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European Leadership in 5G

In-Depth Analysis for the ITRE Committee

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DIRECTORATE GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY

European Leadership in 5G

IN-DEPTH ANALYSIS

Abstract

Prepared by Policy Department A at the request of the European Parliament's Committee on Industry, Research and Energy (ITRE), 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.

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LIST OF ABBREVIATIONS

5G	Fifth generation mobile communications system
CEPT	European Conference of Postal and Telecommunications Administrations
CMRI	China Mobile Research Institute
DSM	Digital Single Market
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FTTH	Fibre to the home
FWA	Fixed wireless access
GSM	Global System for Mobile communications, digital cellular standard for mobile voice and data
GSMA	The GSM Association
ISP	Internet service provider
ITU	International Telecommunication Union
IoT	Internet of Things
LAA	Licensed assisted access
LE	Licence exempt
Li-Fi	Light Fidelity, a bidirectional, high-speed and networked wireless communication technology similar to Wi-Fi
LoS	Line-of-sight
LTE	Long-Term Evolution, a standard for high-speed wireless communication
M2M	Machine-to-machine
MIMO	Multiple-input and multiple-output

MNO Mobile network operator

NFV Network function virtualisation

NGMN Next Generation Mobile Networks alliance

NPE Non-practising entity

NRA National regulatory authority

OFDM Orthogonal frequency division multiplexing

OTT Over-the-top, delivery of services over the internet

PSTN Public switched telephone network

RSPG Radio Spectrum Policy Group

SDO Standards development organization

SON Self-optimising networks

SVOD Streaming video on demand

UPS Uninterruptible power supply

TDD Time Division Duplex

VGTF Verizon 5G Technology Forum

Wi-Fi Wireless Fidelity, technology that allows electronic devices to connect to a wireless local area network

WRC World Radiocommunication Conference

xDSL All types of digital subscriber lines

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EXECUTIVE SUMMARY

5G beyond the hype

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.

Questions over demand, business models and spectrum

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.

1. 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.

1.1. 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.

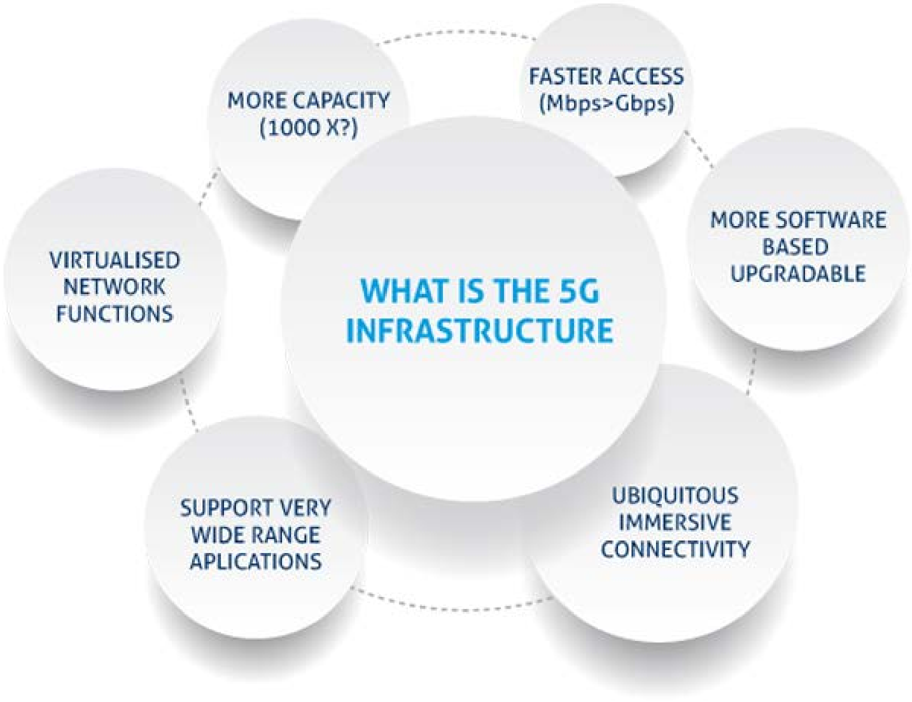
One view of the concept comes from the EU's leading 5G collaborative research initiative, the 5G PPP (public private partnership) with €1.4 billion of funding, which envisages 5G not just as a new network but as the next infrastructure (see Figure 1).

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 1. 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.

1.2. 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).

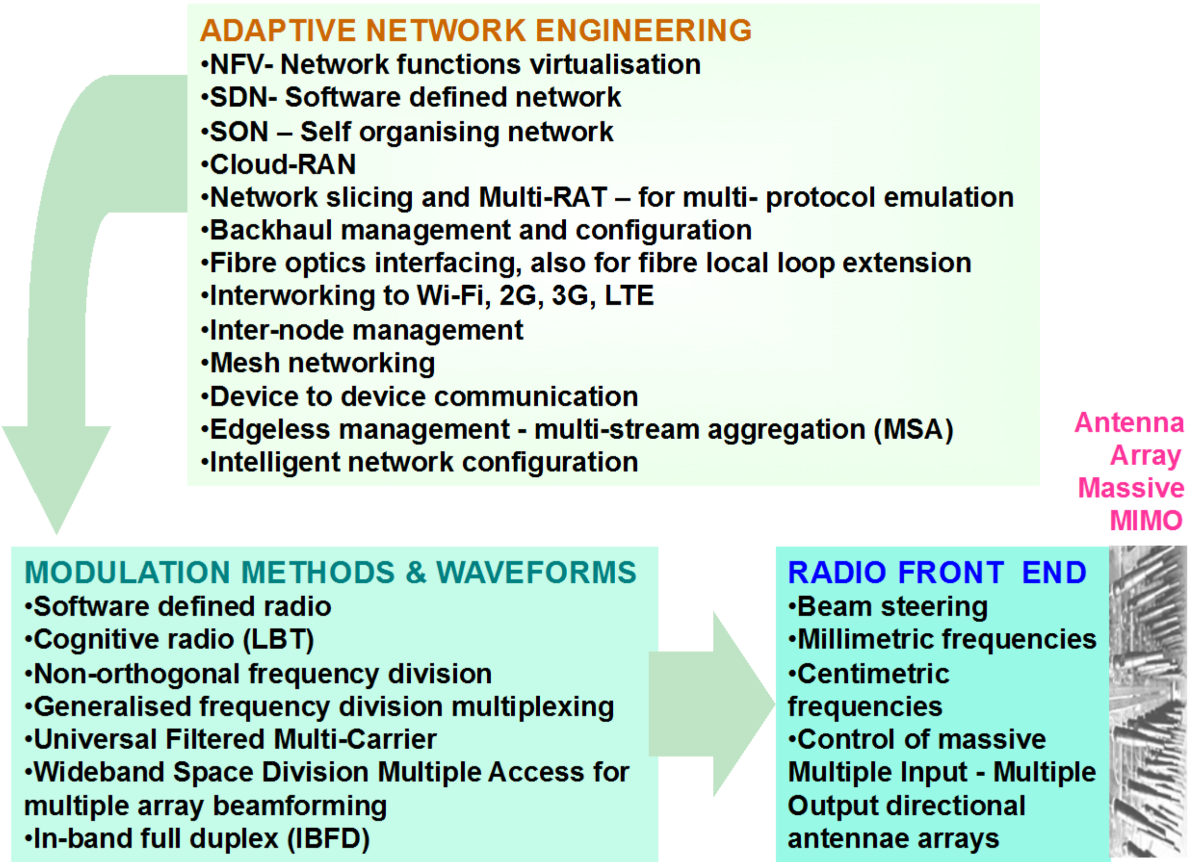
- Complex digital signal processing for Internet Protocol (IP) packet delivery (with the IPv6 addressing), possibly with cognitive radio techniques for dynamic spectrum access (DSA) with adaptive frequency selection.
- Possibilities of non-cellular modes of access with mesh networking between nodes, 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:

1. 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
2. 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
3. A radio front end for transmission/reception which combines technologies for directional beamforming and spatial multiplexing

The major items are shown in Figure 2:

Figure 2. Summary of 5G Advances Categorised by Function



Source: Authors.

1.3. 5G in Relation to Other Connectivity Options

1.3.1. 5G as a Complement or Substitute for Current Networks

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.

1.3.2. Convergence Between Computing-Telecoms-Broadcasting

The technology for 5G will combine very high speed computing with minimisation of electrical energy, which will be necessary for the next generation of communications. Low energy is important for end-user devices, not only for the communications process but also for the display and storage functions. The high bandwidth promised is the ideal link for high definition full motion video content, as 5G promises a thousand times higher peak bit rate than current mobile.

These developments would enable real convergence of telecommunications and broadcast media. MNOs would like to augment their bit-pipe role with higher revenue and margin content while the media sector would covet a new way of delivering their content. Ubiquitous urban 5G networks could facilitate converged operators into global media content distribution (and ownership) markets.

1.3.3. 5G and the Internet of Things

A potentially leading application for 5G, as seen by the telecommunications industry, is machine-to-machine communications for the Internet of Things (IoT). However, whether 5G will emerge as the infrastructure for the IoT is questionable, as other options are possible. For instance, significant players such as GE, with its concept of the Industrial Internet, and early small successful players in the industrial IoT arena, such Sigfox, Semtech and Neul (with its "white space" device technology[3]) see a different kind of infrastructure designed for specific purposes. Many IoT applications will require rather slow data speeds (under 10 kbps and sometimes less than a few kilobytes per hour), long distance (up to 500kms) to meet wide area network requirements, and very low cost (for example, a sensor costing less than €20).

Certainly the 5G network is likely to be the basis for some IoT communications, especially for home networks, and more specifically for home entertainment systems connecting video streams between many consumer devices in the home and also for domestic appliances for internet access. The exact use-cases are still being elaborated in various research projects.[4]

1.4. 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.

1.4.1. 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).

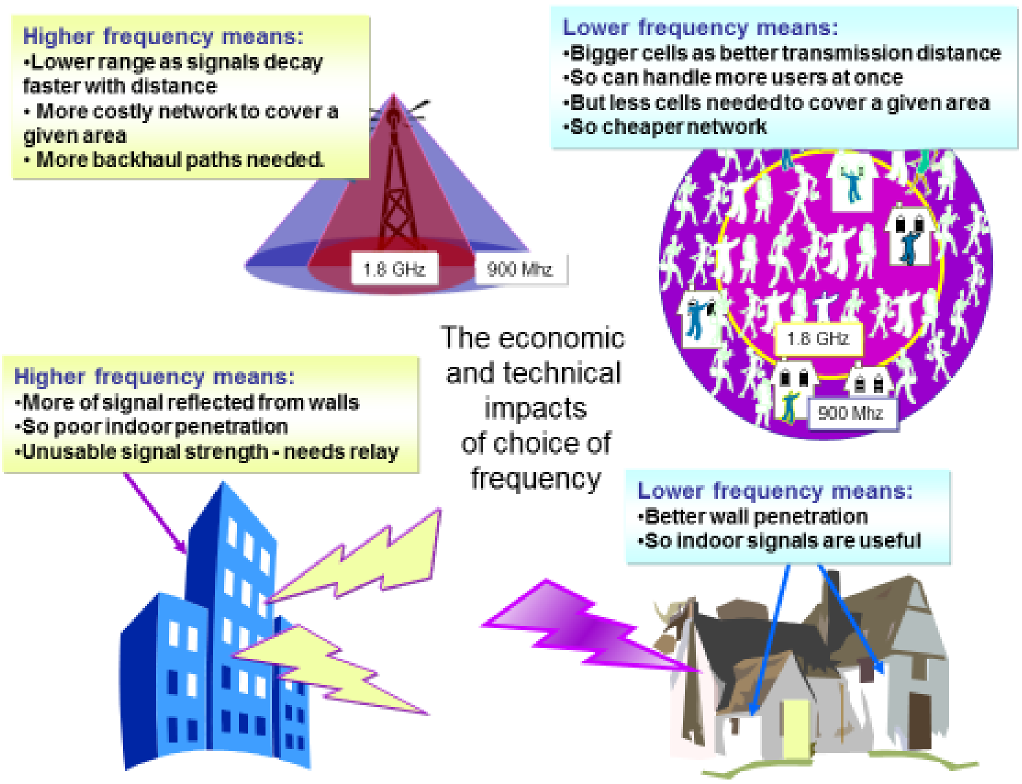
1.5. Issues With the 5G Concept

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.

Figure 3 Economic and Technical Impacts of Frequency Choice



2. THE STATE OF PLAY IN THE EU

2.1. 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.

2.2. 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.

2.3. 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.

2.4. 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.

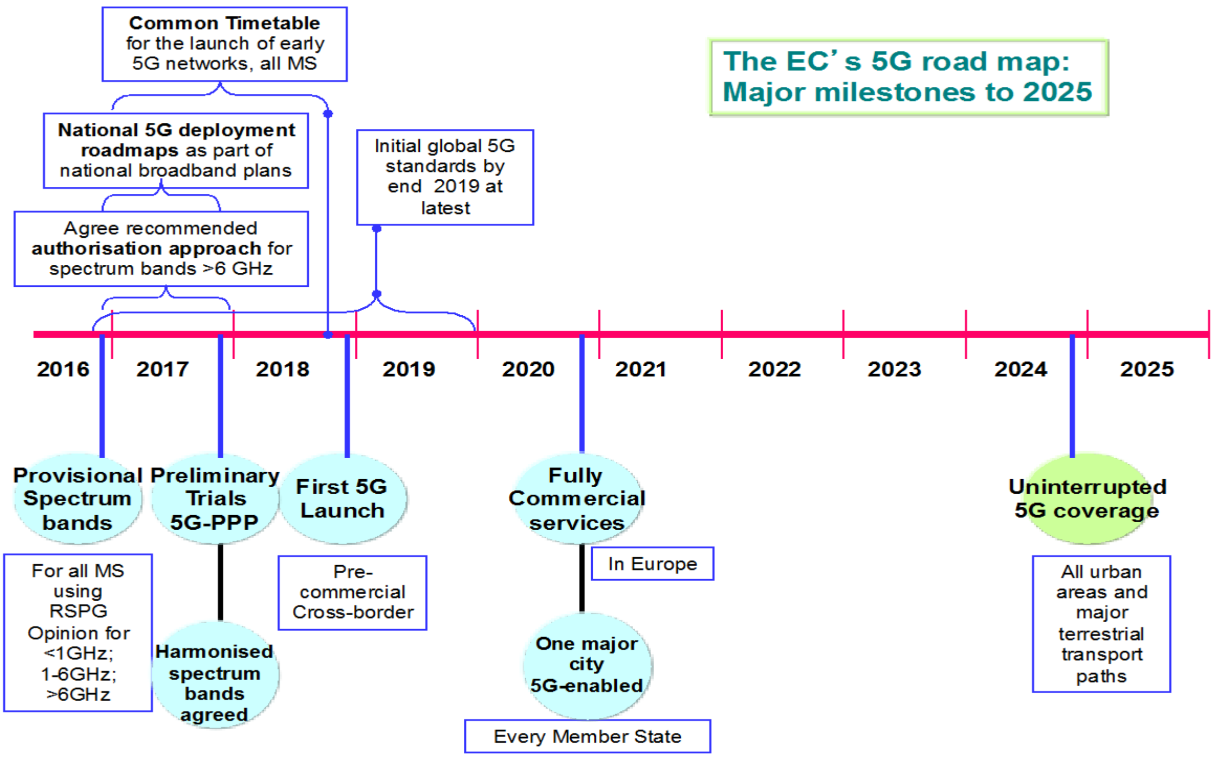
2.5. How Well Placed is Europe in the 5G Race?

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. Figure 2 summarises the EU roadmap for 5G development with planned achievements and notable milestones up to 2025.

Figure 4. European Commission 5G Roadmap 2016-2025



Source: Authors' interpretation of the 5G Action Plan.

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.[9]

3. BUSINESS MODELS AND BOTTLENECKS

3.1. 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.

3.2. 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)?

3.3. 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.

3.3.1. 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.

3.3.2. 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.

3.3.3. 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.

3.3.4. 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.

3.3.5. 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.

3.4. 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 Table 1

Table 1 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.

3.5. 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.

3.6. 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.

4. CONCLUSIONS

4.1. Refining and Improving Policy Support for 5G

Following the analysis in the preceding chapters, the question is whether current policies are appropriate or whether new policies are needed, and for which domain of applicability. Despite the uncertainty surrounding business models for 5G, there is justification for certain types of EU support for the development of the most advanced radio telecommunications innovations because of its long-term potential for the EU economy. Ultimately, the justification for this is that the evolution from current radio technologies proposed under the classification of "5G" could be used much more widely than just for a small-cell broadband network for streaming entertainment video. Consequently, support should be logically structured and administered over the long term, with a 10-year view. Policy should help to both advance the EU's position in the global telecommunications industry and to build the next European communications infrastructure.

Overall, what is needed is a more effective and practical policy for 5G than seen to date, one in which the demand side takes precedence rather than simply supporting research for its own sake. It requires further analysis of two questions:

- What are the short-term applications for 5G, including their detailed business cases, and how can they be brought to market to stimulate new employment and exports?
- What are the long-term research areas that are likely to bring wide-ranging advances to meet consumer needs?

4.2. An Industrial Strategy to Support 5G Leadership in the EU

There is much to commend in the European Commission's approach to 5G, as articulated in its Action Plan.[13] What we propose here is not too different, but in its intentions it diverges from the current approach, placing much greater emphasis on the long term to formulate a comprehensive industrial strategy to support EU leadership in 5G.

Recommendation 1: Precise definition of goals and scope

Current plans for 5G over the short term and its rollout in the EU are not yet well defined, understood, or agreed upon. Hence, the first step should be to determine Europe's business goals for its infrastructure and then its functional requirements. This is entirely missing in the current strategy. It should identify the target technologies for a 5G support effort. For instance, is 5G a technology to replace the fixed local loop cabling in urban conurbations with a fully converged offering of mobile and fixed over a radio carrier? Or, is 5G a more wide-ranging concept, a research project on advanced radio interfaces and network engineering techniques for the longer term? This analysis should clearly identify both the likely shorter-term 5G applications over the next five years, as well as the longer-term technology research to 2030 for a new generation of mixed radio/fixed line infrastructure.

Recommendation 2: Long-term technology research for a new infrastructure

5G should be considered mainly as a long-term research effort for the EU's future communications infrastructure. It should concentrate on new building blocks, such as long-distance rural radio networks for the next generation internet. As such it should feature prominently in the next RTD&I Framework Programme following Horizon 2020, and feature perhaps ten to twenty large projects, the key actions being:

- Identification of major building blocks.
- Choice and mobilisation of major EU research centres and projects.
- Development projects for new network architecture elements.
- Seeding of start-ups and their nurturing with support through industrialisation.

- First deployment of major infrastructure elements.
- Full industrialisation support with funding, preferential procurement, etc.

Recommendation 3: Shorter-term 5G applications for small cell networks

European mobile industry and its suppliers would like 5G to be their next mobile product including industrial and domestic IoT. But the web services providers see it more for high-speed links for untethered devices in urban areas, a sort of super Wi-Fi. However, a wider view should be taken based on a broader consensus to define the real goals that a short-term 5G industrial strategy should support. A much better understanding of the nature of 5G would come from an analysis of the advances in applications and services that 5G may be expected to bring, to offer a major improvement over existing communications technology. While this echoes the Commission's and the industry's approach, more emphasis should be placed on the demand side, with:

- *A needs analysis* of the demands that 5G can meet through its new applications and business models.
- *Technical requirements of the business models.*
- *A detailed roadmap for 5G technical research.*
- *Demonstrators as proof of concept, to bring real 5G advances to market*, e.g. a collaboration between the telecommunications industry, local administrations and a rollout organisation at EU level could set up a series of beacon implementations.
- Finding ways to encourage new service providers to enter the 5G market.

Recommendation 4: Spectrum policy for 5G based on spectrum sharing

To support the ultimate goal – achieving a new communications infrastructure for the EU in the long term – a specific approach to spectrum licensing for 5G networks is called for. The use of licence exempt (LE) status should be considered more seriously since many 5G bands are likely to be shared. Pursuit of efficient sharing technologies, and the open entry to the market that LE affords, would both spur essential innovation in telecommunications technology in the EU, akin to the approach in the USA where the FCC has already designated bands for 5G. However, the EU could take this much further, allowing spectrum sharing in all 5G bands, which would encourage new entrants in technologies and 5G services, leading to a more competitive EU market and cementing EU leadership.

4.3. Impact of the Recommendations

Assessing the full impact of these recommendations is complex, because of the considerable uncertainties involved. In the short to medium term, the recommendations would have an important impact on the EU's strategic position and leadership regarding 5G, although this is difficult to measure because of its intangible nature. The long-term impact of the recommendations is likely to be considerable in terms of their effect on economic growth and employment, as the next generation of the local loop connection is rolled out using 5G technology, merging fixed-line access with mobile. The impact on economic growth and employment could be estimated but would require complex modelling to forecast the effects of more efficient telecommunications as a broad stimulus to business, the costs in deploying new networks, as well as the impact of seeding of new business models for new types of 5G operator.

Table 1 ranks the recommendations according to their likely impact, but note that they interact and their relative priority could change. For instance, long-term research may impact the priorities identified in the definition of goals and in spectrum policy.

Table 2 Recommendations Ranked According to Their Likely Impact

Recommendation	Ranking
Precise definition of goals and scope	1
Long-term technology research for a new infrastructure	2
Spectrum policy for 5G based on spectrum sharing	3
Shorter-term 5G applications for small-cell networks	4

NOTES

1 http://europa.eu/rapid/press-release_SPEECH-16-3043_en.htm.

2 5G PPP, https://5g-ppp.eu/about-us/.

3 White Space refers to the unused broadcasting frequencies in the wireless spectrum between the channels used by television networks.

4 See METIS II: 5G Use Cases from the METIS project, presentation, https://5g-ppp.eu/wp-content/uploads/2015/11/1-METIS-II-5G-use-cases_presentation-with-verticals.pdf.

5 For instance, on 12 October 2016 Ericsson issued a results warning as its global networking business fell 19%, Lex, "Ericsson: network effects", *Financial Times*, 13 October 2016.

6 European Commission (2016), *Connectivity for a Competitive Digital Single Market: Towards a European Gigabit Society*, https://ec.europa.eu/digital-single-market/en/connectivity-european-gigabit-society.

7 European Commission (2016), *5G for Europe: An Action Plan* {SWD(2016) 306 final} COM(2016) 588 final, 14 September.

8 Directive establishing the European Electronic Communications Code (14 Sep 2016), with https://ec.europa.eu/digital-single-market/en/connectivity-european-gigabit-society

9 Directive establishing the European Electronic Communications Code (14 Sep 2016), with https://ec.europa.eu/digital-single-market/en/connectivity-european-gigabit-society

10 Ofcom in the UK has proposed VHF spectrum for IoT applications, *VHF radio spectrum for the Internet of Things*, Statement, 23 March 2016

11 GE figures (2014) for its 'Industrial Internet of Things' with 16% CAGR to 2020 projected to be $15 trillion by 2030, from *Industrial Internet Insights Report for 2015*.

12 http://www.fiercewireless.com/europe/vodafone-cto-johan-wibergh-warns-industry-not-to-over-hype-5g?utm_medium=nl&utm_source=internal&mrkid=795840&mkt_tok=eyJpIjoiTWpWaE16UXlORFV3WXpKaSIsInQiOiJNS0NtRDByT0ZsXC9YT2RLU3V6bzNkNEI0OVp0QWdtNzdhTHhRVzliSjAyYU1yWU5EdzZVVEZ2TUN2djhOWkEyeWZYVmx2S1dEcDBSQVJJVmNsMXZNTzcza2VIWFd1dWdpZzJwQjJ3T09cL1pBPSJ9

13 European Commission (2016), *5G for Europe: An Action Plan* {SWD(2016) 306 final} COM(2016) 588 final, 14 September.

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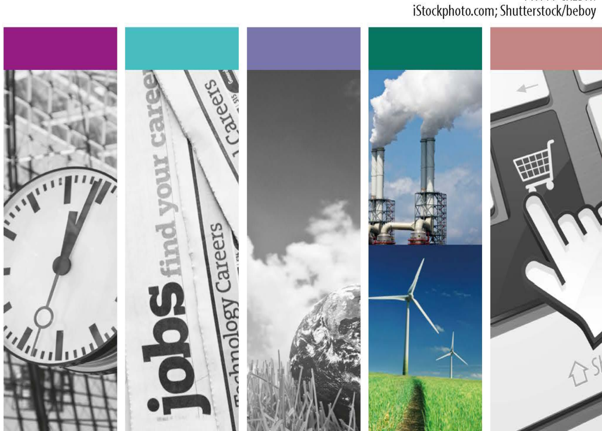

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