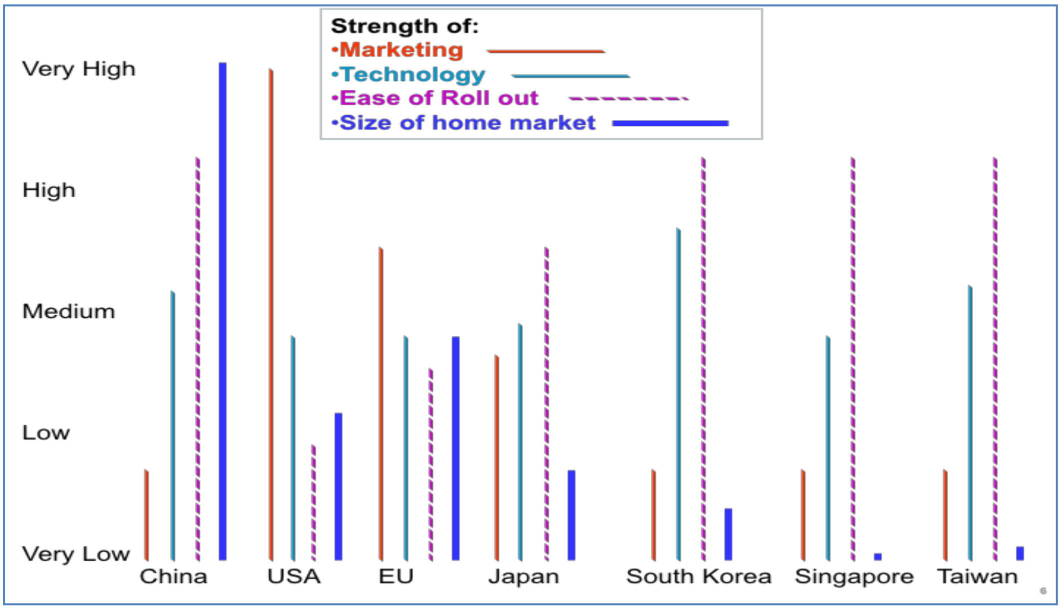
3.2.1. Factors for 5G Success

The ranking takes into account not just technological progress but also practical factors associated with 5G deployment. After technology capability, the key factor will be the ease with which a large number of small cells can be deployed in densifying the network. China and the Asian Tigers have an advantage here because their political structures and culture mean that they can mandate deployment without the need for public assent. In contrast, deployment of small cells in the USA will have to overcome legal challenge at municipal and state level in response to the FCC's proposed light-touch regulation. The driving presence of a government in a command economy, with political power down to local authority level, offers significant competitive advantage. In response, in line with EECC Article 57, the EU is crafting a regime for SAWAP deployment, aiming for permit-free installation from 2020.

A third factor concerns the scale and who is the driving force behind the 5G campaign. The level of marketing activity is key, with intense lobbying of governments by equipment suppliers and operators – and also of the public by governments. A fourth factor is the size of the home market. It needs to be of a critical size to support the first versions of local 5G products, and also for national market testing to improve them, before global promotional launches. For instance, 50% of Huawei's sales in 2017 were in its home market, giving its leading global position (Fildes, 2019a).

These factors are summarised in Figure 3. In terms of the critical technologies for 5G, it is Korea and Taiwan who hold the leading positions in integrated circuit (IC) technologies, processes and plants. They are being pressured by their governments to expand. Thus, in Korea, the second largest player after Samsung, SK Hynix, is setting up new production centres, investing $107 billion for four new plants, for both RF circuit and memory chip production plus a production complex for 50 of its ecosystem partners (Jung-A, 2019). By investing quickly and on a massive scale, SK Hynix and Samsung aim leave the Chinese IC plants, which have older technology, out of the new 5G market. Thus, Korea's interests are served by fast rollout of 5G networks to perfect its 5G chipsets in the field.

Figure 3: Factors Shaping the 5G Market – Comparing the EU with USA and Asia



Source: Authors.

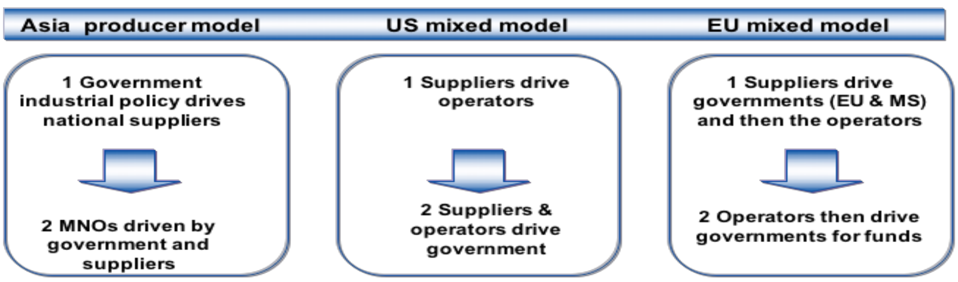
3.2.2. 5G and Different Models of Industrial Strategy

There are broadly three main actors in the 5G initiative – first, governments who can invest, then suppliers and operators. The drivers for politico-economic position between these three players consists of a trio of components ranked in order of impact, based on examining industrial strategy to manage innovation for growth:

- The strongest driver – government industrial policy to stimulate national or regional industry
- Secondary driver – supplier pressure on the MNOs and then on governments
- Subordinate driver – operator acceptance of a sound business case and the need to invest.

Analysis shows three models of 5G promotion and financing – that of the EU, a different version for the Asian producer nations, and a unique form for the USA, as shown in Figure 4.

Figure 4: Operating Models for Funding Promotion for 5G



Source: Authors.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1.1. Funding the 5G Project

Since the 5G endeavour is being driven primarily by the equipment suppliers, it is not surprising that there is a significant marketing campaign underway. This industry effort is reinforced by its long tail supply chain – semiconductor components, software, managed operations and equipment suppliers – that together serve the major operators.

In mobile telecommunications, it is the MNOs who have come to dominate the networking revenue streams with online access as the main growth revenue source. However, the market has become increasingly saturated and revenues are in decline. In dense urban settings, 5G broadband possibly could reinvigorate their fortunes, via increased smartphone traffic mostly feeding Internet platforms' online services (social networking, entertainment video streaming, gaming, etc). It might also enable the MNOs to build new revenue streams in IoT applications for industrial users.

Consequently, the aim of the equipment vendors is to encourage the MNOs to invest in another round of network infrastructure for broadband. Equipment suppliers are a traditional source of operator borrowing, so that equipment is purchased in instalments using future revenue to pay. However, the suppliers' market value, revenues and profits – and thus their own ability to borrow, or to fund new networks from working capital – has declined recently. At the same time, the total market value of the EU telecommunications operators fell from €234 billion in 2012 to €133 billion in 2018 (Fildes, 2019b). All this means that there is less money available for operators at a time when their market value and share price has fallen. They claim the cost of capital is too high (Genish, 2018) and certainly the banks do not have the surpluses that were available for, say, 3G in 2000.

The MNOs globally are considering the fallout from an inevitable increase in the demand for new infrastructure and its finance. The options open to them include delaying investment in a new 5G infrastructure for as long as possible, and/or eventually converging their suitable existing core networks when upgraded, with new a 5G radio access network, to economise on the backhaul capital investment. The only alternative is to seek other sources of investment and the state is the only source with sufficient capital left. Thus, the 5G campaign has to convince governments that the social and economic benefits justify the enormous cost and, hence, the numerous studies forecasting trillions of Euros in value to the economy and the creation of millions of jobs.

4.2. How Does the EU Compare with the Rest of the World?

In broad terms, the EU compares reasonably well with other leading countries. It is certainly not lagging significantly behind technically in comparison with the USA, China and other Asian countries and, indeed, possesses some key strategic strengths, e.g. the EU is host to equipment manufacturers Nokia and Ericsson, and the key 5G standards organization, ETSI/3GPP.

Despite the hype around 5G, the benefits in terms of economic stimulation from new services and products in GDP and employment will not be seen in any country for some time. There is a growing recognition, especially in Asia, that 5G will need much more time to perfect before comprehensive rollout, perhaps with a ten-year timeframe. China has previously called attention to this and China Telecom at the Mobile World Congress, in February 2019 noted that 5G will cost three times more than previous generations (Streaming Media, 2019). Japan has implied this with recent emphasis on understanding the real depth of the challenges. 5G may happen more slowly than many in the industry may think.

A pragmatic assessment of 5G suggest that the marketing campaign too often ignores reality:

- First, while not the strongest driver, the lack of convincing business models, in Europe and elsewhere, is notable.
- On the technical side, the rush to use frequencies in “mmWave” bands (20-100 GHz) for early 5G is not borne out in the majority of deployments so far. Instead it is the much lower frequency UHF band (300-3GHz) or just above it at 3.6 GHz (the “mid-band”) that is gathering attention in Japan, USA, China as well as Europe. The advantage is a much greater propagation range with radio technology that is more familiar than for higher frequencies in centimetric and millimetric bands. Lack of clarity of financial returns in technology costs and network capital costs are the consequence.
- The consequence is that the level of enthusiasm in the operators is less than it might be, if there were established technology ready to go and offer proven returns. Those who have to invest are unsure of the business case for solid revenues.

The hesitancy of the operators may be measured in terms of anticipation of rollout before 2020. Comparing the EU with Asia and the USA, a survey of CTOs show mixed feelings:

Table 2: Timeframe for 5G Rollout

Timeframe	Percentage of CTOs in telecommunications operators expecting rollout in their region		
	EU	USA	Asia
Short-term: before 2020	11	56	40
Mid-term: before 2022	78	44	40
Longer-term: 2022-2025	11	0	20

Source: Grijpink, Härlin, Lung, and Ménard, 2019.

The USA is outwardly more optimistic, setting off with pre-standard equipment. But in their 5G operating model, as illustrated above, this would be expected, as part of their 5G industry’s modus operandi of being more dependent on marketing. Europeans seem to be the most pessimistic in the very short term while it is Asia that tends to see 5G as a longer-term project, of at least 10 years.

4.3. Recommendations Ranked According to Their Likely Impact

Taking all of the analysis into account, the following recommendations are intended to improve the likely long-term success of 5G in the EU:

Recommendation 1: Increasing R&D efforts on the technology of 5G

Long-term technology research is essential. One key problem is the unusual propagation phenomena, especially controlling and measuring RF EMF exposure with MIMO at mmWave frequencies for the handset and the base station. The technology presents challenges to the current level of expertise (based on previous generations of mobile cellular radio engineering) both for suppliers and standards organisations who must incorporate the specifications in future 5G standards.

Recommendation 2: Revisiting 5G business models

More detailed study of business models is needed to better define the goals, scope and revenue sources, with a more diverse range of players than just incumbent operators. This is essential for logical EU investment, attracting outside investment and policy setting for an efficient use of resources for EU-wide infrastructure. The enterprise market, perhaps with IoT, may be the main user.

Recommendation 3: Promote infrastructure sharing for 5G

Policy for 5G networks should be based on encouraging infrastructure sharing with separation of infrastructure and services. This could be fundamental to the financing model for 5G networks to provide widespread coverage for the Digital Single Market.

Recommendation 4: Lightweight regulation for SAWAPs

The EECC supports the use of large numbers of (standardised) small area wireless access points (SAWAPs), which is really aimed at small base stations for 5G, typically for dense urban environments. Developing an EU-wide framework for their permit-free deployment in all member states will become essential.

Table 3 ranks these recommendations according to their likely impact, but note that they interact and their relative priority could change. In summary, the recommendations in terms of a) new policies and/or b) amendments to existing actions are:

Table 3: Recommendations Ranked According to Their Likely Impact

Recommendation	Ranking
Long-term technology research to solve multiple propagation unknowns with the new technology (e.g. measuring and controlling RF EMF exposure with MIMO at mmWave frequencies)	1
Detailed study of business models to better define goals, scope and revenue sources, with a more diverse range of players than the incumbents	2
Policy for 5G networks based on encouraging infrastructure sharing and separation of infrastructure and services	3
Continued efforts for EU-wide agreements for permit-free rollout of small cells across all member states	4

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This in-depth analysis was prepared by Policy Department A at the request of the ITRE Committee. It compares 5G deployment in the EU with other leading economies – the USA, China, Japan, the Republic of Korea, Singapore and Taiwan. On a range of indicators, the EU compares well. However, this is not a short-term race. 5G is more complex than previous wireless technologies and should be considered as a long-term project to solve technical challenges and develop a clear business case.

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