New Direction

THE 5G CHALLENGE

STATE OF PLAY IN EUROPE AND DEPLOYMENT

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New Direction

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CONTENTS

1	INTRODUCTION	7
2	HISTORY	11
3	THE 5G CONCEPT	15
4	RESEARCH ON EMF AND 5G EFFECTS ON HUMAN HEALTH	25
5	THE STATE OF PLAY IN THE EU	29
6	BUSINESS MODELS AND BOTTLENECKS	37
7	CHALLENGES IN 5G	45
8	FUTURE AND CONCLUSIONS	51

1

INTRODUCTION

The concept of a fifth generation of mobile telecommunications (5G) has attracted a great deal of interest in the telecommunications industry over the past five years. It has also captured the imagination of politicians, governments, policy makers, regulators because of the promise of the next generation of mobile communications that will finally bring broadband internet wirelessly, seeding new jobs, new consumer and professional services and whole new market. However, as is common with advances in technology, there is a need to look beyond the industry hype to assess appropriate policy support.

In reality the underpinnings of 5G radio technology are extremely complex technically, and these complexities are still far from being resolved. Its basic operating premise is to use many more units, or cells, an architecture that has compromised mobile radio since the early 1990s, ever since the somewhat unexpected take-off of the first digital mobile telephony generation, GSM. The two generations of mobile cellular radio since GSM may be viewed as limited and only partially successful attempts to bring internet access to the mobile handset.

In general terms, the telecommunications industry sees 5G as the next global market that will serve smart consumer devices, with a major role to play in enabling the Internet of Things (IoT). The key question, however, is whether 5G enables services that consumers – business and individuals – are willing to pay for. In this regard, the 5G initiative in Europe, as well as globally, has so far failed to assess objectively the future needs of consumers.

Revenues for the mobile industry, comprising both the equipment suppliers and mobile network operators (MNOs), are dwindling. The industry has invested considerably in the last generation, LTE/4G, but has yet to see a full and healthy return. One of the reasons for falling revenues and profits is competition from direct internet access for Over The Top (OTT) services (for example, Skype and WhatsApp) that undercut revenues from mobile cellular video and voice conversations and conferencing. Consumers access OTT services through Wi- Fi/fixed broadband when they can, avoiding expensive cellular LTE. So, although we are seeing an explosion in demand for mobile data traffic, that does not necessarily imply that consumers will pay to receive this via an expensive new cellular infrastructure.

The main attraction of 5G is that it has the capability to support superfast broadband – perhaps up to 100 Gbps at higher frequencies. Theoretically, therefore, 5G could:

- Carry streaming IPTV from the internet in an “always-on” mode, which neither the mobile industry with LTE can provide the capacity for, nor can the customer-base afford at the price required by the MNOs.
- Harness very high spectrum bands, up to 70-100 GHz where there is little competition from other users, although the range would be in metres, rather than kilometres.
- Be used for the IoT, although most industrial applications need coverage across very long distances at very low cost rather than high bit rates. Much of the IoT will need data speeds at less than 1 kbps (that is, a million times less in bit rate and bandwidth than 5G).

On the demand side, pressure is mounting for better wireless infrastructure, which could come from Wi-Fi for nomadic users. Today’s fibre optic cable broadband rollout has been patchy, expensive, slow with unreliable performance, and fibre rollout to rural areas has often been just too expensive. A real alternative to fibre and xDSL to the premises could be broadband over radio, either mobile, or fixed radio access. But unfortunately this is where 5G could have limitations, because it may well be primarily just an urban technology.

This is because the availability of licensed radio spectrum used by 4G, mostly below 3 GHz, is in great demand and becoming more expensive. A federal auction in the USA in 2015 raised $45 billion. As a result, the targets for some proponents of 5G (but by no means all) are today's relatively sparsely employed spectrum bands from 6 GHz to 100 GHz for tomorrow's radio-based economy. But there is a major penalty since the distance of transmission shortens non-linearly with frequency, which means many more but much smaller cells, making 5G application untenable except in densely populated areas. Consequently the telecommunications industry finds itself in a Catch-22 situation: in making the case that 5G needs large amounts of licensed spectrum, it has to accept that this can only be found at very high frequencies, but using these frequencies will mean that consumer demand will be much more limited.

An alternative perspective is that 5G's potential sophistication means that raw bandwidth will continue to be replaced by ever-higher power computer processing. That is the kernel of 5G technologies – lots of processing power at low cost. The argument that 5G needs huge amounts of spectrum may not be clear cut, and its spectrum needs may even gradually reduce if advances in its signal processing (effectively its use of spectrum) progress continually and its software defined radio is constantly updated.

POLICY SUPPORT FOR 5G TECHNOLOGY DEVELOPMENT

From the examination of 5G in the following chapters, the key question is whether new policies should be envisaged for 5G technology and markets and, if so, where they should be focused. Perhaps surprisingly, in view of our scepticism of the 5G phenomenon, our analysis does point to 5G having a potentially important role to play for the EU economy. This reflects a slightly different and wider view of what it comprises, more towards how the concept is understood in some Asian countries.

Despite the uncertainty surrounding business models for 5G, explored in detail in Chapter 3, there is justification for certain types of public support for the development of the most advanced radio telecommunications innovations, which are described in Chapter 1. The justification for this is that the evolution from current radio technologies proposed under the classification of "5G" may be used far more widely than just for a small cell broadband network for streaming entertainment video in some dense urban locations.

Consequently, targeted support from Europe for 5G development is warranted, and is outlined in Chapter 4. While there is much to commend the Commission's approach, greater emphasis should be placed on the demand side – what do consumers and industry need and which potential 5G applications are likely therefore to be in demand? Beyond this, the ultimate goal for 5G is to build the future European communications infrastructure and this is a long-term R&D project that will also require a new approach to spectrum policy. Thus Recommendations are proposed for:

- More precise definition of goals and scope for a 5G industrial policy
- Planning long-term technology research for a new communications infrastructure
- Spectrum policy for 5G based on spectrum sharing
- Identification and support for shorter-term 5G applications for small-cell networks.

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.

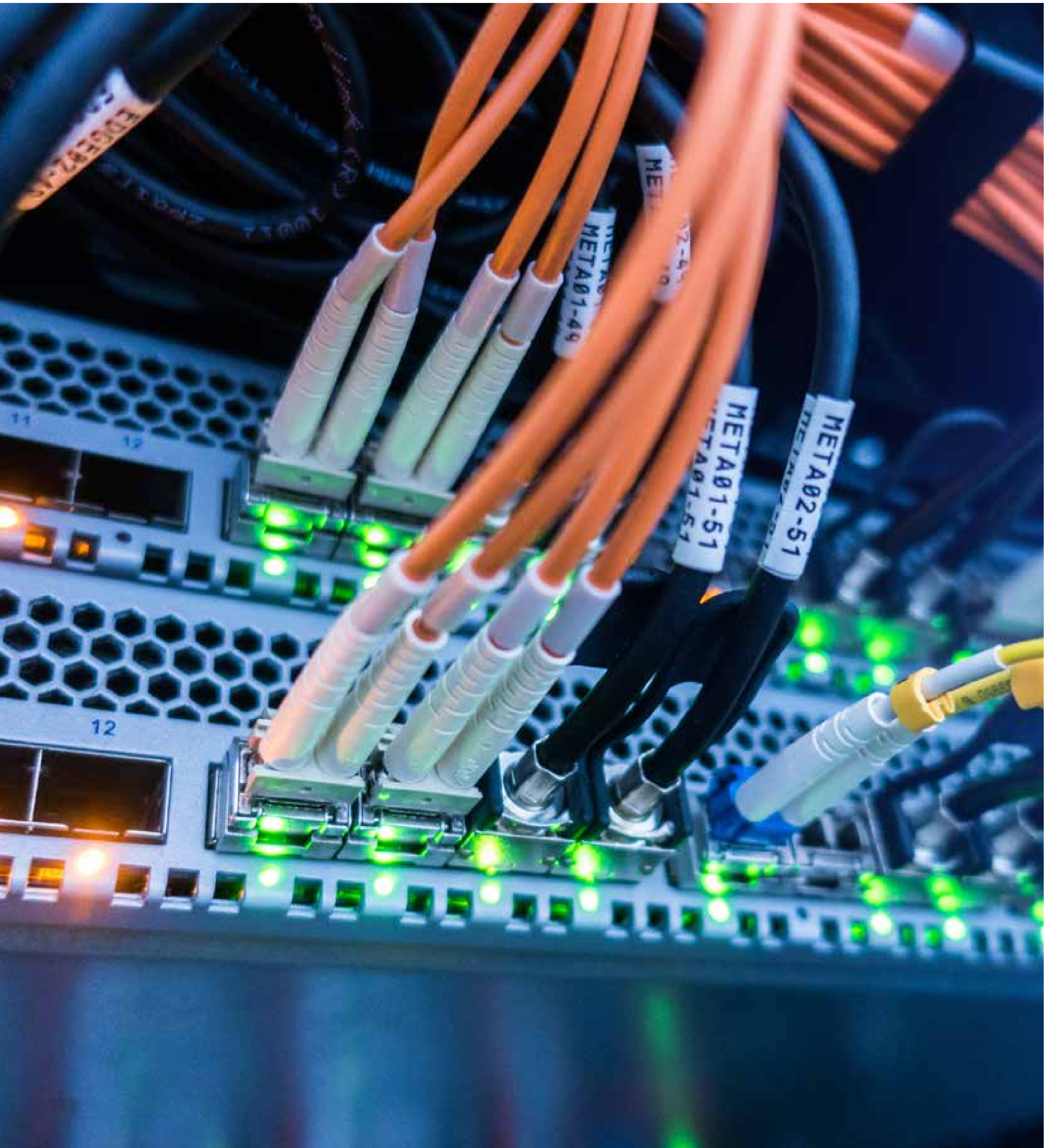
Most importantly, the current mobile network operator (MNO) led business model may be challenged by industrial users. Such users are unwilling to pay for expensive 5G for connectivity, especially for their IoT requirements such as manufacturing, and so new models may emerge for alternative forms of network 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.

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.



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HISTORY

FIRST GENERATION (1G)

In the early 20th century, Mobile radio communications were used in the military communications. Car based telephones was tested in 1946. This system used Single large transmitter on top of a high-rise building. A single channel was used like a half-duplex system was known as "Push-to-talk" systems in 1950. In 1960 IMPS (Improved mobile phone system) was introduced which can handle talk and listen at the same time. IMPS used two channels one for sending and one for receiving in telecommunications for a full duplex mode.

DAWN of Telecommunication: In 1970, private companies started developing their own systems to evolve existing systems further those private organizations were Analog mobile phone system(AMPS) were used in USA, Total access communication system(TACS), Nordic mobile telephone(NMT) used in parts of Europe and Japanese-Total access communication system(J-TACS) used in japan and Hong Kong. These systems were referred to First generation networks introduced in 1982 by BELL Labs popularly known as Advanced mobile phone system(AMPS).

The basic idea in AMPS was to use Geographic locations which can be treated as small cells and then can be used as frequency re-use which can support 5 to 10 times more users which was then referred to 1N IMPS (Improved Mobile Telephone System). The major concerns in 1G was weak security on Air Interface, Full analog mode of communication and no roaming.

SECOND GENERATION (2G)

Furthermore, to enable roaming formation of ETSI (European Telecommunications standards Institute) was created which was the beginning of 2nd Generation. The networks were commercially launched in 1991 at Finland based on GSM (Global System for mobile). Second Generation can deliver Data rates of up to 9.6kb/s. Major benefits were conversations digitally encrypted, more efficient on spectrum and greater mobile phone penetration and introduce data service(SMS). To generate higher data rates GSM carriers started developing a service called General Packet Radio Service(GPRS) referring to 2.5G. It was developed in 1995 and it mainly was packet switch network with GSM. GPRS can transmit data of up to 160 Kb/s**.** The phase after GPRS was Enhanced data rates for GSM Evolution (EDGE) referring as 2.7G in 1997. It introduced 8PSK modulation and can deliver data rates of up to 500 Kb/s using the same GPRS infra. During this time the internet was becoming popular 2.5G started growing and phones started supporting web browsing. This was an Internet boom in 1998.

THIRD GENERATION (3G)

This demand established 3GPP UMTS (Universal Mobile Telecommunications Systems) in 1999. This system uses wide band CDMA and this system was referred by W-CDMA (UMTS).

In 2000 3GPP Formation of governing bodies were developed. In interests of truly producing global standards. The collaboration for both GSM and UMTS were expanded further from ETSI to encompass its regional standards organizational developments such as ARIB and TTC from Japan, TTA from Korea, ATIS from America and CCSA from China. The successful creation for such a large and complex system specification required a well-structured organization. This gave birth to 3GGP which gave birth to the observation of ITU.

ITU-R manages the International Radio-Frequency Spectrum, Ensures the effective use of spectrum, defines technology families, allocate spectrum and proposed requirement for radio technology. Three organizations started developing to meet the requirements proposed by ITU-R is 3GPP, 3GPP2 and IEEE. The evolution of 3GPP started from GSM (Global System for Mobile communications), GPRS (General Packet Radio Service), EDGE, UMTS (Universal Mobile Telecommunications Systems), HSDPA (High-Speed Downlink Packet Access), HSUPA (High-speed Uplink Packet Access), HSPA (High Speed Packet Access), LTE (Long-Term Evolution) and LTE advanced.

The evolution of 3GPP2 started from IS-95, CDMA 2000, CDMA EVDO, CDMA EVDO REV A to CDMA EVDO REV B. The evolution of IEEE started from 802.16 FIXED WIMAX, 802.16 MOBILE WIMAX to 802.16M. Only 3GGP was dominated and widely accepted, this only incorporated Road map evolved by 3GGP Evolution.

The goal of 3GPP (UMTS) was to provide a data rate of 2 Mb/s for stationary/walking users and 384 Kb/s for moving vehicles. 3GGP designated as RELEASE 99. The upgradation was RELEASE 4 of 3GGP standard provided for the efficient use of all IP in core in the year 2001. This was the key enabler which laid foundation for HSPA.

In 2002, RELEASE 5 was introduced which was a core HSDPA. It provided the use for Downloading packet which provides a data rate up to 14 Mb/s by reducing latency (Delay). Further, RELEASE 6 was introduced which included the release of HSUPA in 2004 with a reduction in Uplink delayed enhanced link data rate of 5.74 Mb/s by reducing Latency (DELAY). This release also was the introduction of MBMS for Broadcasting services. Then further RELEASE 7 was introduced which also introduced MIMO and Higher order modulation of up to 64 QAM. Which evolved HSPA+ in 2007 providing Download link (D/L) data rates up to 28 Mb/s and Upload link (U/L) data rates of up to 11 Mb/s.

FOURTH GENERATION (4G)

Initially the goal of telecommunication was mobility and Global connectivity. The whole new architecture was evolved in LTE SAE (System Architecture Evolution) and Radio port. Long Term Evolution(LTE) standardization began in 2004 and in June 2005 RELEASE 8 was finally crystallized after a series of refining.

Important Features of LTE Release 8.

- Reduced Delays for both connection establishment and transmission latency.
- Increased User data throughput.
- Increased Cell-EDGE bit-rate.
- Reduced cost per bit, Implying Improved spectral efficiency.
- Simplified network architecture.
- Seamless mobility, indulging between different Radio-Access technologies.
- Reasonable power consumption for the mobile devices.
- These features made an advancement in radio technology.

Three fundamental technologies that have shaped the fourth-generation system in the radio technology interface were multi carrier, MIMO multiple Antenna technology and application of packet switching on radio interface. As a result of intense activity by a larger number of organizations. Specifications of Release 8 were completed by December 2007. The first commercial deployment of LTE took place in end of 2009 in northern Europe. The advanced LTE of Release 10, 11, 12, 13 in 2011, 2012, 2013 and 2016 were targeting Multicell HSDPA, HETNET, Coordinate multipoint, Carrier Aggregation and massive MIMO.

EVOLUTION OF FIFTH GENERATION

It's time to move from services to multiservice approach. The transformation will be moving from LTE to LTE Advanced and the features would be added as pervasive networks where users can be concurrently being connected to several wireless accessed technologies and seamlessly move between them.

Group Cooperative Relay: This technique is used to avail high data rates below over a wide area of a cell. Cognitive radio technology would enable the user equipment to look at the radio landscaping it is located to choose the optimum Radio Access Network, Modulation scheme and other parameters to configure to get the best connection in optimum performance. Smart Antennas will be redirected for better connection provided to the user.

Furthermore, 5G will leverage on the strengths of both optical and wireless technologies. 5G will be driven by software *Network Functions Virtualization (NFV)* and *Software-Defined Networking (SDN)*, IoT, IoE and Mobile Content Delivery Networks(CDN).

The 5G (Fifth Generation Mobile and Wireless Networks) can be a complete wireless communication without limitation, which bring us perfect real world wireless – World Wide Wireless Web (WWWW). 5G denotes the next major phase of mobile telecommunications standards beyond the 4G/IMT-Advanced standards.

At present, 5G is not a term officially used for any particular specification or in any official document yet made public by telecommunication companies or standardization bodies such as 3GPP, WiMaxForum, or ITU-R. Each new release will further enhance system performance and add new capabilities with new application areas. Some of the additional applications, benefiting from mobile connectivity are home automation, smart transportation, security, and e-books. IEEE 802.16 is a series of Wireless Broadband standards authorized by the Institute of Electrical and Electronics Engineers (IEEE). It has been commercialized under the name "WiMAX" (from "Worldwide Interoperability for Microwave Access") by the WiMAX Forum industry alliance.

IEEE 802.16 standardizes the air interface and related functions associated with wireless local loop. 5G mobile technology has changed the means to use cell phones within very high bandwidth. User never experienced ever before such a high value technology.

The 5G technologies include all type of advanced features which make 5G mobile technology most powerful and in huge demand in near future. For children rocking fun Bluetooth technology and Pico nets has become available in market. Users can also hook their 5G technology cell phones with their Laptop to get broadband internet access. 5G technology includes camera, MP3 recording, video player, large phone memory, dialing speed, audio player and much more one can never imagine [13]. In fifth generation, Network Architecture consists of a user terminal (which has a crucial role in the new architecture) and a number of independent, autonomous radio access technologies (RAT) [14]. 5G mobile system is all-IP based model for wireless and mobile networks interoperability. Within each of the terminals, each of the radio access technologies is seen as the IP link to the outside Internet world.

Figure 1.
Difference between all the Generations

GENERATION	1G	2G	3G	4G	5G
Deployment	1970/1984	1980/1989	1990/2002	2000/2010	2017/2020
Data Bandwidth	2 Kbps	14-64 Kbps	2 Kbps	200 Kbps	1 Gbps
Standards	AMPS	TDMA, CDMA, GPS, GPRS	WCDMA	Single unified standard	Single unified standard
Technology	Analog cellular	Digital Cellular	Broadband with CDMA, IP technology	Unified IP and seamless combination of broadband LAN, WAN and WLAN	Unified IP and seamless combination of broadband LAN, WAN and WLAN and WWWW
Services	Mobile Technology (voice)	Digital voice, SMS, Higher capacity packetized	Integrated high quality audio and video	Dynamic Information Access, Wearable devices	Dynamic Information Access, Wearable devices with AI capabilities
Multiplexing	FDMA	CDMA, TDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit and panel	Packet	All Packet	All Packet
Core Network	PSTN	PSTN	Packet network	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical

3

THE 5G CONCEPT

In his 2016 State of the Union address, President Jean-Claude Juncker highlighted the need for high-speed connectivity and the crucial role of 5G, the fifth generation mobile communication system, in empowering EU citizens and the economy.[1] This report examines the concept for 5G, how it might fit in the future telecommunications landscape, the state of play in R&D in the EU and globally, the possible business models and the role of standards and spectrum policy, to assess the EU's strategic position.

DEFINING 5G

5G is still being defined. Many analysts still see it as an "undefined" standard and concept despite at least three years of intense discussion. However, generally the term implies the next major phase of cellular radio communications technology for mobile, nomadic or stationary users. The general concept of the fifth generation of mobile technology is a set of multiple advances over preceding generations:

- Improved performance so the quality of experience for the user is significantly enhanced, with better signal strength, and fewer outages and interruptions. In principle delays in transmission (the latency) will be much reduced.
- Much higher bandwidth for each user, to create an alternative to fixed line access for a ubiquitous broadband radio channel for the general public.
- Use of smaller cells for much denser coverage, suitable for crowded urban environments where the majority of the population in many Member States now resides and works.
- Fewer problems arising from the lack of availability and cost of spectrum by accessing a range of frequencies outside the normal mobile bands (that is, the UHF range of 300 MHz to 3 GHz) as much higher frequencies are envisaged. Currently these higher frequencies are not used by commercial mobile cellular technologies so a wide range of scarcely used spectrum is available. Much wider channel bands could offer higher data transmission rates.
- New modes of use beyond 2G, 3G and LTE communications (for voice, SMS, limited data and video) such as machine-to-machine (M2M) applications for the IoT.

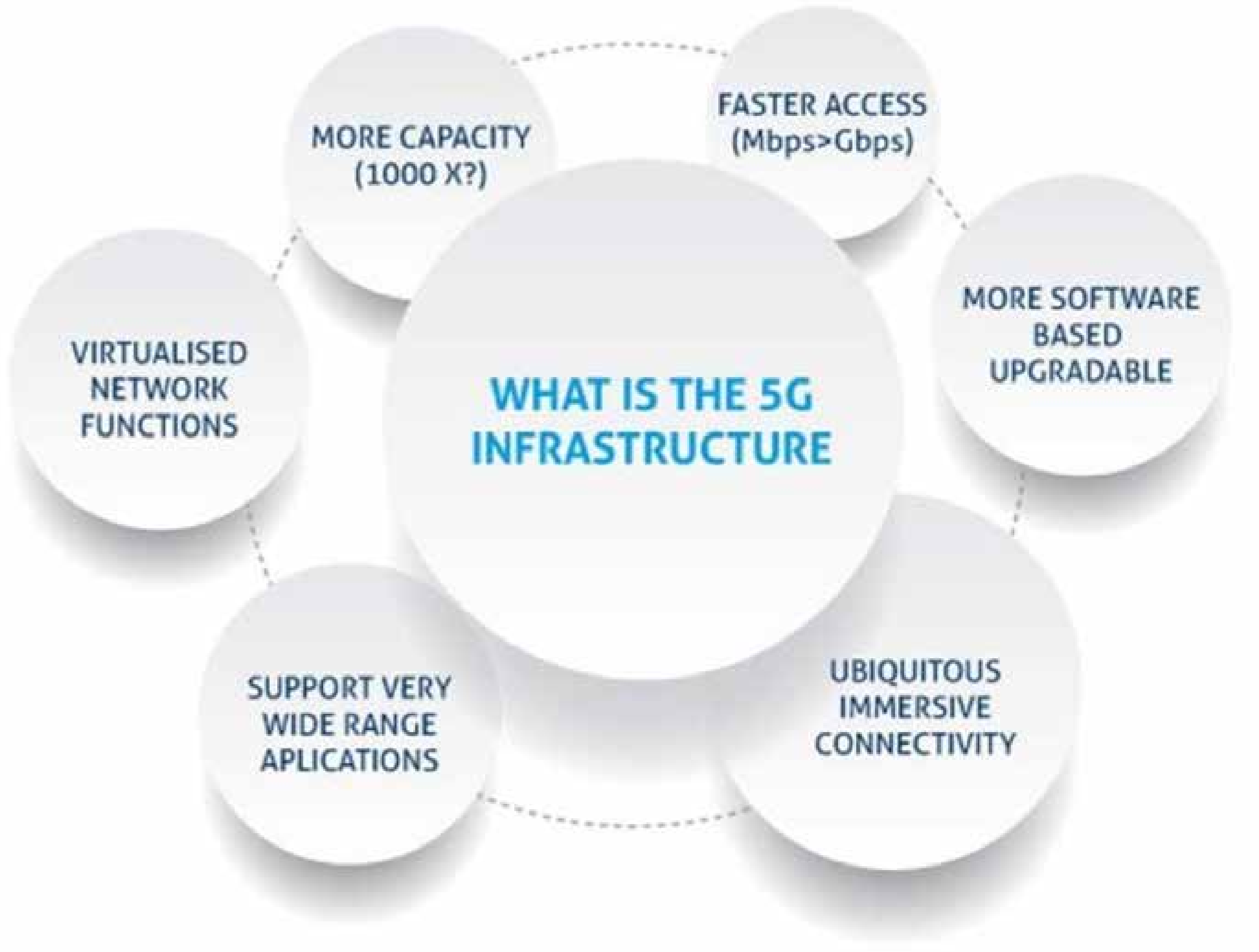
One view of the concept comes from the EU's leading 5G collaborative research initiative, the 5G PPP (public private partnership) with €1.4 billion of funding, which envisages 5G not just as a new network but as the next infrastructure (see Figure 1).

The 5G PPP is a joint initiative between the European ICT industry and the European Commission that aims to completely rethink the communications infrastructure by creating the next generation of communication networks. With a ten-year timeframe for its realisation, the 5G PPP sees the revolutionary network characteristics of 5G as:[2]

- Provision of 1000 times' higher wireless area capacity and more varied service capabilities compared to 2010.
- Saving up to 90% of energy per service. The main focus will be in 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 dense deployments of wireless communication links to connect over seven trillion wireless devices serving over seven billion people.
- Enabling advanced user-controlled privacy.
- Network operation via a scalable management framework that can enable fast deployment of novel applications, including sensor-based applications, with reduction of the network management operational expenditure by at least 20 percent compared to today.
- Lightweight but robust security and authentication metrics for a new era of pervasive multi-domain virtualised networks and services.

Figure 2.
5G PPP Vision of the Future 5G Infrastructure



Source: 5G PPP, https://5g-ppp.eu/about-us/

The ways in which 5G will be used – the use-cases – are still being explored. Moreover, yet to be defined are the basics of its operation – the technical standards, the air interface, which spectrum bands will be used and especially which network configurations would be optimal in a real deployment.

The most promising aspect of these advances is the provision of high-speed internet access for any mobile device. To offer this networking over a radio interface, much improved internet packet handling for high-speed data will be necessary as well as advances in signal processing, antennae and software defined radio front-ends in handsets and cellular base stations. For indoor working, various additional technologies are likely to be used to ensure that signal levels are maintained.

TECHNOLOGICAL DEVELOPMENT OF 5G AND COMPETING TECHNOLOGIES

Key developments can be seen in the technical presentations from companies such as China Mobile, Huawei and Ericsson, alliances such as the Small Cell Forum, and 5G research projects, such as METIS. In simplified terms they are:

- A next generation of network orchestration with all of the management and processing functions of the base station held in a cloud configuration – the network function virtualisation model (NFV) and optimisation of operations to suit local conditions with self-optimising networks (SON).
- Complex digital signal processing for Internet Protocol (IP) packet delivery (with the IPv6 addressing), possibly with cognitive radio techniques for dynamic spectrum access (DSA) with adaptive frequency selection.
- Possibilities of non-cellular modes of access with mesh networking between nodes, which may be devices as much as base stations.
- New antenna technology using steerable beams with arrays for better signal differentiation by employing directionality with higher signal strength. It may be possible to also use reflections in additive mode to increase signal quality.

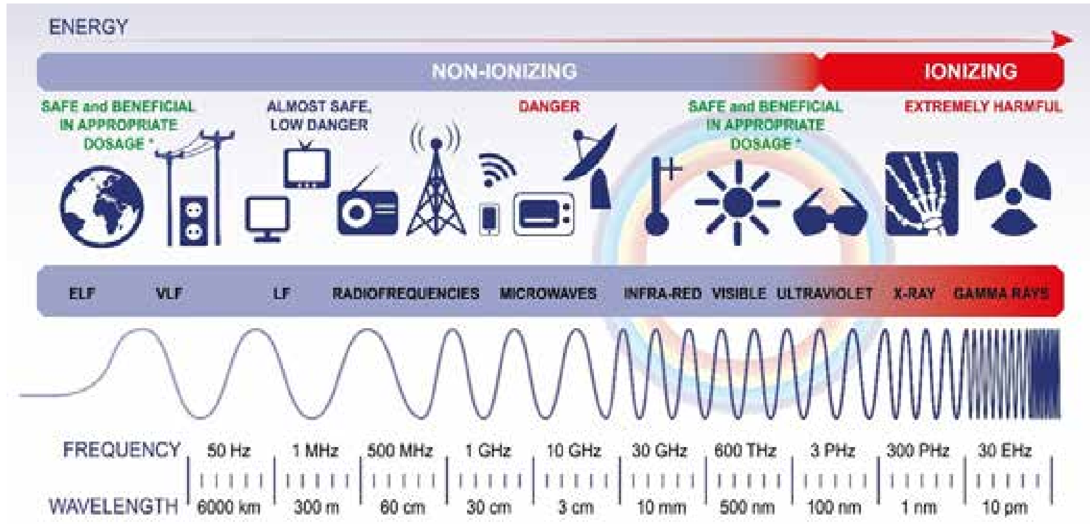
These advances can be grouped under three major headings that follow the 5G network architecture:

- Transformation of the core (or fixed) network functions in software defined networks, hosted in remote data centres to re-engineer the network and its switching paths
- Signal modulation and processing with far more adaptive, intelligent and sophisticated computing power, at low cost, locally in the base station, for new waveforms and discrimination for multiplexing
- A radio front end for transmission/reception which combines technologies for directional beamforming and spatial multiplexing.

DIFFERENCE BETWEEN 5G AND CURRENT TECHNOLOGY

Employing millimetre waves and higher frequencies than previous technologies, 5G needs a much more extensive network of antennas and other transmitting devices. Electromagnetic fields (EMF) are invisible areas of energy,[7] measured in hertz (Hz). Longer wavelengths with lower frequency are less powerful in terms of energy, while shorter wavelengths at higher frequencies are more powerful. Depending on the frequency, there are two categories of EMF: ionising and non-ionising radiation (see Figure 3).

Figure 3.
Electromagnetic spectrum



Source: Polina Kudelkina / Shutterstock.com.

Ionising radiation (mid to high-frequency) includes ultraviolet rays, x-rays and gamma rays. The energy from ionising radiation can damage human cells and cause cancer. Non-ionising radiation has lower frequencies and bigger wavelengths. Many experts are of the opinion that non-ionising radiation produces only thermal effects, or tissue heating, and that at high exposure levels, temperature-sensitive biological structures, including humans, and processes can become damaged.

Microwave and millimetre wavelength radiation is non-ionising. Millimetre wave ranges from around 10 to 1 millimetre. This is a very effective spectrum with large bandwidth, but it is also very sensitive to external variables and can be subject to interference from walls, trees or even rain.

For the first time, 5G will use millimetre waves in addition to the microwaves that have been used to date in 2G, 3G and 4G technology. Due to the limited coverage, to implement 5G, cell antennas will have to be installed very close to one another, which will result in constant exposure of the population to millimetre wave radiation. Use of 5G will also require new technologies to be employed, such as active antennas capable of beam-forming, massive inputs and outputs.[8] With higher frequencies and shortened ranges, base stations will be more closely packed into an area, to provide complete coverage and avoid 'not-spots'. This could mean possible ranges of 20-150 metres with smaller coverage areas per 'small cell.[9] 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 EECC). This contrasts with 3G and 4G technologies, which use large or 'macro' cells, offering ranges of 2-15 kilometres or more, and therefore covering a larger area but allowing fewer simultaneous users since they have fewer individual channels.

Furthermore, 5G will employ higher frequencies than previous 'G' networks and greater bandwidth which will enable users to transfer wireless data faster.

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:

Figure 4.
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;.

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.

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.

5G IN RELATION TO OTHER CONNECTIVITY OPTIONS

How will 5G fit in the future telecommunications landscape? It will complement as well as compete with other technologies. It could provide complementary high-bandwidth connectivity interfacing links for both fixed (with broadband fibre optic and xDSL) and with the other wireless bearers (Wi-Fi, Bluetooth and new IoT networks), as well as satellite, and line-of-sight laser beam connectivity with LI-FI.

5G's advanced configuration capabilities using virtualised network functions (NFV) and flexible shaping through its "soft" parameters enables its network hardware to mimic several types of networks simultaneously. It can thus optimise itself for a specific network application (the usual example is IoT though that may not turn out to be a major market for 5G). This capability for "network slicing" could also enable one base station to serve different operators and their different customer bases with different services. It may also enable a 5G network to act as the integrator of other networks:

- The main opportunity for 5G is as an element in the foundation of the next cellular or non-cellular infrastructure, including fixed-line services. As in today's 3G or LTE/4G core networks, a fibre optic long distance network would carry all communications, nationally and internationally. But 5G could provide the last kilometre or 100 metres connection of the "radio tail" into the customer premises. Thus 5G fixed links could replace all fixed cable local loops. For instance, the Verizon 5G Technology Forum (VGTF) is pursuing fixed radio links for a 2017 rollout, assessing 28, 37 and 39 GHz (Mumford 2016c). However, use of higher frequencies would could limit this model to dense urban and possibly denser suburban areas, where restricted distances between dwellings make indoor signal levels viable.

- Many projects are currently researching the potential of 5G to integrate different radio spectrum bands. One example is licensed assisted access (LAA) from Qualcomm, standardised by ETSI, to integrate LTE Advanced/4G with Wi-Fi for mobile broadband. This would amalgamate licensed and unlicensed spectrum, a form of carrier aggregation across radio networks for greater bandwidth. Certainly 5G could be combined in this way with Wi-Fi.

- 5G could also have more of a handover role between the two networks rather than just expanding available bandwidth, in that 5G may act as an access gateway for multiple Wi-Fi hubs or for calls from other mobile or fixed networks. Thus it could offer interconnectivity between mobile and Wi-Fi networks and specific hubs with minimal latency as well as backhaul access into the fibre optic long distance networks, for OTT services.

Alternatively, 5G could substitute some current telecommunications offerings, replacing:

- Fibre to the home (FTTH), as long as its penetration through brick, plaster and ferroconcrete is efficient enough to assure a strong signal at all points indoors. That attenuation is highly frequency dependent both for reception and transmission. The use of an indoor repeater may be necessary for certain buildings and operating frequencies. Moreover it could only act as the last kilometre or last 100 metres if the frequency were suitable for the range in question, that is, if the premises were not too far from the local base station.

- xDSL copper broadband connection to the premises, with the same caveats as to frequency, range and indoor penetration.

- Other cellular technologies in a static situation or perhaps mobile context, specifically 2G, 3G and LTE/4G, for voice, SMS and data connection. For mobile use, urban speed limits would tend to support reasonable vehicle tracking but very fast cell handover would be necessary because of the small cell size.

- Depending on pricing and metered charging plans, 5G technology could also challenge existing local in-premises networks, like Wi-Fi, possibly offering an indoor domestic local area network. That could be used to interconnect video devices to a home entertainment centre, at the video streaming peak data rates required. Also it could interconnect IoT appliance networks for refrigerators, washing machines, thermostats, and so on.

- Current fixed networks in special applications, such as vehicle wiring, because of 5G's promise of low latency.

APPLICATION AREAS FOR 5G

The industrial sectors expected to benefit most from 5G deployment include:

- *Entertainment industry* - high speed media content delivery for the last 100 metres or possibly up to a kilometre into the home or office for the local loop connection – this is the view of certain players, such as Verizon in the USA, to provide streamed Internet content, e.g. Netflix. Many entertainment TV content providers and the associated content distributors, be they cable operators, MNOs moving into broadcast entertainment or the broadcasters themselves could all be 5G infrastructure users.

- *Domestic video appliance industry* – for networking certain between video display devices in the home where high-speed data is a premium and the 5G data rates will be essential for home entertainment hubs. This is a form of IoT application, the most likely type inside the home.

- *Car and truck equipment* – for certain intelligent transport systems, specifically automotive applications for in-car services and between cars in fairly close proximity (up to 30 to 50 metres) for anti-collision services, automatic traffic management, rear and side view video, preventive maintenance and diagnostics, also in-car entertainment and navigation services.

- *Business internet*– more general internet content for social and business networking activities, i.e. a generic replacement for DSL and FTTH local loop networks.

- Building messaging and control – for indoor business networks needing to carry video, e.g. factory, hospital, warehouse as well as general building and campus surveillance and control.

- *The telecommunications chameleon* – The 5G infrastructure is also seen by the telecommunications industry as a flexible protocol broad highway along which many different lanes may run in parallel. Under the banner of network slicing, a "slice" of the 5G network could be used for a specific purpose, perhaps for much lower speed data and charged for on a proportional usage basis. This could be attractive for dedicated industrial networks that may have much slower speeds requirements.

GLOBAL 5G DEVELOPMENTS

Around the world many pilots and trials have been announced over the past two years and are now well under way for field test in 2017 or 2018:

- Vodafone and Huawei announced high-speed trials in July 2016 claiming to have reached 20 Gbps using MIMO (multiple input, multiple output) in the 70 MHz band. The trials managed to transmit 10 Gbps to multiple users, according to Vodafone (Mumford 2016a).

- Already some 'pre-standard' 5G systems are being promoted. In 2016 Verizon announced the release of its proprietary "5G" standards (V5G.213), as "a common and extendable platform for Verizon's 28/39 GHz fixed wireless access trials and deployments". Verizon's statement came shortly before the FCC made its announcement in July 2016 about spectrum for 5G (FCC 2016), which has been developed under the auspices of the Verizon 5G Technology Forum with supplier partners, including Ericsson, Qualcomm, Intel, LG, Nokia, Cisco and Samsung.

- In May 2014, NTT DoCoMo, Japan's biggest mobile operator, announced it was working with six suppliers to conduct various "experimental trials" for 5G involving higher frequency bands than those used for existing mobile technologies, targeting 2020 for its 5G commercial launch.

- Samsung aims to launch 5G-based products in time for the 2018 Winter Olympic Games in Pyeongchang.

- Huawei is targeting the 2018 FIFA World Cup in Russia for 5G trials, and has signed a memorandum of understanding (MoU) with MegaFon in Russia, with plans to roll out commercial 5G services in 2020.
- SK Telecom has teamed with Nokia to conduct joint R&D on 5G with the ultimate goal of demonstrating the technology in 2018 with commercially launch in 2020.
- South Korea, China and Japan announced in July 2016 they were testing the suitability of 5G at 28 GHz, with Takehiro Nakamura, managing director of NTT DoCoMo's 5G lab, recently saying he hoped Europe would follow suit (Mumford 2016b).
- It was reported in October 2016 that China Mobile was planning to roll-out 5G services in 2020, following trials in more than 100 cities (Bushell-Embling 2016).

While China, Japan South Korea, are examining 5G for 28 GHz, the Radio Spectrum Policy Group (RSPG) has previously said 3.6-3.8 GHz should be the core European 5G band and has highlighted 24.5-27.5 GHz, 31.8-33.4 GHz or 40.5-43.5 GHz as the spectrum to focus on above 24 GHz (RSPG 2016).

ISSUES WITH THE 5G CONCEPT

The overall concept for 5G has ambitious goals but is still vague. Many key aspects of 5G suffer from a lack of definition and consensus between different countries and different industrial sectors. While there are undoubtedly some impressive technological advances being made, equipment manufacturers, network operators and their representative industry groups have yet to fully define and articulate in detail the business models and use cases for 5G from which added value will come, with services that users will be willing to pay for. Until now, 5G is a classic case of "technology push" and what is sorely lacking is a sound demand- side analysis.

There are also significant technological issues that have yet to be resolved, principally:

- 5G will require a dense backhaul network but there is little indication of whether this would be provided by fixed line (fibre) or other solutions, for example, line-of-sight microwave;
- At higher frequencies, say above 4 GHz, the short propagation range could limit 5G's application to denser urban environments (see Figure 3), with no benefit to rural users and enhancing the digital divide;
- A further issue arising from these higher frequencies is the poor building penetration for indoor reception and transmission, which may require indoor repeaters.

4

RESEARCH ON EMF AND 5G EFFECTS ON HUMAN HEALTH

The academic literature on EMF exposure effects and 5G in particular is growing rapidly. Some research papers support possible health risks, while others do not.

The WHO[14]/International Agency for Research on Cancer (IARC) classified radiofrequency EMF as possibly carcinogenic to humans in 2011. The IARC has recently prioritised EMF radiation for review in the next five years (2020-2024).

A section of the scientific community – mainly doctors and researchers in medical sciences argues that there are negative impacts from EMF exposure and that these will increase with the implementation of 5G.

A 5G appeal was presented to the United Nations in 2015, and to the European Union from 2017, with an increasing number of scientists' signing (268 scientists and medical doctors as of 18 December 2019). The signatories state that with the increasingly extensive use of wireless technology, especially when 5G is deployed, nobody could avoid exposure to constant EMF radiation because of the huge number of 5G transmitters with an estimated 10 to 20 billion connections (to self- driving cars, buses, surveillance cameras, domestic appliances, etc.). In addition, the appeal states that a large number of scientific publications illustrate EMF exposure effects such as an elevated risk of cancer, genetic damage, learning and memory deficits, neurological disorders, etc. The appeal points out not only harm to humans, but also to the environment.

The appeal recommends a moratorium on the deployment of 5G for telecommunications until potential hazards for human health and the environment have been fully investigated by scientists independent of industry. They urge the EU to follow Resolution 1815 of the Council of Europe, and demand that a new assessment is carried out by an independent task force.

In this regard, some scientists consider it necessary to establish new exposure limits that take account of the new characteristics of exposure. Such limits should be based on the biological effects of EMF radiation, rather than on the energy-based specific absorption rate.

Non-ionising radiation, which includes radiation from mobile phones and 5G, is perceived as harmless in general, due to its lack of potency. However, some of the above-mentioned scientists point out that, in the particular case of 5G, the issue is not the potency, but the pulse,[15] the frequency to which the whole population will be exposed due to the dense network of antennas and the estimated billions of simultaneous connections. As 5G employs a very high level of pulsations, the idea behind 5G is to use higher frequencies, which allows such high levels of pulsation, in order to carry very large amounts of information per second. Studies show that pulsed EMF are in most cases more biologically active and therefore more dangerous than non-pulsed EMF. Every single wireless communication device communicates at least partially via pulsations, and the smarter the device, the more pulsations. Consequently, even though 5G can be weak in terms of power, its constant abnormal pulse radiation can have an effect. Along with the mode and duration of exposures, characteristics of the 5G signal such as pulsing seem to increase the biologic and health impacts of exposure, including DNA damage, which is considered to be a cause of cancer. DNA damage is also linked to reproductive decline and neurodegenerative diseases.

A 2018 review of more recently published peer-reviewed articles on the biological and health effects of radio frequency EMF, including 5G, also verifies the available evidence on the effects of millimetre waves. The review concludes that evidence of the biological properties of radiofrequency EMF are accumulating progressively and even though they are, in some cases, still preliminary or controversial, point to the existence of multi-level interactions between high-frequency EMF and biological systems, and to the possibility of oncological and non-oncological (mainly reproductive, metabolic, neurological, microbiological) effects. Moreover, it points out that the wide and increasing density of wireless devices and antennas raises particular concerns. Taking this into account, '... although the biological effects of 5G communication systems are very scarcely investigated, an international action plan for the development of 5G networks has started, with a forthcoming increase in devices and density of small cells, and with the future use of millimetre waves'. However, there are indications that millimetre waves can increase skin temperature, promote cellular proliferation, and inflammatory and metabolic processes. According to the review, further studies are necessary to improve independent exploration of the health effects of radio frequency EMF in general and of millimetre waves in particular.[16]

Considering the already existing complex mix of lower frequencies, it argues that in addition to those, the expected higher frequency 5G radiation would cause negative impacts on physical and mental public health. Concretely in the case of millimetre waves, it analyses the results of studies which find effects on the skin, eyes, and immune system, and bacterial antibiotic resistance. The review suggests that the effects of radiofrequency EMF will be problematic to sort out epidemiologically, as no unexposed control group will remain. The study consequently calls for precaution in the deployment of this new technology. The author argues that while physicists and engineers give assurances that the only measure to harm health is heat, medical scientists indicate that there are other mechanisms whereby cellular functioning can be disrupted by non-thermal exposures to radiofrequency.

A 2016 review of scientific articles, covering experimental data on the oxidative effects of low-intensity radiofrequency radiation in living cells, finds that, among 100 currently available peer-reviewed studies (18 *in vitro* studies, 73 studies in animals, 3 studies in plants and 6 studies in humans), '... dealing with oxidative effects of low-intensity radiofrequency radiation, in general, 93 confirmed that radiofrequency radiation induces oxidative effects in biological systems'. More precisely, in 58 studies of laboratory rats, 54 show positive results, and 4 of 6 studies in humans were positive. In addition, 17 of the 18 of the *in vitro* studies were positive, including two on human spermatozoa and two on human blood cells. According to the authors, 'The analysis of modern data on biological effects of low-intensity radiofrequency radiation (RFR) leads to a firm conclusion that this physical agent is a powerful oxidative stressor for living cells'.

A 2018 study carried out on animals, showed that electromagnetic radiation emitted by wifi networks can lead to hyperglycaemia, increased oxidative stress and impaired insulin secretion in rat pancreatic islets. A method of creating diabetes (which can lead to kidney deficiency in the long term) in laboratory rats is to expose them, even briefly, to 2.4 Ghz.

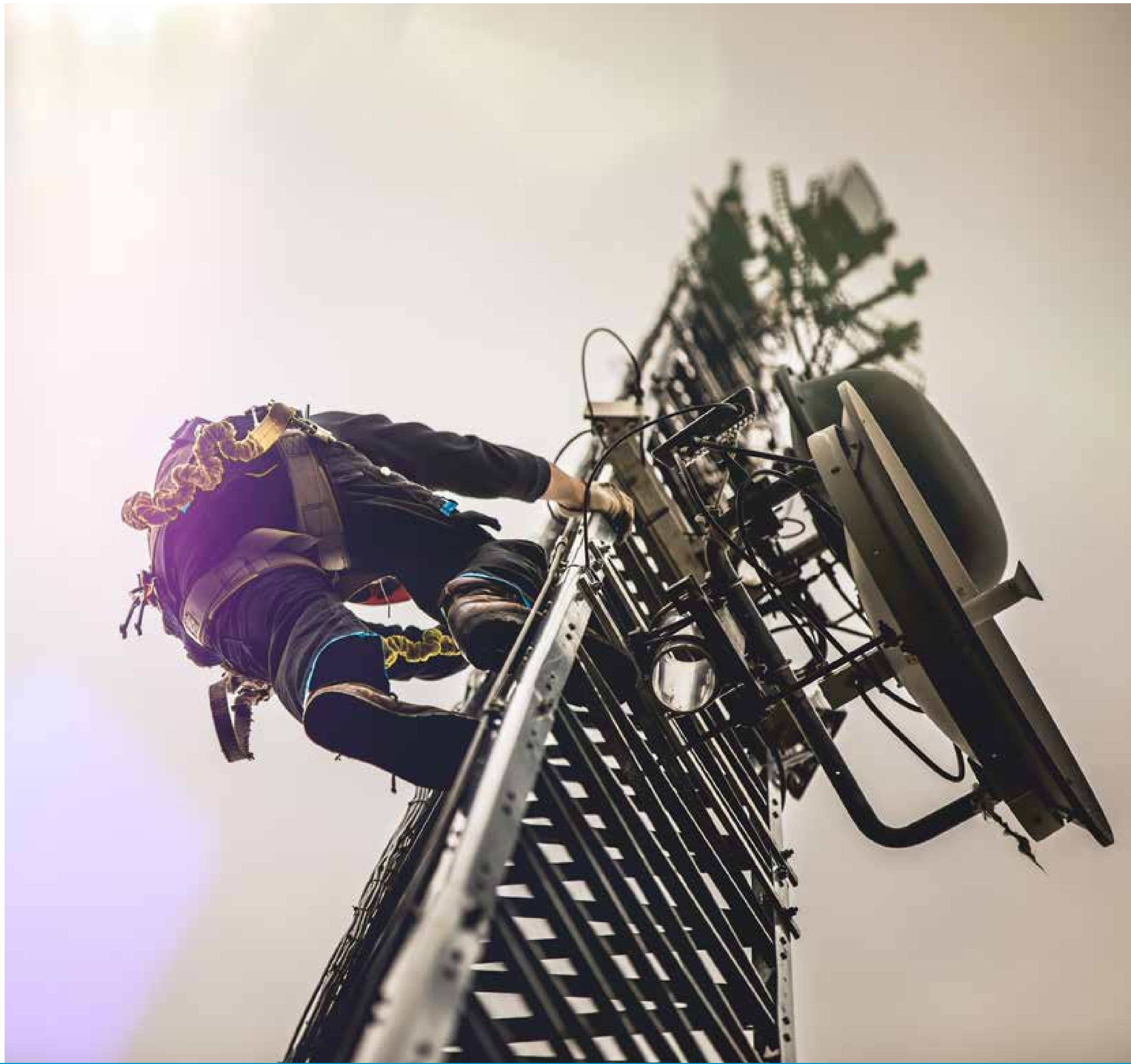
A 2019 report of the Swedish Radiation Safety Authority's Scientific Council on Electromagnetic

Fields considers two large animal studies: the US National Toxicology Program (NTP) study and the Italian Falcioni et al. study, which analyse the relationship between radio wave exposure and schwannoma of the heart in male rats.17 The report concludes that there is some inconsistency in the results between the two studies and that no new causal relationship between EMF exposure and health risks was established. It recommends that further research is important, particularly regarding long-term effects and especially since the entire population will be exposed. It points out that a possible relationship between radio wave exposure and oxidative stress should be a subject of further research, as well as the association between weak low-frequency magnetic fields and childhood leukaemia, as observed in epidemiological studies.

The scientific community reaction in response to this report, is illustrated in the recent 'Commentary on the utility of the National Toxicology Program study on cell phone radiofrequency radiation data for assessing human health risks despite unfounded criticisms aimed at minimizing the findings of adverse health effects.' The author states that the NTP study was designed to test the hypothesis that, at non-thermal exposure intensities, mobile phone radiation could not lead to adverse health effects, and to provide data for assessment of health risks caused by any detected toxic or carcinogenic effects, as little was known about long-term exposure to mobile phone radiation health effects. Regarding the NTP study results, among others, the author defends the use of animal studies that can eliminate the need to wait until enough human cancer data are available before implementing strategies to protect public health. According to the author, the intensity of exposure in the brains of rats in the NTP study were similar to potential human mobile phone exposures.

In turn, a 2019 review of 94 articles, funded by Deutsche Telekom, states that the '... available studies do not provide adequate and sufficient information for a meaningful safety assessment, or for the question about non-thermal effects. There is a need for research regarding local heat developments on small surfaces, e.g., skin or the eye, and on any environmental impact. There was no consistent relationship between power density, exposure duration, or frequency, and exposure effects'.

There is no noticeable increase in everyday EMF exposure since 2012, despite the increasing use of wireless communication devices, according to another review of studies from 2019. Nevertheless, it remains unclear how well these studies of everyday exposure represent the population's absorbed radiofrequency EMF dose. This study maintains the urgent need for better quantification of the population's absorbed radiofrequency EMF dose from their own communication devices.



5

THE STATE OF PLAY IN THE EU

THE MAIN PROPONENTS OF 5G

In the 5G initiative we may discern at least eight major groups of players who are proponents of the initiative globally and in the EU, each with their different objectives:

- *Mobile network operators (MNOs)* – who view 5G in terms of their licensed spectrum model using extensions of their mobile cellular architecture for small cells. MNOs primarily see 5G as the next major opportunity to "churn the market", to resell a revamped mobile offering to the installed base. MNOs are yet to see a return on their investments in 4G and may take a further decade in some cases. Thus despite their positive public stance on 5G, behind the scenes they are more circumspect because the capital needed for investment will be significant, especially if denser fixed-line backhaul is necessary. Consequently their broad business model for 5G would be a continuation of the SIM-card based cellular model of 2G, 3G and now LTE, perhaps with some new features for the IoT, with exclusive spectrum ownership to retain market power.

- *Equipment supply industry* – manufacturers such as Huawei, Ericsson and Nokia, also including semiconductor manufacturers such as Qualcomm. The latter tends to see 5G based on extending 4G technology, for instance a leading contender for the air interface protocol is OFDM (orthogonal frequency division multiplexing). Such players already control much of the 4G IPR. So 5G can extend sales of their IPR packaged in chips. *Both the equipment and handset suppliers* are keen supporters of 5G because, potentially, it is their next wave of sales and they are enthusiastically investing in the extra key patents via research or acquisition. The market for LTE telecommunications network equipment has peaked, as recent results from Ericsson and Nokia show.[5] The supply side therefore needs to discover a new generation of products and customers. However, any gap between the end of sales of 4G LTE network equipment, chips, and handsets and being able to sell 5G is a problem. The lack of global agreement on a definition of 5G and its standards blocks the next generation of equipment and handsets. That will hit revenue streams, as so far there is little agreement on what 5G embodies other than much faster delivery of content (Purdy 2016). To do this via a radio carrier will require some form of allocation of spectrum (which has already been decided in some countries, notably the USA). Thus, while equipment suppliers are working hard in the standards organisations to achieve a definition, each supplier will seek to set a standard that is based on its IPR that it has already prepared to be embedded in chips and equipment (Forge 1993).

- *Standards development organisations* (SDOs) - the key standards forum in Europe for 5G is the European Telecommunications Standards Institute (ETSI) through its 3G Partnership Project (3GPP), whose committees have set the 3G and LTE standards for the detailed architecture, its operation and the air interface. The 3GPP is set to release a first version of an early standard for 5G in 2018 (designated as Release 15). For spectrum, the International Telecommunication Union (ITU) is the most important for global spectrum allocations, at the World Radiocommunication Conferences (WRC) held every three or four years. SDOs are the motor for a definition of 5G globally. Largely, their committee work is funded by the operators and particularly by the suppliers in the form of their financial support for full-time workers on the committees, above all for ETSI and its 3GPP initiative. In effect, the standards in telecommunications are directed by the supply industry and MNOs.

- *Research funding entities* – specifically the EC and Member State governments in Europe as well as those in the more advanced economies around the world. Supporting research in new technologies is their raison d'être, so 5G is receiving strong interest. At member state level, no-one wants to miss out on what could be the next mobile technology race. Many of the academic centres have industry partners who finance and share the research.

- *The academic research community* – who see 5G as an opportunity for advanced research in radio propagation and new techniques such as MIMO antenna design with generous funding from governments. Academic research is led by centres of excellence, such as NYU Wireless in New York, and universities such as Surrey in the UK, Kaiserslautern in Germany and Rennes in France. They concentrate research on millimetre wave technologies, DSP and development platforms for 5G radio communications. There are also industry research centres of excellence participating, such as Huawei's European Research Institute at Leuven in Belgium, and China Mobile Research Institute (CMRI) who are working with Ericsson.

- *Policy makers and regulators* – often stimulated by those governments with a covert industrial policy to drive telecommunications, for instance, the US administration, whose Federal Communications Commission (FCC) released 11 GHz for 5G in July 2016. Ofcom in the UK held its first seminar in early 2015 to define 5G, with some early demonstrator projects. Most NRAs in Europe have allocation of 5G spectrum on their agenda and the RSPG has published its draft Opinion (RSPG 2016) on the subject while the Body of European Regulators for Electronic Communications (BEREC) and the European Conference of Postal and Telecommunications Administrations (CEPT) are also involved via their working groups.

- *New entrants: media content providers and distributors* – media companies, such as Vivendi**,** wish to enter the 5G networking market as the generous bandwidth would enable them to stream films at higher resolution. Those players with both content and content distribution networks backed by major financing may see 5G as the platform to run their own services and perhaps favour separation of the infrastructure from services, with network operators who are independent of the MNOs.

- *New entrants*: *web services and computer industry players* – include companies such as Google and Facebook, and possibly those with information-technology sales, such as Apple and Samsung. Alphabet (as Google Fiber) now operates broadband fibre networks in various USA cities, on utility poles, at an estimated average cost of $1 billion per city. It could easily switch to rolling out a 5G radio network and, in buying Alpental Technologies in 2014, a start-up developing radio distribution networks using the 60 GHz band (or mmWave), it already has a pre-standard 5G working network model. Apple, IBM and Samsung also interest in 5G, not only for selling more end user devices but also in shaping services and content. Apple could follow the Alphabet lead as well with its end-to-end offerings, and it has already developed 5G baseband transceivers, holds some key 5G patents, and like Google Fiber, is hiring experienced radio and radar engineers. Facebook is launching its own 5G model, which may be seen as more of a guerrilla operation with release of open source designs for 5G equipment than a massive mobile industry push. It sees 5G as the next technology for its services and is playing an active role in developing standards with its Telecommunications Infrastructure Project for much larger global networks to connect its expected five billion internet users.

KEY PLAYERS AND THE MAIN INDUSTRY CONSORTIA

The key European players among the MNOs are the international operators with larger marketing and R&D budgets, such as Orange, Deutsche Telekom, Telefonica, TeliaSonera and Vodafone.

From outside Europe, AT&T and Verizon (USA), NTT DoCoMo (Japan), KT (South Korea), and China Mobile are leading investors. The latter held the first 5G showcase field trials on a working network in Wuxi, with Ericsson, in June 2016, as part of China's National Key 5G Project (Light Reading 2016), with the aim of a tenfold increase in peak data rates (Chih-Lin I 2014) and 1000 times in capacity.

The key equipment suppliers are more global, notably from China, Huawei and ZTE, but also Samsung (Korea), Qualcomm and Cisco (USA), Ericsson and Nokia from the EU, with Japanese equipment and component vendors such as NEC and Fujitsu.

Huawei stands out as being highly visible in planning, demonstrations, marketing and trials of early equipment.

Because 5G is still emerging, it sometimes brings traditional competitors into collaborative consortia. Thus Cisco and Ericsson are working with Intel on a pre-standard 5G router (Zander 2016). This is a common theme, for instance, as already mentioned, Ericsson is collaborating with China Mobile, and Verizon is trialling 5G with one of its equipment suppliers, Cisco and with its chip supplier, Intel.

Note that 5G is equally about semiconductor chip manufacture as about networking equipment. Thus Intel must get into this new market, as its major rival here, Qualcomm now leads the field. Intel is trying to penetrate the mobile market more for 5G than 4G, teaming with KT, Verizon, SK Telecom, Nokia, LG, and Ericsson (Intel 2016), as well as Cisco for products and future trials of its radio technology into 2018.

There are many other consortia, some with longer-term goals and some with immediate short-term goals. For instance, Verizon has its 5G Technology Forum for early demonstrators aimed at first pilots in 2017 and 2018. Many European MNOs and suppliers, with the industry body, the GSMA, are aiming for 2020, through the Next Generation Mobile Networks (NGMN) alliance based in Frankfurt, to support SDOs with the views of the MNOs.

THE STATE OF RESEARCH, INNOVATION AND COLLABORATION

The research community, funded both nationally and by the EU, has been working on technologies related to 5G for at least a decade. Under the FP7 initiative, at least 10 research projects examined advanced wired and radio communications including COMBO, METIS, 5GNOW, iJOIN, TROPIC, Mobile Cloud Networking, PHYLAWS, CROWD and MOTO. Thus, in terms of preparedness, the state of EU research is well advanced.

To seed collaboration between industry and the public sector, the 5G PPP partnership was launched as a €1.4 billion joint initiative between the European ICT industry and the European Commission. European industry has embraced the 5G PPP enthusiastically. Moreover the public sector, in the form of Horizons 2020 programme, is engaging the EU with players from around the world to advance its research interests so potential 5G technology suppliers from Asia and the USA are also involved.

5G FROM A DEMAND PERSPECTIVE IN THE EU

The demand side of 5G has been insufficiently examined. Many demand scenarios have been put forward, firstly the use cases from the research projects (such as METIS, 5GNOW, COMBO, TROPIC, iJOIN and others) and also various studies commissioned by stakeholders, notably the MNOs, NRAs, and the European Commission. Generally these studies forecast enormous data traffic increases in connection with 5G, driven by internet access but, above all, by Netflix-style Streaming Video on Demand (SVOD) services to every portable device. As a result, they anticipate mobile networks with capacity for 500-1000 times today's traffic per user. These forecasts are questionable because of the assumptions they make and for the methodologies used.

For instance, the European Commission has recently published a study on 5G demand (Tech4i2 et al 2016). It predicts an enormous market for 5G goods and services of €113 billion per year in 2025, expected to be result from €62 billion directly and €50 billion indirectly from just four sectors – utilities, transport, health, and automotive, the latter considered separate from transport. Some 2.3 million jobs are forecast to be created directly and indirectly. As before, the study's forecasts rests on the assumption that 5G would be used for SVOD to every device in both urban and rural environments. Moreover, these forecasts also rely on 5G being used as the basis for the IoT, but as already indicated, in the main the IoT will most likely rely on different kinds of networks for low bit rates over short distances.

Others such as TMF Associates and the European Broadcasting Union have questioned the figures for spectrum requirements produced using the ITU's mobile spectrum models. ITU- R Report M.2290-01 presented forecasts for growth in the total amount of global mobile traffic up to 2020. It then estimated spectrum demand based on traffic density globally for urban, suburban and rural areas, concluding that in 2020 between 1340 MHz and 1960 MHz would be needed (in low and high demand situations respectively).

This enormous spectrum demand is to some extent what drives the 5G initiative. However, there are other sources of doubt about future traffic levels, especially the estimates of data traffic growth from the Cisco VNI sources, which are also used by the FCC and the ITU in their demand projections. Between 2009 and 2014 Cisco VNI tended to overestimate future traffic levels, but by 2014 it had begun to consistently reduce these. It also noted that OTT traffic via Wi-Fi connection to fixed line broadband was taking much of the data traffic demand emanating from mobile devices via Wi-Fi offloading.

The viability of the 5G initiative in the EU will depend on its business models, which are as yet not only unproven in the market, but barely articulated (Webb 2016). Whether industry excitement will translate into large-scale EU demand from business, but above all from the domestic consumer for streaming video, is moot.

HOW WELL PLACED IS EUROPE IN THE 5G RACE?

In its strategy for the Digital Single Market (DSM),[6] the European Commission emphasises the need for very high capacity networks, like 5G, as a key asset for Europe to compete in the global market. Following this strategy, the Commission published its action plan identifying the following key elements for the development of 5G:[7]

- Align 5G technology roadmaps and priorities for a coordinated 5G deployment across all EU Member States, targeting early network introduction by 2018, and moving towards commercial introduction by the end of 2020 at the latest.
- Unite leading actors in working towards the promotion of global standards.
- Facilitate the implementation of an industry-led venture fund in support of 5G-based innovation.
- Make provisional spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference (WRC-19), to be complemented by additional bands as quickly as possible, and work towards a recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz.
- Promote pan-European multi-stakeholder trials as catalysts to turn technological innovation into full business solutions.
- Promote early deployment in major urban areas and along major transport paths.

This series of actions is intended to gain 5G support from the EU IT and telecoms industry in the Member States. It forms an ambitious 5G introduction programme, drawn up with the view that it is essential for Europe to have a leading position and to take advantage of any market opportunities enabled by 5G, not only in the telecoms sector, but in theory for its economy and society as a whole. Digitalisation of European industry would be promoted on the basis of using the available radio networking resources (4G/LTE, Wi-Fi or satellite) with the aim of accelerating that by progressive adoption of 5G from 2018 onwards.

In summary, the EU is well placed, despite the optimistic market forecasts. Private initiatives, such as those from Vodafone and Ericsson, may set the pace but the overall EU plan for rollout to urban areas by 2025 seems prudent. That enables a reasonable development time for the technology to mature. Taking seven years between proof of concept in 2018 and wide rollout by 2025 appears realistic. Note that the technologies proposed for 5G are a significant advance and 3G took from 1999 to 2006 to become fairly mature while LTE research and development from 2006 continues a decade later.

China, South Korea and the USA are attempting to go faster but, as in Europe, detailed analysis of potential demand and revenues is lacking. The USA has quickly allocated some high frequency spectrum to enable its 5G market to develop but how fast the take-up will be remains to be seen, given that its residential geography consists of many remote rural communities, small towns, sprawling cities and scattered remote suburbs.

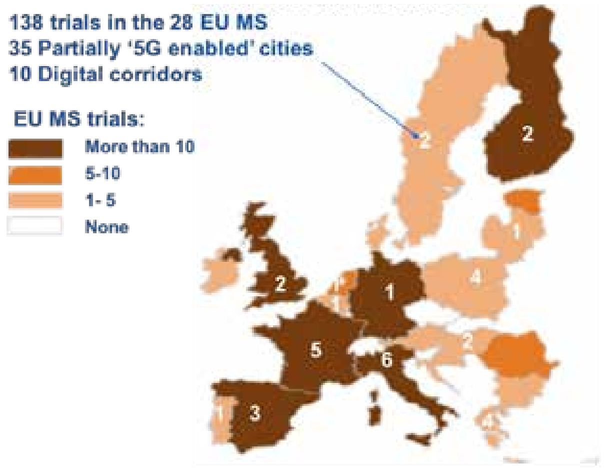
Research efforts alone will not be sufficient to ensure Europe's leadership in 5G. A wider effort is needed to make 5G and the services that may flow from it a reality, specifically the nurturing of a European "home market" for 5G. The 5G PPP points the way for this, so that the EU is quite well positioned if a market for 5G does transpire. Furthermore, the proposed European Electronic Communications Code published in September 2016[8] will support the deployment and take up of 5G networks, notably as regards assignment of radio spectrum, investment incentives and favourable framework conditions, while the recently adopted rules on an open internet provide legal certainty as regards the deployment of 5G applications.

COMPARING THE EU WITH OTHER LEADING COUNTRIES

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.

Figure 5.
The 5G Trials and Initial City Pilot Rollouts



Source: European 5G Observatory, 2019.

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.

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 5.

RANKING OF EU AGAINST OTHER COUNTRIES

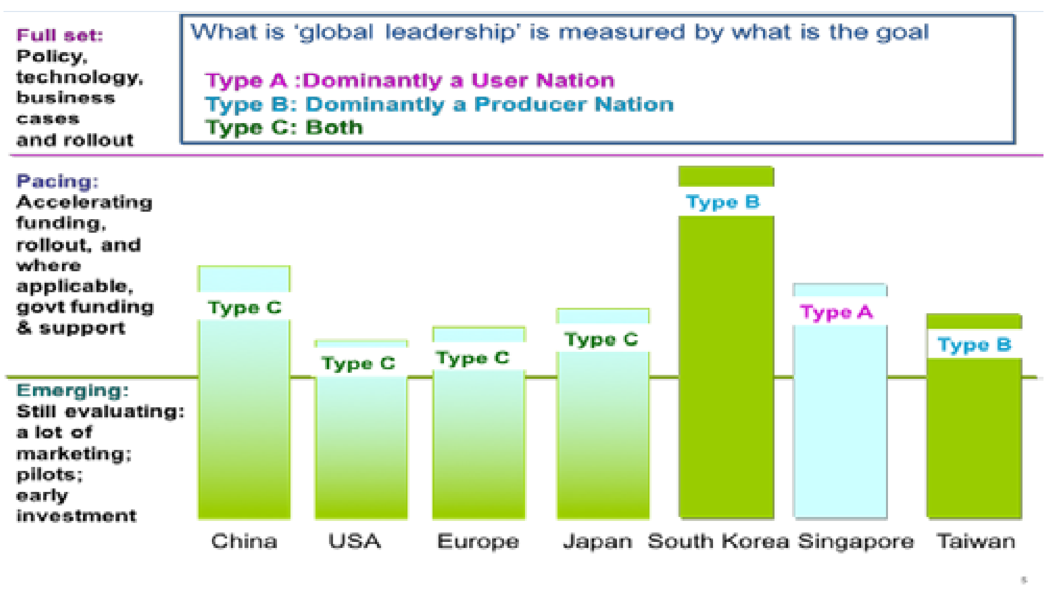
In comparing national or regional progress in 5G, in terms of technology, deployment and acceptance by investors and by the public, a pragmatic assessment depends upon whether the objective of the country or region is to be a user, producer or both:

- **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 6, 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 6.
Ranking 5G Development across the Globe Based on Multiple Criteria



FACTORS FOR 5G SUCCESS

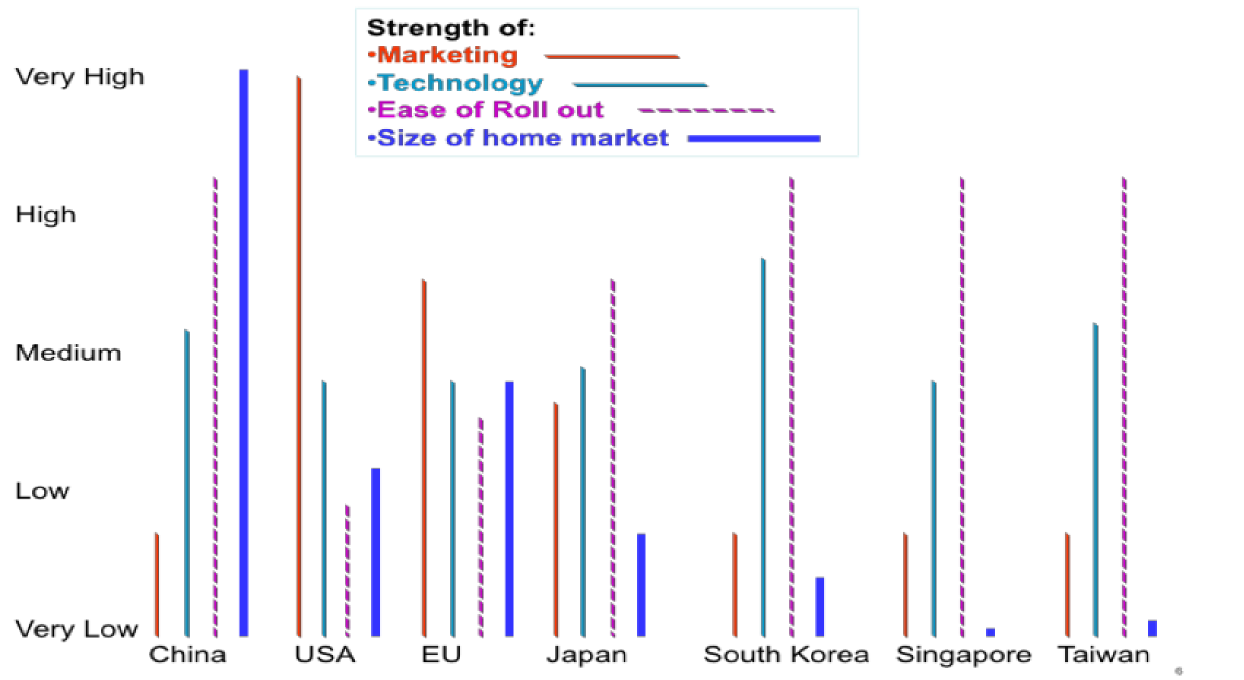
The ranking takes into account not just technological progress but also practical factors associated with

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 7.
Factors Shaping the 5G Market – Comparing the EU with USA and Asia



Source: Authors.

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.

6

BUSINESS MODELS AND BOTTLENECKS

5G UNKNOWNS AND UNCERTAINTIES

A difficulty with 5G is that there are still too many key unknowns among the operating variables on which the technology depends – distance ranges, penetration and capacity in numbers of users, all of which impact the primary business model parameters, of cost and capability. This is different to the situation with prior cellular technologies, which were less complex, better understood, with tested performance before rollout. The main areas of doubt are as follows:

- Usable ranges are not yet clear: the distance for a “good” signal is uncertain because it depends on the frequency band, which varies by power levels, propagation environments with fading effects (“urban canyons” v suburban high foliage streets), degree of mobility, weather conditions (sunlight v heavy rain), load mix and reflections which may interfere, or augment the signal. The difference in range between tens of metres and hundreds, or as some claim, thousands of metres, is crucial to the viability of a particular business model. Distance is a key limitation on the viability of the cost model as it determines the support infrastructure density needed for backhaul, power supplies, customer experience and numbers of concurrent users.
- Building penetration: the built environment is where 5G will operate. But at its likely frequencies, poor penetration for ferroconcrete and brick is the norm, and even signal power concentration via beamforming may not be insufficient. Therefore other solutions may be needed, for example, a femtocell may be needed to retransmit the outdoor signal indoors, via access points or distributed antenna systems. This complicates the business model because it becomes partially akin to the Wi-Fi (and femtocell) cost model where the user, not the MNO, owns the retransmitting hub.

Overall capacity in the number of simultaneous user sessions is also unclear as it depends on new techniques for digital signal processing yet to proven in the field. Key among these techniques is the discrimination between many signals sent concurrently but with different encoding and other forms of multiplexing which are yet to be proven in 5G.

BUSINESS MODELS FOR 5G AND THEIR VIABILITY

As already mentioned, the Commission’s 5G Action Plan expects 5G revenues for MNOs in the EU to reach €225 billion by 2025 (Tech4i2 et al 2016). But the business models to achieve this are unclear. Unfortunately, this is often the approach in the telecommunications industry. Although mobile communications is considered a great success, there have been many failures over the past thirty years in the telecommunications industry, largely the result of blind faith in technology advances and an attitude of “build it and they will come”, especially for consumer services. Some well known examples include WAP, ISDN, and Iridium.

Indeed, the history of the cellular mobile industry in marketing large volumes of high-speed data has had mixed success. As soon as cellular mobile data tariffs are imposed and then raised, often to avoid network saturation, consumers quickly tend to switch to Wi-Fi whenever it is available and will install home Wi-Fi hubs just for this, which are then connected via lower-cost fixed cabled broadband. They combine this with OTT services (e.g. Skype, WhatsApp for voice and video) to avoid paying metered tariffs in duration of session, or in volume of data. It tends to suggest that revenue projections for 5G should be founded on free or low-cost OTT services.

The basis of the current mobile industry's 5G business model is to offer the mobile equivalent of fixed line broadband speeds, ranging from 100 Mbps up to 10 Gbps and more. But future demand for superfast broadband is questionable. For instance, in the UK, only 22% of households have chosen to upgrade their home broadband to BT's Infinity with its higher fixed line broadband speeds of up to 100 Mbps over a fibre local loop (Webb 2016). Moreover, there comes a point when ever-faster broadband becomes unnecessary.

There are also questions over the third major advance for 5G communications – its claims for low latency. That could be useful for low time-constant applications, e.g. driverless cars for interactions such as keeping distance but, for the reasons given before, this will be of limited value if 5G networks are confined to dense urban conurbations. In other applications, the latency reduction may be useful, perhaps for business and consumer transactions processing.

A further tenet of the business model for 5G is its role as the basic infrastructure for the IoT. However, there are many industries that have long had the aim of wirelessly connecting all kinds of devices without voice or high-speed data connectivity. Yet often these applications tend to work at low data speeds, frequently less than 100 kbps, or even less. So the notion that a dense networking infrastructure is needed to send tiny amounts of data with lower latency may appear irrational. Industry wants the very low costs of purpose-built networks that can operate in standalone modes, and perhaps for years, even decades, without change in operational supports.

For the industrial IoT that stretches over larger areas outside cities, up to whole Member States or even all the EU, 5G is unlikely to be the answer. Major industrial IoT players are already focused on quite different networking technologies, often wishing to own their networks, not to hire time on a 5G network. These industrial networks emphasise low cost, low data rates and perhaps wide area propagation and thus most often unlicensed spectrum in narrow bands, set if possible in the lower frequency ranges (even VHF and below[10]) to obtain the coverage.

Licence exempt operations are cheaper from the point of view of having no licence costs for market entry for a new business plus avoidance of fees to a licensed operator for use of an IoT service from a service provider. Thus the narrowband, wide area technologies favoured by industrial users are likely to dominate the IoT (which are already valued at over $300 billion by GE[11]). While new IoT networks and services will soon emerge for many industrial sectors from water supplies to food processing, they are unlikely to need broadband speeds and are often defined in performance by vertical industry standards.

The one area where the 5G speed could be used in an IoT application is in the smart home's video distribution network for multiple devices. It might also carry the control signals for the smart home's operation in terms of energy management and for control systems for embedded processors in domestic appliances. It would make sense to share a local area network that is already present for the home entertainment centre's services.

In essence, for IoT applications, there appears to be a leap of faith from providing gigabit speeds at low latency to enabling "new business models," for now largely unimagined applications.

The business case for 5G as a general integrator for different types of networks implies that the different networks could not integrate directly, but each would integrate to the 5G network locally. The more probable integration situations are first business/industrial, between different types of IoT network, and second, for consumers between different types of mobile cellular network and Wi-Fi as well as offering gateways to other networks, to the PSTN and the internet. It may be attractive that a 5G standard could act as the lingua franca between different IoT networks and between different mobile and Wi-Fi networks. However, direct gateways are more likely for the IoT cases. For consumer networking, a mix of interfacing in the end-user device and by ISPs using 5G networks as the integrator is less likely.

That leaves one possibility for a solid business model, which some operators have already seized on – fixed and mobile convergence for a broadband link to replace fibre to the home (FTTH) or xDSL copper in the local loop. If well engineered, this could be cheaper to deploy and, with a short line-of-sight positioning, fairly robust and reliable. Thus 5G could conceivably become the converged broadband "fixed wireless access" (FWA) of the future, possibly with some limited mobility capability. The impact of that would be greater capacity for the same applications, not necessarily new applications. Here, 5G would suit streaming video on demand (SVOD) for entertainment in the home. However as most capacity is required *inside* the home, the building penetration issue must be overcome. Note that it would be in competition with fixed line broadband and Wi-Fi hubs in the home.

In summary, the 5G concept has yet to be coupled with a solid business case and a revenue steam with realistic margins. Many questions remain unanswered, such as:

- What new "killer apps" 5G could offer?
- Where will new funding come from for 5G network investment as well as for seeding new user devices that take advantage of its technical progress?
- How would 5G integrate in the MNO business model with existing offerings, for instance, would it cannibalise LTE/4G margins before all LTE returns on investment have been recouped?
- Will the consumer market or the business market (for IoT) be the key target?
- How much are consumers and businesses willing to spend when average revenue per user (ARPU) is declining and the economic outlook is stagnant (Giles 2016)?

BOTTLENECKS

5G is one of the most complex technologies we have seen over the past decade regarding detailed definitions, technical development and demand patterns in business models, which is leading to bottlenecks in its support, standards and strategies for funding.

THE IMPORTANCE OF STANDARDS

A stable standards roadmap is essential for 5G, especially with its range of possible specifications, spectrum bands and technologies and the lack of clarity over its applications. Standards would clarify the concept and concretise its early conception in firmware, software and hardware. To this end, the lead SDO in the EU, ETSI/3GPP, has given a date of 2018 for a revised version for 5G of its LTE release (to be Release 13).

However, many of the other standards bodies and related actors have not reached agreement. They may even have incompatible goals and objectives, although many issues are in negotiation, such as spectrum. While some see it as the *mobile* cellular radio replacement, others see it as fixed line broadband substitute and want specific standards for this (such as Verizon in the USA with its own 5G alliance). That makes it difficult to predict which alliances will win in each area of dispute, or how long this will take. The first emerging set of standards may therefore be stopgaps as those further amendments that really matter materialise. The range of actors involved in standards now interacting includes (at least):

- ETSI (3GPP – Third Generation Partnership Project)
- ITU-R and the WRC (World Radio Conference) forum
- RSPG
- 5G PPP
- METIS
- NGMN
- IETF
- IEEE
- Telecoms networking equipment and semiconductor manufacturers
- BEREC and the national regulatory authorities (NRAs)
- National and regional SDOs
- CableLabs

With the overabundance of players, stakeholder interests and initiatives, it is to be hoped that the various proposals will have crystallised into standards following Release 13 in 2018, with discussion at

WRC-19 in 2019. Stable standards at a global level may transpire by 2020/2021 when there has been time to better define the scope, objectives and key application areas of 5G from the trials. Timelines are detailed in Figure 2.

SPECTRUM FOR 5G

What should be the guidelines for the EU for future-proof 5G driven spectrum policy? The spectrum range cited for 5G is often relatively enormous - far more than any previous radio technology, apart from satellites perhaps, if all the claims of practical working at the millimetric high frequencies are accepted. Thus the FCC, in its releases announced in June 2016 for 5G, mixed licensed use (at 28 GHz, 37 GHz and 39 GHz) with unlicensed use in the 64 -71 GHz band, with shared access in the 37-37.6 GHz band. The latter indicates 600 MHz for dynamic shared access between different commercial users, and between commercial and federal users (FCC 2016). This is clearly aimed at the small cell networking of 5G. Some of the specific bands are in the ranges 3.4 up to 3.9 GHZ (3GPP, UK FWA and FCC), ISM at 5GHz then in various bands 10, 12, 14,24,25, 27, 28,29,31, 32, 37-52, 38-40,41, 42-48, 45, 57-66, 64-71, 71-76, 81-86 GHz, but others may also be proposed.

This surplus of choice could lead to fragmentation of the spectrum standards with different selections by ITU Region and even by EU Member State. Fragmentation in spectrum may also be generated by the early commercialisation dates, the first being at the Winter Olympics in Korea from SK Telecom in 2018, while ETSI/3GPP expects commercial choices to be mature by 2020, if it concentrates on the fast (or "ultra") broadband possibly by 2019 (Mumford 2016d). Those with more pragmatic considerations have proposed more limited ranges. For instance, in its 5G Opinion (RSPG 2016) the RSPG favours 3.4-3.8 MHz as the primary introduction band up to 2020, and also 700 MHz and above 24 GHz as defined at WRC-15 (bands at 24.5-27.5 GHz, 31.8-33.4 and 40.5-43.5 GHz). The RSPG's proposal for the 3.4-3.8 GHz band because it is already harmonised for mobile networks, with 400 MHz for wide channel bandwidth. The RSPG considers that this has the possibility to put Europe at the forefront of the 5G deployment.

Until spectrum for 5G is agreed it will act as a roadblock in that the technologies may be quite different across the range of frequencies under consideration. Judicious frequency setting players are opting for some lower frequencies, some even below 1 GHz, because of the advantages of distance of propagation and penetration of brick, plaster and ferroconcrete structures. Overall, making any spectrum choice provides various challenges with a resulting delay owing to:

- *Uncertainty over the end result in spectrum allocations*: there is a balance between not committing as against pro-actively mobilising as soon as the conflicts between incumbents (MNOs, broadcasters, satellite operators, military, government) and future 5G users are slowly resolved.

- *Adjusting to a new mix of novel spectrum licensing models such as shared access, cognitive radio collective spectrum use, etc*: against traditional licensed and unlicensed bands. There may be new licensing models that depend on major technology challenges, never resolved before, all tending to delay final roll-out as co-existence is worked out

- *Spectrum choices will be set in the international standards fora*: however, these could be set by an emergence of de facto spectrum choices expected in those large markets that are early movers, specifically China and the USA. They may well define which bands are the premature focal points for pre-5G and then first full 5G progress. The USA, China, Japan, the EU and Korea may all be contenders for this early mover advantage through early implementations.

- *Sharing criteria for unlicensed bands for duty cycle (DC) and power limits*: at some point, NRAs will have to decide which bands have which power limits for sharing without unmanageable interference. Some licence exempt bands are already restricted to low power and DC use (e.g. ISM bands, 868 MHz, 915 MHz, 5 GHz and 60 GHz) to ensure sharing and possibly to protect adjacent band users and the existing in-band incumbent users, such as the satellite operators in the higher frequency bands.

- *Beam forming for directional transmission for spatial multiplexing*: 5G includes beam- forming technology in many (not all) 5G technical specifications. Moreover some proponents are expecting services to be highly asymmetric, as the major payload for them is HD video streaming. So most traffic could be downloads to consumers with much less volume in uploads to the network and so the uplink channel could also be in another frequency band. However, some 5G network architectures expect to see full duplex in- band by signal cancellation as being the standard 5G bi-directional mode. Others expect TDD channels as the connection mode, so an in-band up-link would just have fewer time slots. If 5G bands are licensed, whether that asymmetry in links would modify licences is unclear.

- *There is also simply confusion, not just an embarrassment of choice of bands*: the candidate frequency bands are many but each has its own complications in each national and regional market. In theory, 5G could be frequency band agnostic in technical terms, i.e. applicable in any permitted spectrum as with mobile technologies (2G, 3G, LTE/4G). However, because of the wide range of available frequencies, different 5G flavours by frequency band may appear. This could be accentuated by the lack of definition today, so there may well be 'pre-5G' versions of the technology. That might generate a focus on early-preferred bands.

IMPACT OF MARKET FRAGMENTATION

How important is market fragmentation for the EU's global leadership in this technology? At this early stage, when the concept is still to be fully defined, and the focus is on R&D rather than sales, EU market fragmentation is not a significant concern.

Key developments are being researched in the various centres of excellence in the EU, supported by both Member States and the Commission. Moreover, the EU, through ETSI and the 3GPP, are a key to setting technical standards.

In consequence the lack of an EU Digital Single Market today is not hampering the EU as it seeks to take a leadership role when it comes to 5G. It may become an issue in future, but only if 5G takes off as a technology for the larger, richer economies, rolled out only for the most prosperous cities. That could widen the digital divide as it is unsuited to sparse rural settings.

HOW WILL 5G BE FINANCED?

Given the uncertainties we have described, it is unclear how much financial investment will be needed for 5G and where it will come from. Currently the main financiers are the industry players, the mobile equipment suppliers, the MNOs, the key chipset producers for 5G equipment for both handsets and networking, and governments. In the EU, the European Commission also provides R&D funding and effectively start-up commercial finance (through the 5G PPP).

Behind the commercial mobile operators stand the banks and the equity and bond markets. Most mobile operators tend to rely on banks for the capital for building new networks, although the bond markets (and "junk" bonds) have been used. Covenants with the banks are how the MNOs tend to see their financing, which will be strongly linked to their current share prices. This financing model may be complicated by funding advances made by the suppliers to the operators in exclusive deals, in which an MNO may be financed by its suppliers in return for long-term contracts that can include not just original equipment supply but also maintenance, and today, much of the network operations.

However financing may be far more diffuse if the business models extend beyond the MNOs and the equipment suppliers (see below). In that case a much wider range of players could enter the market, including local authorities, media companies of all kinds and smaller services providers.

The technology is open to a "small build strategy" as well as the big bang rollout of the traditional next generation operation in the mobile industry. So its financing may come from many small projects which are independently set up. They could be financed by local as well as national players. That would alleviate the need to find large-scale funding for a major launch.

OTHER BOTTLENECKS

The number of base station sites required could be enormous and real estate costs in dense urban settings will be expensive. Backhaul cost and difficulty of installation must be considered, as 5G will use large numbers of small cells. There are thus the potential impediments of a high density of infrastructure, with large numbers of:

- Sites to acquire and equip with 5G transceivers that require mounting on buildings or masts with protective housings, perhaps one at every 100 to 200 metres or even less depending on the technology and frequencies used, in theory on a regular grid pattern. Planning permission may be necessary, difficult and expensive. Mobile cellular roll-out has always depended on an extensive real estate acquisition operation and cost. 5G may be even more difficult and costly.

- Backhaul, with wayleaves if they are cabled, again at every 100 metres. One alternative suggestion is engineering sets of line-of-site microwave links to concentrators, rather than cabled backhaul, where LoS exists. Again, planning permission may be necessary, difficult and expensive, with added health concerns over microwave bearers. Alternatively there are the costs and permissions of cable laying in city streets with their restrictions on civil works.

- Power supplies, including uninterruptible power supply (UPS) backup and possibly air-conditioning for a large number of sites.

A further possible bottleneck could arise if 5G poses health risks. Since its inception, there have been concerns over the health hazards of irradiated human tissues by mobile telecommunications networks, although these fears have diminished in recent times. However, these concerns could to re-emerge with 5G technology because of its urban concentration and dense cellular structure, its use of much higher microwave frequencies and its highly directional concentration.

WHO WILL CONTROL THE 5G MARKET?

Given the complexities and uncertainties we have described, at this stage it is difficult to say who will eventually control the market for 5G. At least three possible models for the eventual market are apparent. In the first, 5G would just be another type of mobile cellular technology play, owned largely by the MNOs and the equipment suppliers with market entry being controlled through spectrum auctions for licences. Their control could be weakened to some extent if licence exempt (LE) spectrum becomes a partial, or the total, form of spectrum allocation, as entry would be open to more types of players.

A second model is that new entrants to the 5G market, who are not the established MNOs or other players, set up competing operations, with a locality-based business model and gateways to the internet and the PSTN, including into other 2G, 3G and LTE/4G networks. Agreements at the EU level, and globally, on LE spectrum for 5G would accelerate this model by opening the market to new entrants. That would give a much more diffused control of the EU 5G market. This could be the most interesting model, in that a separation of network infrastructure ownership and operation, and services provision with applications on top of “plain vanilla” services could emerge, so that the MNOs and internet service providers (ISPs) might not dominate. For instance, local broadcasters could enter the market. That could seed a prolific market among the Member States as local languages and cultural programming would flourish more easily than under dominance by the traditional players.

A third control model for the 5G market would be restricted to local distribution and is characterised by the building penetration problems of 5G, that could be solved by access points or repeaters on the outside of a building with internal distribution, either by cabled of radio bearers within the building – the femtocell model of a repeater. That in-building network could be the property of the building owner or leaser, just as a Wi-Fi hub may be privately owned. It probably would be an adjunct to either the first or second models outlined above.

Here it should also be mentioned that control of the 5G market includes its essential IPR in the form of patents controlled by some major players, including non-practising entities (NPEs), for example, InterDigital and Headwater Partners. The latter hold patent portfolios and, especially in the US legal system, seek to licence the technology they own to equipment manufacturers and ultimately end-users through the pricing of network equipment and handsets. Early estimates for a 5G handset indicate a cost of about $400, with royalties to patent holders of about $120 (Pratap and Vijh 2016). These contracted royalties would be mainly agreed in the USA, as major suppliers such as Apple, Qualcomm and Intel are headquartered there along with key NPEs). The cost of patent royalties may even exceed the cost of the handset’s components. In comparison, royalty charges for 4G LTE cellular functionality approach $60 for a $400 smartphone. However, the average cost of the baseband processor that implements the LTE mobile technology is now as little as $10 to $13, dwarfed by net patent costs.

This implies that the companies involved in 5G technology development are likely to employ aggressive legal strategies to maximise profits from IPR holdings. Being just a mobile component or technology service manufacturer offers limited revenue and profitability from the 5G market. Much more profitable is the NPEs’ business model, of pure IP licensing with higher yields at little risk compared to the manufacturer or MNO business model. It avoids any manufacturing or network operations costs. The largest patents holders are shown in Figure 8.

Figure 8.
Largest Patent Holders of 5G Technologies

5G TECHNOLOGY AREA	LARGEST PATENT HOLDERS
RF front end and RAN	Ericsson (64) Qualcomm (63) InterDigital (58)
5G waveforms and modulation technologies	Qualcomm (121) Nokia (73) InterDigital (45)
5G core network engineering	Nokia (39) Qualcomm (36) Headwater Partners (34)

Source: Pratap and Vijh 2016.

ROLLING OUT 5G IN EUROPE EFFECTIVELY

What should be the data speed targets for the EU for 5G is a question of who is supplying and operating, as much as who is using. The supply emphasises high data speeds above 1 Gbps and perhaps higher than 20 Gbps. However, given that 5G will be used outside in inclement weather or indoors, and not in the lab or under ideal propagation conditions, a target of 1-3 Gbps may be more realistic. The case for ultrafast broadband has not been made, and slower speeds of 100 Mbps will be sufficient for most consumer needs, depending on the number of people in a household and the number and kind of applications running concurrently.

Of more concern to consumers is ubiquitous coverage to enable them to access the internet wherever they are located. If 5G coverage is restricted to urban settings, transport arteries, and isolated campus examples in education, health facilities and business, this will severely compromise its appeal to consumers.

HOW FEASIBLE IS THE 5G INITIATIVE?

The timelines for technology development and proving are ambitious and may take longer both for prototypes, pilots and rollout to be completed than the current schedules that aim for 2020 or soon after.

In considering the feasibility of the concept as a whole, the small cell model is the most precarious part of the whole venture as obvious applications for it, for example, the SVOD market, can only be served in dense urban settings at the millimetric bands proposed. Lower centimetric frequencies and even UHF versions may be technically more attainable in practice.

Moreover, although the mobile industry is positive about 5G, financial investment from the MNOs and their backers may be rather reluctantly forthcoming. Recently, senior industry representatives have cautioned about fuelling the hype around 5G, such as Johan Wibergh, the CTO of Vodafone Group, who said he is concerned that the mobile industry is already beginning to over-hype what 5G can do, and called for caution on what is promised with the next-generation technology.[12] The MNOs still have to recoup their outlays on LTE and its expensive data offerings and, so far, the expected returns have yet to materialise. Thus, in reality, the banks and even the telecoms equipment suppliers are likely to take a prudent and pragmatic view before committing the major investment required.

If a more diffuse business environment starts to emerge with many more new players potentially entering, possibly with separation of services from network infrastructure to offer more opportunities, then the 5G operation may be viable in higher income dense urban environments.

Although there are still many issues to resolve, the technology itself is less of a challenge in that its trajectory of development is fairly predictable. The main challenge will be in making it robust and reliable in the field in all weathers and in all environments. That will only come with longer-term experience which, based on previous mobile generations, is likely to require three to six years of commercial operation.

7

CHALLENGES IN 5G

TECHNOLOGY

The aforementioned vision 5G reveals a plethora of challenges that we can outline: 5G strives to provide a universal ICT infrastructure that addresses wider societal challenges through a flexible alignment of stakeholder incentives by virtue of being truly programmable, secure, dependable, privacy preserving, and flexible, while minimizing the costs per bit by efficiently harnessing all communication capabilities and reducing the system power consumption by harvesting any kind of accessible energy from the environment. First, this vision points towards a significantly increased (in comparison to earlier generations) set of stakeholders that 5G needs to accommodate when providing communication solutions. Examples of stakeholders are:

- Individual and communities of people.
- SMEs, corporations, not-for-profit and social organizations.
- Digital asset owners, such as public transport and utilities authorities and organizations.
- Vertical sectors like energy, health, manufacturing, robotics, environment, broadcast, content and creative industries, transport, smart cities.
- Municipalities and public administrations.
- Public safety organizations and defense bodies.

Providing communication solutions for this large set of stakeholders with current communication solutions is intrinsically difficult due to the large set of requirements that needs addressing at any point in time of deployment. Following our vision, it seems clear that 5G will be able to provide broadband location independent access to places like planes, high-speed trains and ships. 5G networks will optimally explore the underlying L2, and will use the existing context to provide energy efficient communications. This means that 5G will be multi-technology – not in the sense that resorts to different physical layers, but that they can resort to different networks as well, either from the point of view of technology or of administrative ownership. In this, we consider the future 5G network a “not always all-IP network”, bringing the advantages of other network architectures to the forefront where they may provide value over IP-only systems (e.g. ICN, ZigBee, etc.…). The network will also be inherently multi-tenant, in order to be able to explore the technology diversity that will exist. Driven by Moore’s Law, the networks (or some network nodes) will need to be seen as intelligent “computing & storage” entities, bringing different features into the network realm, where some concepts that resided until now at the service layer are integrated, enabling the synergetic development of network functions based on software engineering principles (thus lowering the product development costs). The 5G network thus brings to users not only better performance, but also new functionality. Its scope is not limited to the radio access, but encompasses the whole network, including aspects as subscriber management, core network and transport features.

This view on 5G leads to many key performance challenges that 5G technologies will need to address for meeting expected key performance indicators (KPIs):

Throughput: provide 1000x more available throughput in aggregate, as well as 10x more speed to individual end users, in order to enable fully immersive experiences. This may require the integration of new forms of broadcast services.

- **Latency**: provide service-level latency down to about 1ms (when needed) for tactile Internet, interactive and immersive experiences as well as standard Internet services.

- **Energy efficiency**: Wireless/mobile broadband infrastructures account for more than 50% of the energy consumption of telecommunication operator networks, while the amount of global energy consumption of ICT approaches 4.5% with a rising trend. It is important that future 5G networks meet requirements and challenges in an energy efficient manner

- **Service creation time**: enable the creation of user experiences from the application over the individual service components down to the individually participating network(s) in a matter of seconds or less.

- **Battery lifetime**: provide 10x better battery lifetime for low throughput solutions such as sensors.

- **Coverage**: with many more people expecting to have the same coverage when travelling (on cruise liners, passenger aircraft, high-speed trains and in holiday villas), it is key to provide seamless extension of 5G services anywhere anytime. IoT coverage to wide areas involving sensors and M2M connections are ideal services to make use of satellite wide area coverage.

In addition to the key performance challenges, we also outline system-level challenges that arise from the changing ecosystem in which 5G is expected to operate:

- **Privacy by design challenge**: provide accountability within the communication substrate and enable truly private communication when needed, aligned with policy constraints in terms of data management and ownership, ensured by the infrastructure operators that realize the overall service.

- **Quality of Service challenge**: in order to allow for optimizing the Quality of Experience5 (QoE) for the end user, 5G should provide differentiated services across various dimensions such as throughput, latency, resilience and costs per bit as much as possible independent of users' location with respect to the antennas deployment geography. This includes increased security, availability, resilience and delivery assurance for mission critical applications such as health-related or emergency applications, but also ultra-low cost solutions for emerging countries with less stringent QoE requirements.

- **Simplicity challenge**: provide to 5G users the best network services seamlessly without complex customer journeys (e.g. for inter RAT switching).

- **Density challenge**: increased number of diverse devices connected in proximity, e.g., challenging the current architecture for mobility management.

- **Multi-tenancy challenge**: provide service solutions across different infrastructure ownerships, with the different networks (not necessarily IP-based) co-existing and providing and providing an integrated as well as efficient interaction between the wireless domain and the backhaul.

- **Diversity challenge**: Beyond the diversity of stakeholders, 5G must support the increasing diversity of optimized wireless solutions (to different application domains, e.g., M2M) and the increasing diversity and number of connected devices, and associated diversity of traffic types.

- **Harnessing challenge**: exploit any communication capability, including device-to-device (D2D), for providing the most appropriate communication means at the appropriate time.

- **Harvesting challenge:** devise radically new approaches to provide devices with power, which not only has to come from batteries, but also harvests existing environmental energy.

- **Mobility challenge**: support for unlimited seamless mobility across all networks/technologies. Location and context information challenge: provide positioning and context capabilities in the sub meter range in order to enable the Internet of everything, e.g., through the integration of cellular and satellite positioning systems.

- **Open environment challenge**: enable horizontal business models by opening the right business interfaces within the system in order to enable flexible operator models in a multi-tenancy fashion.

- **Manageability**: Improve manageability of networks in order to reduce the need for manual management and reduce the human involvement. QoE is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and / or enjoyment of the application or service in the light of the user's personality and current state. Whitepaper for public consultation, August 2014 13.

- **Hardening challenge**: deploy a communication system through a combination of bearer techniques such as cellular and satellite that is intrinsically robust to attacks from malicious entities as well as to natural disasters; a resilience without which the smart-grid/smart-city paradigm will never be achieved.

- **Resource management challenge**: provide access agnostic control, policy and charging mechanisms and protocols for dynamic establishment, configuration, reconfiguration and release of any type of resource (Bandwidth, Computation, Memory, Storage), for any type of devices (e.g. terminal, car, robot, drone, etc.) and services (e.g. Network, Security, Data, Knowledge, Machine, and Thing as a Service), including in E2E fashion when necessary.

- **Flexibility challenge**: devise truly flexible control mechanisms and protocols for relocating functions, protocol entities and corresponding states in a truly end-to-end manner, leveraging programmable network technologies such as SDN and NFV.

- **Identity challenge**: provide identity management solutions for any type of device (terminal, car, robot, drone, etc.) with access agnostic authentication mechanisms that are available on any type of device, device to device and network to device, independent from specific technologies of communication entities and of their current location.

- **Flexible pricing challenge**: provide methods for flexible pricing mechanisms across and between different parts of the future 5G value chain in order to enable pricing regimes that are common across the industries that will utilize the future 5G infrastructure. Furthermore, new business models could consider the underlying technology (e.g., wireless or mobile, legacy or later one) as well as other aspects like the contribution of a privately owned small cell to the operator's infrastructure through its open access.

- **Evolution challenge**: provide the ability for evolution and adaptation, allowing a transparent migration from current networks and permitting future development.

From a system level perspective, our vision outlines one challenge that overarches all technology focused research priorities; this challenge is that of flexibility. Given the wide range of stakeholder incentives and requirements, future 5G system must provide an enormous degree of flexibility. This challenge drives 5G away from the rather rigid pre-5G designs with limited service classes available to its users and few assumed deployment models at the communication substrate level. Specialized network components provided as specialized hardware boxes, based on commonly agreed standards, reflect this rigidity in design. In order to achieve the necessary flexibility of 5G systems, we foresee a high degree of programmability of otherwise standard network-enabled hardware components, such as reflected in the current network function virtualization (NFV) efforts. This programmability pushes the resolution of incentive conflicts from the early standards phase to the later deployment phase where network emulation as well as validation of software components paves the way to significantly reducing the service deployment time from several days to minutes or even seconds. The programmability also provides the ability to account for the usage of resources across the network, enabling the envisioned flexible incentive alignment across several stakeholders. Furthermore, with resources interpreted as that of computing, storage, volatile memory and bandwidth, the envisioned programmability of the network will also facilitate solutions for the guarantee challenge at the system level by allowing for optimizing across all these resource dimensions towards a single deployed solution. Combining flexibility and programmability in future 5G systems should also allow to build complex, mission-critical services with specific requirements in terms of service quality, where a dedicated physical infrastructure would be normally required. Harnessing the true benefits of programmability is only achieved by openness of key APIs to network services across different domains.

Furthermore, the future 5G system needs to perform in an energy-efficient manner, by meeting at the same time all the necessary 5G KPIs in line with the 5G vision. This trend will result in the design of energy-efficient hardware that ultimately reduces the energy consumed per bit. Beyond these identified technology challenges, we also identify research priorities needed in economic and policy research that investigate the impact of this new flexibility on business and standards processes as well as on policy- making processes. We believe that this research will be transformative to today's processes. For Whitepaper for public consultation, August 2014 14 instance, we need to investigate the role of standards to agree on technological and business interfaces within the system in the light of upcoming virtualization solutions. We will also need to investigate the impact of new spectrum management approaches on spectrum policy, possibly integrating the technological solution (e.g., the exchanged information for spectrum sensing) into the policy approach itself.

Finally, the flexible alignment of incentives, as envisioned by our 5G vision, will truly enable fluid information-driven markets through our 5G platform. We will need to study the potentially transformative changes within the many industries that 5G intends to provide solutions for in the light of this new economic market fluidity. For instance, we can already see today that the 'app economy' of smartphone- based applications has had an impact on areas such as public transport as well as health. Quantifying this impact, identifying new business models as well as fostering emerging stakeholders in these future markets are the priorities of this economic research in the 5G context.

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.

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:

Figure 9.
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.

8

FUTURE AND CONCLUSIONS

The many initiatives and discussions on 5G going on around the world by governments, vendors, operators and academia demonstrate the continuing ethos of collaboration and innovation across the industry. In these debates, we must ensure that we continue to co- ordinate with aligned goals to maintain momentum in completing the definition of 5G. The key 5G considerations at this stage are: When 5G arrives will be determined by what 5G turns out to be as discussed earlier, there are currently two differing views of what 5G is. The first view makes its implementation somewhat intangible – 5G will become a commercial reality when sufficient industry voices say so, but this will be difficult to measure by any recognizable metric. The second approach is more concrete in that it has a distinct set of technical objectives, meaning that when a service is launched that meets those objectives it will count as the advent of 5G.

As the requirements identified for 5G are a combination of both visions, in some cases the requirement set is self-contradictory – for example, it would not be possible to have a new RAN with beam forming and meet a requirement for power reduction, because beam forming uses a lot more power than today's RAN. As a result, there must be an established answer to the question of what 5G is before there can be an answer to the question of when it will arrive. The case for a new RAN should be based on its potential to improve mobile networks. The principal challenge in the 5G specification is the sub-1ms latency requirement, which is governed by fundamental laws of physics. If, as discussed above, this challenge proves too much and the requirements for sub-1ms delay are removed from 5G, the need for a new RAN would be questioned. Whether a new air interface is necessary is arguably more of a question of whether one can be invented that significantly improves mobile networks, rather than on a race to the arbitrary deadline of 2020.

This raises the question of where the industry should go next. Without a new air interface, the '5G' label makes less sense, as the industry would need to shift to the evolutionary view of 5G - with the new networks building on LTE and Wi-fi by adding new functionalities and architecture. 5G should not distract from more immediate technological developments. Technologies such as multiple-carrier LTE-A, NFV/SDN, HetNets and LPLT networks will form an important part of the evolution of mobile networks. Each has the potential to offer tangible benefits to operators within the next few years, and so the industry should not risk losing focus on the potential benefits of these technologies in the short and

LTE remains very important and will continue to evolve, there remains considerable potential for future LTE growth, which still only accounts for 5% of the world's mobile connections. LTE penetration as a percentage of connections is already as high as 69% in South Korea, 46% in Japan and 40% in the US, but LTE penetration in the developing world stands at just 2%. Hence there is still a substantial opportunity for operators to generate returns on their investment in LTE networks. LTE technology will also continue to develop, with operators already making a considerable amount of progress in increasing the data speeds of their existing networks by adopting multiple-carrier LTE-A technologies. Therefore, while there remain monetization and interconnect issues around LTE, these advancements will enable operators to offer many of the services that have been put forward in the context of 5G long before 5G becomes a commercial reality.

The industry should make full use of governmental interest and resources, there is a considerable level of governmental interest worldwide in the subject of 5G, not to mention a substantial amount of funding available for research and development in the field. It is important that the industry leverages this and effectively channels the focus and resource into something meaningful for both operators and their customers. This should be implemented in a coordinated framework to avoid a fragmented vision of 5G for different parts of the world.

5G is an opportunity to develop a more sustainable operator investment model. If previous generations of mobile technology have taught us anything, it is it that, as with each preceding generation, 5G will unlock value in ways we cannot and will not anticipate. Services that were initially expected to have a negligible impact became hugely popular (e.g. SMS), while those expected to be the 'next big thing' have been slow to gain traction (e.g. video calling). Through the development of 5G, we as an industry can expect a paradigm shift in the way that all the stakeholders in the mobile ecosystem play their role. Regulators especially can use this as an opportunity to create healthier environments that stimulate continuing investment in next generation technology. Some of the business cases that have worked well for 3G and 4G technologies may not be the right ones for 5G. By actively conceiving and exploring 5G business cases at an earlier stage, operators will have greater potential to shape the new paradigm. The GSMA will continue to work with its members to shape the future of 5G. Whichever form 5G eventually takes, the GSMA, as the association representing the mobile industry, looks forward to contributing to the development of a 5G ecosystem through collaboration and thought leadership.

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