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Study on Implications of 5G Deployment on Future Business Models

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A report by DotEcon Ltd and Axon Partners Group

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Executive summary

5G is evolutionary rather than revolutionary

It is commonly supposed that 5G will lead to a step-change in the capability of mobile networks, opening up possibilities for innovative new services, such as the Internet of Things (IoT), connected vehicles and augmented reality (AR). Whilst 5G may eventually be transformative for some sectors, in the short to medium term these developments are more likely to be evolutionary rather than revolutionary. The speed of roll-out and adoption of 5G will depend on complementary investments being made in network infrastructure as well as new services, applications and products using 5G.

What 5G might bring

Network slicing will allow differentiated services

5G brings a number of enhancements over 4G, including high speeds, low latencies, enhanced reliability, lower power consumption and greater terminal device densities. Perhaps most important, 5G offers new network management possibilities that could enable a single physical network to support a number of virtual networks with different performance characteristics.

This network slicing creates, for the first time, the possibility of tailoring mobile data services to the particular characteristics of specific users. For example, a dense IoT sensor network might prioritise low power consumption of terminals over connection speed; at the same time, a separate network slice on the same infrastructure could deliver high-speed mobile broadband.

New business models

Services can be targeted to the needs of verticals and specific user groups

This new ability for differentiation of services without having to build different physical networks raises the possibility of services targeted at particular economic or industrial sectors – so called ‘verticals’ – as well as at specific user groups. Therefore, 5G has the potential to change business models for network operators relative to the current marketplace, where network operators have offered largely standardised services and differentiation has been limited to pricing plans.

There may be new intermediaries

This also opens up potentially new roles for intermediaries in the value chain, positioned downstream of network operators, offering to bundle and repackage connectivity for particular industries. For example, aggregators might put together trans-national connectivity packages for particular industries. In general, there are likely to be opportunities for orchestration of different networks, tying them together to create connectivity services for specific verticals.

Upstream entrant of wholesale cell densification services

There may also be opportunities for new players upstream of traditional mobile networks. For example, 5G is likely to require significant densification of current networks at high frequencies to meet bandwidth requirements. This may create new opportunities for independent operators to acquire sites in dense urban areas and indoor public spaces and deploy 5G infrastructure, offering wholesale services providing patches of connectivity to 5G operators. Given availability of appropriate spectrum, traditional network operators could also be bypassed by entrants focussed on providing connectivity for specific industries (for example, within factories or warehouses).

Entry should not be prevented by spectrum award design

Spectrum award designers need to be aware of these possibilities for upstream entry, rather than assume that the only buyers of spectrum will be incumbent MNOs. Spectrum should be packaged to allow entry, for example by allowing bidders to assemble smaller blocks to give flexibility over the amount of spectrum acquired.

Drivers of 5G roll-out

eMBB, is the initial driver of 5G

Despite these transformative possibilities of 5G in the long-run, there is currently broad consensus amongst stakeholders that initial deployments of 5G will be driven by enhanced mobile broadband (eMBB). Operators will be incentivised to deploy 5G by lower unit costs of network capacity and the need to maintain competitive service quality in the face of continued data growth.

eMBB may generate limited additional revenue

It is possible that eMBB alone will not create significant additional revenue from 5G for network operators. Experience of previous migrations from one mobile technology to the next suggests consumers pay a broadly similar amount even though data speeds have increased and bundled data and call allowances have grown due to falling unit network costs.

Prospects for additional revenue sources

Long-run incentives depend on additional revenues from new services

In the longer run, 5G roll-out incentives depend on incremental revenues from new services. In turn, incentives to develop and market novel services dependent on 5G will require sufficient 5G coverage, which creates a coordination issue.

Developers of applications and services will mitigate risks by having fall-back connectivity options

Any commercial developer of a new service or product benefiting from 5G connectivity will want to reduce its exposure to the risk of 5G roll-out being slow or geographically limited. We have found that developers tend to follow diversified approaches to connectivity, looking to develop services that will fall back smoothly onto slower or less capable mobile networks or which might even use quite different technologies. For example:

- Agricultural applications of dense sensor networks are unlikely to wait until 5G becomes ubiquitous in rural areas. Rather, developers wanting to get new products and services to market will adopt other interim technologies that are readily available. For example Long Term Evolution for Machines (LTE-M) or NarrowBand IoT (NB-IoT), or low-power wide-area technologies such as LoRa in a hub and spoke arrangement with centralised backhaul, possibly even using satellite.

- So-called 'vehicle to everything' (V2X) communications have a development path through 4G and are not dependent on 5G availability. Connected vehicles will need to make use of a wide range of connectivity strategies, include fall back to lower specification networks and peer-to-peer networking. We understand that car manufacturers are keeping all these options open, rather than relying on 5G availability. In the short term, 4G cellular vehicle connectivity will be used to deliver infotainment.
- A leading national broadcaster indicated that because of its public remit to make services available widely, it was concerned about developing new services using 5G capabilities if this would lead to a digital divide with those services only being available in urban areas and would need to have fall-back options.

Lack of a killer application

Incremental revenues from 5G are limited by substitute technologies…

For some applications, 5G will have a convenience yield. However, willingness to pay for 5G services in the short-to-medium term might also be limited by the availability of alternatives, including 4G and faster RLANs for example.

…but there may be many niche applications where the 5G is needed, just no killer application

It is likely that incremental revenues from 5G will derive first from niches where 5G provides capabilities that are not readily or cost effectively met by alternatives. Examples are services requiring very low latency over a wireless connection crucial for real-time control and safety critical applications, or those where high reliability and dedicated capacity may be very important for critical machine-to-machine communications, especially where the number of devices is massive.

Much of the discussion of 5G to date suggests that there are certain sectors where 5G will be important – or even critical – such as transport, medical applications and, more generally, IoT. However, we disagree that there are certain sectors that, by themselves, can provide significant additional new revenues within a reasonable timeframe to drive 5G roll-out. Rather, 5G is much more likely to have a large number of niche applications across many sectors, meeting particular needs that are not already well met by 4G or by alternative technologies.

The impact of 5G may in the long run be pervasive and much broader than the usual case studies suggest; at the same time, there is a challenge in identifying these various likely demands for 5G and creating services and pricing arrangements targeted at those uses.

Pricing structures and efficient take-up

Some pricing structures could lead to inefficient outcomes

Take-up may depend on providers establishing a suitable charging structure that is attractive relative to the alternatives. There is a danger that over-reliance on per-connection charging models could distort users' choices towards less efficient alternative technologies. Pricing structures need to balance benefits to new users and cost to the network provider; this may require certain risk-sharing arrangements between network operators and verticals.

Private networking

Private 5G networks should encouraged

We see considerable scope of private 5G networks within the confines of factories and warehouses. This is pro-competitive and will help drive broader 5G roll-out. It is important that spectrum allocation models take this possibility into account. Unlicensed spectrum may not be appropriate for these applications due to their reliability and security needs. A secondary licensing model could work well at higher frequencies with limited propagation.

There may be need for some degree of coordination about which bands should be used for private 5G networks and the licensing model for spectrum across Member States. This is a matter for possible guidance from BEREC.

Consequences of small cells

Site owners may gain power due to small cells

A particular issue is the possibility of site owners gaining increased power within the overall value chain due to the difficulties of finding appropriate sites for small cells, especially in dense urban areas and 'quasi-public' spaces such as stadia and shopping centres that are privately controlled.

Owners of pivotal sites may have a degree of market power and might even have an incentive to limit access to network operators to extract more rent from those operators that are present. Any distortion of downstream competition in mobile services can be removed with obligations on any network operator present to make a corresponding wholesale service available (in effect a neutral host).

Governments can take action to increase the supply of sites

This measure does not entirely prevent rent extraction by pivotal site owners. However, their power can be reduced by increasing the supply of sites. Planning constraints should not be excessively tight. Public sector bodies may control appropriate site for small cells in urban areas (e.g. street furniture or roofs of social housing); there is a danger that in seeking to maximise their commercial returns, these bodies might have a degree of market power.

It is possible that fixed operators might have certain advantages over pure mobile operators in deploying small cells, for example bundled in consumer routers to support FTTP services.

Availability of backhaul

Rural 5G deployments need backhaul and, in some cases, the necessary fibre infrastructure may be lacking. It may be possible to piggy-back on interventions aimed at encouraging high-speed broadband in rural areas. Physical infrastructure access may help to some extent, but this may not be particularly effective in encouraging fibre in rural areas if physical infrastructure is lacking.

Infrastructure sharing

5G is likely to lead to much more infrastructure sharing, due to the use of small cells. Sometimes there may be physical limits on how many distinct networks can be accommodated at a site.

Regulators need to be alert to excessive concentration at the network level due to infrastructure sharing. Charging models for shared infrastructure should ideally be based on capacity-based charges to ensure that there are no retail competitive effects. However, we question how effective this can be in protecting competition, when the agility of 5G networks might allow rapid reallocation of capacity between sharers.

Edge computing

It is possible that applications such as augmented reality might use edge computing for low latency applications. Edge computing can only be procured from 5G network operators. Open standards for portability of edge computing applications may be important to ensure that consumers are not locked in to one network operator.

1 Introduction

The Body of European Regulators for Electronic Communications (BEREC) has commissioned DotEcon Ltd (DotEcon) and Axon Partners Group Consulting SL (Axon) to conduct a study on implications of 5G deployment on future business models.

This study aims to help BEREC improve its understanding of 5G in terms of the key technologies and services that may emerge, and the obstacles and enablers for success, with a focus on the near term, specifically the time period from **2018-2022**. In particular, BEREC would like to understand the implications of 5G for market structure, market dynamics and competition in the telecommunications market and other related markets.

In line with these objectives, our report is divided into six sections:

Background and context to the development of 5G - This section summarises the main European 5G initiatives and regulatory measures.

Key 5G technologies - This section provides an overview of the key aspects of 5G technology and their implications for services, including developments in the radio access network (RAN) and underlying network infrastructure. We consider the progressive 'evolution' from 4G/LTE-A, but also how 5G might allow for more fundamental changes than the shift from 3G to 4G in terms of enabling services that were not previously possible.

Identifying potential use cases of 5G – We consider the main 'vertical' industries typically considered to be potential beneficiaries of 5G and consider possible use cases within these sectors. We ask which of these use cases are likely to be important in providing incentives for 5G roll-out and identify any particular issues or barriers to 5G adoption in those sectors.

Potential implications of 5G deployment on business models and value chains - We consider the possible impact of 5G on business models and value chains within telecoms and vertical sectors and consider any new opportunities that may arise, including the potential for an increasing role for intermediaries. This may have implications for both the telecoms and adjacent markets in terms of market structure, competitive impacts and charging models to monetise 5G network investments.

Drivers and obstacles – In this section we consider the main drivers and obstacles to deployment of 5G services.

Regulatory options - Having identified the drivers and inhibitors, we will consider the key questions BEREC and NRAs should consider when assessing how the regulatory environment can be set to facilitate successful deployment of 5G services.

2 Background and context: the development of 5G

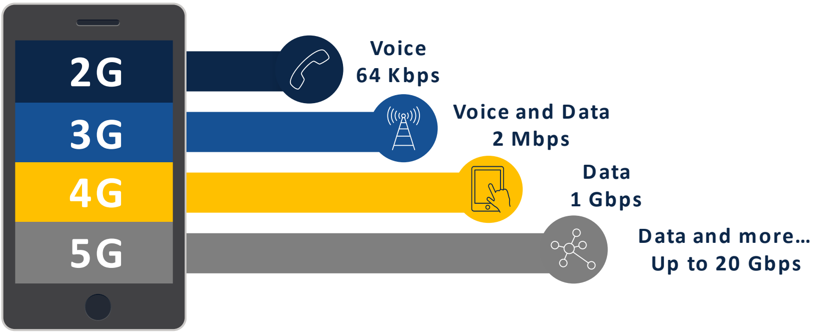
2.1 Defining 5G

The next generation of wireless networks

5G is the term used to describe the next (and fifth) generation of wireless networks, beyond current 4G LTE networks. Although a final standard for 5G is yet to be formally designed,[1] 5G networks are expected to build on, and smoothly integrate with, the legacy of previous generations of wireless network. In the first instance, 5G represents an evolution of existing radio access technologies.

From 2G to 4G, each radio access technology generation over the last 25 years has focused on improving the speed and efficiency of wireless networks to enhance mobile services.

Figure 1: Evolution of cell data rates under different radio access technologies



Source: DotEcon and Axon

Each transition has been driven by the greater capabilities of each generation over its predecessor. 3G enabled mobile internet and data connectivity at a much more advanced level than 2G.[2] 4G was able to serve the massive increase in mobile data traffic, something 3G was not capable of.

With more people using mobile broadband as services and applications expand, more devices of various types connecting to mobile networks and continued growth in data, further enhancements will eventually be required. Operators are looking

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[1] Although, 3GPP Release 15 has defined the 5G system architecture. See 3GPP Release 15: www.3gpp.org

[2] The emergence of (limited) data connectivity and mobile internet predated "3G" in the form of General Packet Radio Service (GPRS) (Release 97).

ahead to identify ways their networks can be readied to meet future capacity and performance requirements.

5G will support expected mobile data growth

The deployment of 5G networks is seen as important in fulfilling expected mobile data traffic growth. However, 5G differs from previous generations in important ways. Improvements to existing mobile broadband services to provide enhanced mobile broadband (eMBB) is just one use-case for 5G. In the longer run, 5G is expected provide tailored connectivity to meet the particular demands of different user groups, including particular industries (so-called '**verticals**'). Verticals may need data connectivity both to use internally for their own operations and to embed within the products and services they supply to their end customers.

5G will allow for the emergence of new services.

5G will create opportunities for network operators to tap new sources of revenue by developing infrastructure that can deliver a range of innovative services for enterprises, including IoT (**Internet of Things**) applications and deep integration of connectivity (e.g. transport telematics). For the first time, mobile networks will be designed to address the varying needs of different industries and the rise of connected devices (so-called **massive machine-type communications** – mMTC). As more devices and objects need to be securely, automatically and remotely connected and monitored – allowing systems, machines and infrastructures to run with end-to-end machine-to-machine communication – a large number of sectors may become increasingly reliant on wireless network solutions.

5G brings network performance enhancements

5G is projected to co-exist with the 4G networks, but to deliver improved **connectivity** through high speed, reliable and secure communications to approximately one-third of the global population by 2025, five years after its launch[3].

5G is able to bring **enhanced capabilities** (a topic discussed further in Section 3), including lower latency, high resource efficiency, decreased energy consumption, and enhanced security. This can drive access to a broad range of applications and services, as well as opening opportunities for new business models within the telecommunications sector and key verticals.

The software and IT industry in Europe stands to evolve because the 5G network services will rely on software and virtualisation, creating an **expanded ecosystem**. This may create options to develop new partnerships and synergies across industries.

5G brings agility in network characteristics

5G will allow for a shift from networks designed and built from the outset for specific performance characteristics to **agile networks** that can be programmatically assembled and configured for specific use cases. In effect, a common network infrastructure can carry

[3] GSMA Intelligence, Global Mobile Trends, 2017.

multiple ‘virtual’ networks with differing performance characteristics aimed at different types of users, with this being readily reconfigurable without needing further physical investment.

2.2 Global trends in information and communications technologies

The requirements for 5G ultimately derive from established, global ICT trends, as more industries look to ICT both to improve their productivity and to develop attractive new services and products for their customers. This creates demand for faster connections, increased portability, higher quality experiences and increased security from mobile data.

Table 1 below shows some of the emerging trends in the ICT sector, discussed in more detail below. These are likely to be significant drivers of growth, innovation and disruption across many industries; 5G may have an important role in supporting them.

Table 1: Role of 5G in global telecom trends

Major trend	Key role of 5G
Connectivity: growth in devices, content and data traffic	• Handle growth in a cost-effective, high-speed and energy-efficient manner.
Proliferation of value-added services and over-the-top (OTT) players: operators adapting to changing times	• Support evolution of richer content types such as 4K, 8K, VR, AR, 360° videos etc. • Enable telecoms operators to compete with OTT players through partnerships and quality offerings.
Fixed Wireless Access (FWA) technology: the great wireless migration	• Utilise much higher frequency bands than current 4G networks. • Solve the last mile problem[4].
Digitisation and advanced analytics: achieving maximum value from each customer	• Digitise and overhaul business models of telecom and adjacent industries. • Provide data analytics to accurately segment and generate maximum value from each customer.
Internet of Things (IoT): explosion of connected devices	• Connecting everything from smart home devices to self-driving cars and robots. • Improve the latency capabilities of current 4G LTE systems, leading to increased efficiency.
Network upgrades and security: need for security by design	• Ensure quality, security and safety. • Transform security to be the new area of competitive advantage for operators.
Consolidation, bundling of services and M&A: attractive vehicle for entering new markets	• Increase consolidation and M&A activities amongst operators to gain returns on investments in 5G networks. • Increase network sharing to achieve densification.

Source: DotEcon and Axon

Connectivity: There has been a massive increase in demand for connectivity driven by smartphones (and other connected devices) becoming a channel for consuming content such as music and video, running a large number of applications including payments and e-commerce, and remotely controlling devices of various types. In the longer run, it is unrealistic to expect sustained - or even accelerating - rates of data growth to come from consumer devices alone. Long-run growth in data volumes may also come from new services, including connected devices communicating directly machine to machine. 5G is expected to have a role in meeting this growing demand by both delivering enhanced mobile broadband and opening up new opportunities serving industries.

[4] Last mile is the portion of the network that reaches the user´s premises. Bulk of the costs and most of the complexity involved in fixed access deployments are associated with the last mile.

Proliferation of value-added services and over-the-top (OTT) players: OTT (over-the-top) players have continued to make gains in core communication services such as messaging and voice. 5G could help support OTT services based on even richer content types.

Fixed Wireless Access (FWA) technology: Fixed Wireless Access (FWA) is an established means of providing internet access to homes using wireless network technology rather than fixed lines. FWA might become an alternative to fixed broadband access due to increased spectrum availability and technological progress in the 4G and 5G arena. Although FWA can be achieved through current mobile technologies, it cannot offer the download speeds or latency levels that might be demanded by the users in future nor is it currently a cost-effective option in fixed locations. 5G-based FWA might enable more robust services with improved capacity and at a lower cost. FWA based on 5G would also be a stepping stone to full 5G mobility, possibly contributing to a smoother and swifter transition from 4G to 5G for users.

Digitisation and advanced analytics: Digitising business operations can make companies more productive and improve customer satisfaction, all of which lead to increased revenues. Advanced analytics can allow businesses to segment customers and allowing them to predict customer behaviour, deriving more value from each customer. 5G´s ability to support data collection and distributed processing through edge computing might assist certain aspects of data analytics and digitisation.

Internet of Things (IoT): Significant growth in the number of connected IoT devices is expected, with a CAGR of 21% per annum until 2022[5], driven by a growing range of use cases and the falling cost of devices. Mobile network operators are well placed to offer connectivity for emerging IoT applications due to their existing coverage. Although alternative technologies may be sufficient at present, including improvements being made to 4G services to support such applications, 5G might achieve the reliability, latency, scalability, security and ubiquitous mobility that could support proliferation of a mass-scale IoT environment.

Network upgrades and security: The demand for improved customer experiences and cost-efficient network operations are currently driving network upgrades. Further improvement in network coverage may be important for serving some verticals. There will also be increasing demands for network security and integrity from Governments, businesses and consumers. 5G

[5] Ericsson, "Mobility Report", 2017. Available at: https://www.ericsson.com/assets/local/mobility-report/documents/2017/ericsson-mobility-report-june-2017.pdf

networks will be aiming to serve not only individual customers, but also other industries in providing diverse services. Through scalable identity management, distributed authentication and network slice security amongst others, 5G will be capable of building a more efficient and effective security solutions.

Consolidation, bundling of services, and M&A: Acquisitions are an attractive vehicle for telecom players to create product offerings and services beyond their traditional capabilities and for entering new markets and businesses. We have already seen operators expanding the range of their offerings through quadruple play of services of telephone, television, broadband and wireless. Some transactions are also targeted at entering adjacent industries. The level of cost and capabilities required to achieve scale in 5G might become a further factor in M&A plans among network operators, communications companies, and mobile and fixed operators.

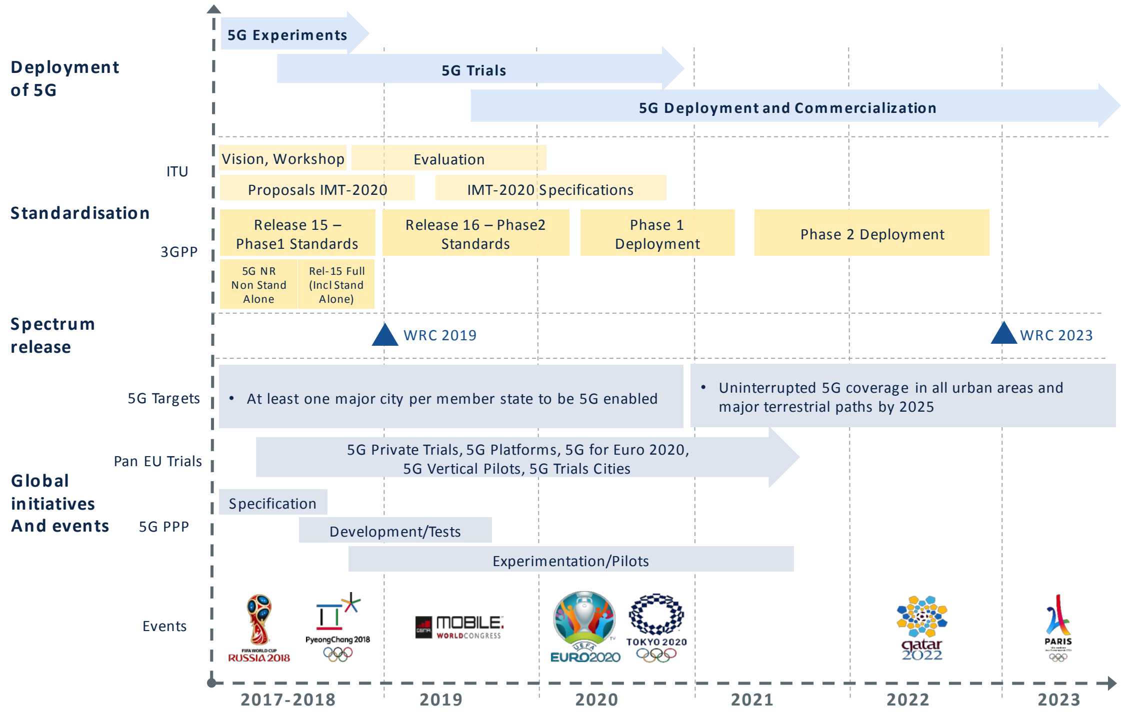
2.3 The roadmap towards 5G

The industry has generally accepted that the start of commercial deployment of 5G systems is expected to take place around 2020, following research and development and the conclusion of standardisation and regulatory initiatives.

It is perhaps too early for (European) operators to commit to network rollouts, but many are predicting commercial availability of 5G around 2020 to 2025. The exploratory phase to understand detailed requirements for 5G future systems and to identify the most promising technical and technological options has already started. Ambitious 5G trials and pilots are currently being implemented in various parts of the world.

Figure 2 below illustrates the major expected milestones on the journey to 5G availability with respect to standardisation, spectrum release and global initiatives and events.

Figure 2: Expected roadmap towards 5G



Source: DotEcon and Axon

Standardisation supported by ITU and 3GPP

Relevant standard bodies, both regional and global, have set out timetables for the development of 5G. For example, ITU and 3rd Generation Partnership Project (3GPP) are focused on studying technological requirements for 5G and releasing the standards by 2020. In 2012, ITU-R[6] embarked on a programme to develop IMT for 2020 and beyond, setting the stage for 5G research activities currently emerging around the world. IMT-2020 is set to be the global communication network for the coming decades and is on track to be in place by 2020.

The core of 5G standardisation related to mobile technologies will happen in the context of 3GPP standardisation.[7] This foresees two phases of 5G deployments:

- **5G New Radio** (NR)[8] features set out in **3GPP Release 15** will form the first phase of 5G deployments;

[6] ITU Radiocommunication sector (ITU-R) is one of the three sectors of the ITU and is responsible for radio communication.
[7] 3GPP Release 15 and Release 16.
[8] 5G NR is the wireless standard that will become the foundation for the next generation of mobile networks.

- Full compliance with ITU´s **IMT-2020** requirements is anticipated with the completion **of 3GPP Release 16** in 2019, forming the second phase of 3GPP´s 5G deployments.

In December 2017, 3GPP announced the completion of Release 15 NSA 5G NR specification, which introduced a relevant milestone to complete the first implementable specification for Non-Standalone 5G NR operation. The Non-Standalone mode revolves around the enhanced Mobile Broadband (eMBB) use case and will use existing LTE radio and an evolved packet core network as an anchor for mobility management and coverage while adding a new 5G NR radio access carrier. This is the configuration that will be the target of early 2019 deployments. This mode will be a cornerstone of 5G in the early years of adoption as mobile carriers introduce network compatibility. The completion of this specification gives the industry the green light to accelerate design and implementation of equipment adhering to the standard. The completed specifications have support for low-frequency (600 MHz, 700 MHz bands), mid-range (3.6 GHz[9] band), and high frequency (50 GHz band) spectrum. The technical specifications for Standalone 5G NR, which implies full user and control plane capability for 5G NR, are expected to be completed in June 2018 as part of 3GPP Release 15.

Plans for designating and releasing spectrum for 5G

The spectrum needs of 5G can be segmented into three key frequency ranges, <1 GHz, 1-6 GHz, and >6 GHz, reflecting the desire to deliver widespread coverage and capacity. Out of sub-1 GHz spectrum, the 700 MHz band is frequently identified as a suitable candidate band and would be demonstrative of the transition from 4G to 5G. Within the 1-6 GHz range, the first band prioritised for 5G is the 3.6 GHz band. For the third category, the 26 GHz has been identified as a pioneer band and generally millimetre wave **(mmWave)** spectrum is being considered for meeting the needs of transmitting large amounts of data. World Radio Conference (WRC) 2019 will be vital to realise the ultra-high-speed vision for 5G. The work at WRC-19 will look at spectrum for mobile broadband in frequencies between 24.25 and 86 GHz.

Global initiatives and events to support 5G deployment

All the major economies are vying for leadership in 5G and to make the first launch. South Korea aims to complete the deployment of a commercial 5G mobile network in the second half of 2019. A 5G trail service was launched by 2018 Winter Olympics[10] on the KT mobile

[9] We acknowledge that this band (which includes 3400-3800 MHz) is referred to in a number of different ways. For example, EC refers to this as the 3.5 GHz band, RSPG refers to it as the 3.6 GHz band and CEPT refers to the 3.4 – 3.8 GHz band. For the consistency throughout this report we refer to the 3.6 GHz band.

[10] International Olympic Committee, "Fans of the Olympic Winter Games 2018 to experience word's first broad-scale 5G network", 9 February 2018. Available at: https://www.olympic.org/news/fans-of-the-olympic-winter-games-2018-to-experience-world-s-first-broad-scale-5g-network

network (with Intel and Samsung) to support the high data usage arising from the combination of the 'Olympic App', drones, virtual reality systems, large stadiums and promotion of social media sharing throughout the games. China[11] and Japan (2020 Tokyo Olympics)[12] are planning commercial deployments by 2020, with the UK also running a 5G testbed and trials programme[13] targeting 2020 for commercial deployments. In France, ARCEP opened a "5G Pilot" window, to allow all of the players along the 5G value chain to explore use cases and the challenges of this new generation. The scheme seeks to bring together different players along the value chain, allocate frequencies to interested players, conduct the 5G trials and obtain initial feedback on the potential uses of 5G.[14]

The European Commission has set targets and milestones

The European Commission (EC) is applying considerable effort to place Europe at the forefront of 5G. To ensure the timely deployment of 5G, the EC has requested Member States to align roadmaps, make provisional spectrum available, undertake trials and promote early deployment. The EC has set out a preliminary timetable for achieving widespread 5G deployment in Europe:

- The first milestone is the launch of pre-commercial 5G trials in early 2018. This should be followed by the launch of early 5G networks in the same year;
- The EU has set the ambitious target to launch fully commercial 5G services by the end of 2020. To this end, the EC has requested member states to make pioneer bands available ahead of the WRC-19;
- The EC also asked member states to identify at least one major city to be 5G enabled in 2020, while all urban areas and major terrestrial paths should have uninterrupted 5G coverage by 2025.[15]

Furthermore, to accelerate research and development of 5G, the EC is co-financing an initiative called the 5G-infrastructure public private partnership (**5G-PPP**), which was launched in 2013. 5G-PPP brings together a wide range of industry stakeholders who, through

[11] Mobile World Live article "China outlines 5G R&D roadmap". Available at: https://www.mobileworldlive.com/featured-content/top-three/china-outlines-5g-rd-roadmap/
[12] GSMA 5GMF – "Strategy and Activities on 5G Development in Japan and 5GMF".
[13] UK DCMS 5G Testbed & Trials Programme- https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/672118/Next_Generation_Mobile_Technologies__An_Update_to_the_5G_Strategy_for_the_UK_Final_Version_with_Citation.pdf.
[14] Arcep, "5G, Frequencies And Innovation", 16 January 2018. Available at: https://www.arcep.fr/index.php?id=8571&no_cache=1&no_cache=1&tx_gsactualite_pi1[uid]=2119&tx_gsactualite_pi1[backID]=26&cHash=b9046864c82ce08ebebc240f271ef97f&L=1
[15] European Commission Communication, "5G for Europe: An Action Plan" and the accompanying "Staff Working Document", 14 September 2016.

research projects and cross-project working groups, will help deliver infrastructures, technologies and standards to allow 5G deployment from 2020. Within the 5G-PPP, the 5G Infrastructure Association (5G-IA) represents private interests, with the EC representing public interests.

Projects to support specification and trails for 5G technologies and use-cases

5G-PPP projects and working groups have been organised into three phases. Phase 1 has been completed and was focused on specification. Phase 2 projects will actively contribute to the development and testing of 5G technologies for vertical use cases. Phase 3 will target large-scale trials through projects focusing on end-to-end test facilities and platforms and on vertical pilots integrating 5G technologies.

5G-PPP's Phase 2 and Phase 3 projects are typically Pan-European Trials. The 5G-PPP is working on a comprehensive strategy to develop Pan-European coordinated trials, as well as international trials with non-EU partner countries, addressing several key elements of the EU 5G Action Plan (5GAP)[16]. The 5G-PPP "5G Trials Working Group" released a "5G Pan-European Trials Roadmap" earlier in 2017, establishing four main pillars, including 5G Private Trials, 5G Vertical Pilots, 5G for Euro 2020 and 5G Trials Cities[17].

2.4 Regulatory environment

It is expected that regulation will play a key role in shaping the roll-out of 5G. Not only must regulators make suitable spectrum available in the appropriate bands, in sufficient amounts and with appropriate licence conditions, but there may be other regulatory decisions that may help or hinder the roll-out of 5G. As a general principle, we can expect that the significant investments required for 5G will be encouraged by a stable, consistent and proportionate regulatory framework for all stakeholders.

Whilst we consider the role of regulation in more detail later in this report, it is helpful to understand the key decisions already made at a European level and the plans already in place to facilitate 5G investment, as well as some of the topics relevant to 5G currently being investigated by National Regulatory Authorities (NRAs).

[16] A roadmap by European Commission that sets out measures to guarantee a coordinated approach among all member states to make 5G accessible in line with the 5GAP goals of "*at least one major city [per member state] to be 5G enabled in 2020*", and making sure that "*all urban areas and major terrestrial paths (…) have uninterrupted 5G coverage by 2025*".
[17] Defined in 5G IA Pan-European trials roadmap version 1.0. Available at: https://5g-ppp.eu/presentation-of-the-5g-pan-european-trials-roadmap/

EU-level identification of spectrum for 5G

Europe has largely agreed on some important steps that will need to be undertaken to support the roll out of 5G infrastructure and 5G services, the first of which is to ensure the EU-wide availability of 5G spectrum for coverage and capacity uses as soon as possible.

For example, priorities for 5G spectrum harmonisation and identification of 'pioneer bands'[18] for 5G in Europe were outlined in "5G for Europe: An Action Plan"[19] (**5G Action Plan**). The action plan and accompanying staff document set out a strategy aimed at ensuring that all urban areas have uninterrupted 5G coverage by 2025, and the EC proposes a coordinated approach to 5G deployment in Europe.

The 700 MHz, 3.6 GHz and 26 GHz bands have been identified as key bands for 5G

To achieve this goal, the EC action plan identified the 700 MHz and the 3.6 GHz[20] bands for early 5G deployment. Following a request by the EC to publish an opinion on 5G spectrum requirements, in its "Strategic Roadmap Towards 5G for Europe" the Radio Spectrum Policy Group (RSPG) agreed that the 3.6 GHz band is most suitable for the immediate introduction of 5G and proposed to Member States that large blocks of this band ought to be made ready for authorisation by 2020.[21] The 700 MHz band is recommended for nationwide and indoor coverage[22]. The RSPG also recommends the 26 GHz (24.25-27.5 GHz) band as a pioneer band above 6 GHz, suggesting that a sufficiently large portion (e.g. 1 GHz) of the band ought to be made available by Member States in response to local market demand by 2020.[23] The opinions also outline recommendations regarding licensing and flexibility of authorisation for these bands.

These findings and recommendations are also in line with the EC mandate issued to The European Conference of Postal and Telecommunications Administrations (CEPT) requesting a report on

[18] Pioneer bands are described as early available frequency bands to be harmonised for 5G use.
[19] European Commission Communication, "5G for Europe: An Action Plan" and the accompanying "Staff Working Document", 14 September 2016.
[20] We acknowledge that this band (which includes 3400-3800 MHz) is referred to in a number of different ways. For example EC refers to this as the 3.5 GHz band, RSPG refers to it as the 3.6 GHz band and CEPT refers to the 2.4 – 3.8 GHz band. For the consistency throughout this report we refer to the 3.6 GHz band.
[21] Radio Spectrum Policy Group, "Strategic Roadmap Towards 5G for Europe – Opinion on spectrum related aspects for next- generation wireless systems", 9 November 2016 and Radio Spectrum Policy Group, "Strategic Roadmap Towards 5G for Europe – RSPG Second Opinion on 5G Networks", 30 January 2018.
[22] Radio Spectrum Policy Group, "Strategic Roadmap Towards 5G for Europe – Opinion on spectrum related aspects for next- generation wireless systems", 9 November 2016.
[23] Radio Spectrum Policy Group, "Strategic Roadmap Towards 5G for Europe – RSPG Second Opinion on 5G Networks", 30 January 2018.

technical conditions, as well as sharing conditions for 5G spectrum.[24]

The CEPT is mandated to develop harmonised technical conditions for spectrum use in the 26 GHz band. The CEPT has also been requested to revise harmonised technical conditions in the 3.6 GHz band, and to study potential extensions of the 1.5 GHz band.

Both the RSPG opinion and the CEPT mandate have emphasised the importance of taking into account international developments to facilitate interoperability and economies of scale from common tuning range. The mandate also indicates that the 700 MHz, 800 MHz, 900 MHz, 1.5 GHz, 1800 MHz, 2.6 GHz and 3.6 GHz bands are already potentially available for 5G use.[25]

66-71 GHz might meet future needs that exhaust the 26 GHz band

Although on the agenda for WRC-19, the 32 and 42 GHz bands are not mentioned in the EC mandate. Even though RSPG identified the 32 GHz band as a priority for studies in its first opinion, it is now of the opinion that 31.8-33.4 GHz band should no longer be considered a priority because of reasons such as incompatibility for radio-navigation, declining interest, and interest in keeping this band for backhauling fixed services. The RSPG is also of the opinion that there is no urgency in potential harmonisation of the 42 GHz band because the 26 GHz band will eventually provide capacity in excess of 3 GHz of spectrum for 5G, which is likely to cover the potential demand. Further, in its second opinion, RSPG suggests that the 66-71 GHz band should be prioritised in terms of studies for second-stage 5G mmWave bands for reasons such as the reported lack of use of these bands in most CEPT countries, its proximity to and better propagation characteristics than the adjacent 57-66 GHz band, its existing primary allocation for mobile and its potential to become a primary European band.

Therefore, at present, the three bands that have been identified for harmonisation and to facilitate the launch of 5G in Europe are:

- The **700 MHz** band for sub 1 GHz spectrum;
- The **3.6 GHz** band for spectrum between 1 GHz and 6 GHz; and,
- The **26 GHz** band for above 6 GHz spectrum.

[24] EC mandate to CEPT to develop harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the Union, 7 December 2016.

[25] RSPG also recognises the need to ensure that technical and regulatory conditions for all bands already harmonised for mobile networks are fit for 5G uses.

Support for investment in 5G

In 2016, in response to a call for input for the **5G Action Plan**, a number of telecommunication companies wrote a manifesto formulating their recommendations for 5G deployment.[26]

Operators have claimed that regulation needs changing to support 5G investment

The manifesto asserted that it would not be viable to invest in 5G networks without changes to the regulatory environment and argued that, in order to incentivise investment, MNOs would need greater regulatory certainty through:

- simplification of infrastructure access regulation;
- encouragement of co-investment and risk-sharing models; and
- withdrawal of ex-ante regulation on 5G-ready infrastructure.

Furthermore, the manifesto claimed that 5G’s need for dense infrastructure deployment could only be achieved through removal of deployment barriers. For example, network slicing is a fundamental functionality of 5G to bring added value across vertical industries yet, according to the manifesto, the Net Neutrality guidelines put forward by BEREC are excessively prescriptive and might limit the telecom industry’s motivation to invest in 5G by creating significant uncertainties around returns on 5G investment.

The draft ECC looks at measures to encourage 5G roll-out

Some of the issues raised in the operators’ manifesto are covered in the proposal for a **European Communications Code** (ECC)[27]. The draft ECC sets out proposals that support 5G roll-out by creating a more favourable investment environment.

In particular, small cell deployment is intended to be facilitated by the proposals of Article 55 and 56. Article 55 intendeds to clarify conditions for relating to the use of RLANs (e.g. Wi-Fi) within public communications networks, including the use of equipment such as routers on customers’ premises to support publicly accessible networks and the ability of end-users to maintain control over their own RLANs. Article 56 intends to allow deployment and operation of small-area wireless access points, thus reducing deployment costs for very dense networks.

Articles 45 and 46 proposed in the draft ECC also intend to enable more flexible management of spectrum rights by competent

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[26] The Manifesto is effectively an open letter to the Commissioner of the Digital Economy and Society dated 7 July 2016. Its signatories are the telecoms operators BT, Deutsche Telekom, Hutchison Whampoa Europe, Orange, Proximus, KPN, Tele2, Telecom Italia, Telefonica, Telekom Austria, Telenor, Telia, Vodafone; the vendors Ericsson and Nokia and the satellite operators, Inmarsat and SES. Five companies from vertical industries expressed interest in the initiative.

[27] Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code, COM/2016/0590 final - 2016/0288 (COD), 14 September 2016

authorities, which will be more suitable for 5G deployment. These articles promote general authorisations over individual licences and determine that individual spectrum rights should be minimised and only granted where necessary to maximise efficient use. The Articles encourage shared use of spectrum and the trading and leasing of frequency use rights. However, we understand that these proposals are still under discussion and subject to change.

In their manifesto, the operators also stressed the need for seed-corn funding to drive 5G deployment. One such instrument was a fund to incentivise verticals to undertake large-scale trials with innovative 5G services; it was suggested that such trials could help align requirements between mobile operators and verticals. The 5G-PPP confirmed this is a crucial step towards 5G implementation[28] and has integrated this recommendation into its roadmap, as described above.

The manifesto also recommends the EC to set up a 5G Venture Fund that supports start-ups in developing 5G technologies and applications. The telecoms companies warned that any "*infrastructure funding should be focused on physical infrastructure, such as ducts or digital spine*". In the 5G Action Plan, the EC took into consideration the suggestion made in the manifesto for a 5G Venture fund and proposes to work with the industry and EIB group to assess the possibilities.

Significant funding is already committed to trials and demonstrations

In any case, with regards to funding development and trials, the EC has committed €700 million in funding to the projects selected by the 5G-PPP, which is expected to leverage private investment of five times that amount.[29] The Phase 3 projects, which will run from 2018 to 2020 in accordance with the EC roadmap, will be leading with large-scale trials and demonstrations of 5G. In addition to these trials using pioneer bands, the 5G-PPP has expressed a need for trials of new frequency bands available from 2020 before their network deployment.

Consultations at a national level

In addition to discussions and regulatory guidance of various forms issued at the European level, a number of NRAs have individually launched calls for input (CFI) or consultations to help shape their thinking on how to support and encourage 5G deployments.

[28] 5G-PPP white paper, "Vision on Software Networks and 5G SN WG", January 2017.
[29] European Commission, "EU unveils 22 projects selected under the 5G Public, Private Partnership", 1 July 2015. http://europa.eu/rapid/press-release_MEMO-13-1159_en.htm

Ofcom, UK

For example, the UK regulator Ofcom has recently published its action plan to enable 5G in the UK, which provides an overview of the spectrum pipeline to meet the increasing demand for mobile broadband.[30] In order to enable a range of players to test innovative new uses, Ofcom has also launched a new trial and innovation portal.[31]

Ofcom has already indicated the 700 MHz band will be auctioned in 2019[32]. An auction including frequencies for 5G deployment within the range 3.4-3.6 GHz is scheduled to take place in 2018[33]. Ofcom have also announced that further spectrum in the range 3.6–3.8 GHz will be made available for mobile and auctioned in 2019.[34] Following an initial Call For Input on 3.8-4.2 in 2016, Ofcom plans to further consider the potential for increased shared access to this band for innovative new uses, while taking into account existing users.

In 2017, Ofcom also launched a call for inputs (CFI) on likely demand, timelines and spectrum authorisation options for 5G at 26 GHz[35]. Ofcom's CFI was focussed on:

- The likely demand, with regard to locations, services, channel bandwidth and deployment models to use 5G technologies at 26 GHz;
- The timelines for 5G equipment operating across the 26 GHz band and the technology features that may be relevant to authorising spectrum;
- The range of spectrum authorisation options that may be relevant in response to the specific market demand at 26 GHz and whether different authorisation types are required to meet the needs of different deployment models and services;
- Options for existing users of the band to allow the introduction of 5G.

Ofcom also sought stakeholders' views on making the 26 GHz pioneer band available on a progressive basis. The UK regulator also

[30] Ofcom "Enabling 5G in the UK", 9 March 2018. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf
[31] Ofcom, "Innovation licensing including 5G". Available at: www.ofcom.org.uk/innovation
[32] Ofcom, "Update on spectrum in the UK", 8 February 2017.
[33] Ofcom, "Award of 2.3 and 3.4 GHz spectrum by auction", https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-in-progress/2-3-and-3-4-ghz-auction
[34] Ofcom, "Improving consumer access to mobile services at 3.6GHz to 3.8GHz: Update on timing of spectrum availability", 2 February 2018, Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0018/110718/3.6GHz-3.8GHz-update-timing-spectrum-availability.pdf
[35] Ofcom, "Call for inputs on 5G spectrum access at 26 GHz and update on bands above 30 GHz", 28 July 2017.

recommends studying the possibility of using the 40.5-43.5 GHz (as part of a wider tuning range at 37-43.5 GHz) and 66-71 GHz bands for 5G.

RTR, Austria

RTR, the Austrian regulator, has confirmed it will make the 700 MHz band available for 5G in 2020 at the latest, in line with the EC's request.[36] In their spectrum release plan, the regulator indicated that the 700 MHz band is likely to be auctioned together with the 1.5 GHz band.

RTR has already started preparations for a 5G spectrum auction planned to run in 2018. The spectrum to be awarded consists of frequencies in the 3.6 GHz band. Licensees will be allowed to each use one frequency block for 5G deployment. Spectrum in the 3.4-3.6 GHz range will be available from end of 2019, while the 3.6-3.8 GHz range will be available in 2020. RTR plans to allow infrastructure sharing to facilitate densification of small cell deployment for 5G roll-out. The regulator also considered spectrum sharing through a two-tier model that allows secondary use of frequencies as long as this does not interfere with the licence holder's use.[37] However, we understand that this would require an amendment of the telecoms act that has not yet been made.

BNetzA, Germany

In 2017, the German regulator BNetzA launched a public consultation on 5G frequencies to identify demand for 5G spectrum.[38] The 3.6 GHz band and also the 2 GHz band were subject to consultation over likely demand (despite the 2 GHz band not having been identified as one of the pioneer bands).

Ministerie van Economische Zaken en Klimaat, Netherlands

The Netherlands' Ministry of Economic Affairs and Climate Policy is preparing for a national frequency auction of 4G/5G mobile spectrum in the 700 MHz, 1400 MHz and 2100 MHz bands in autumn 2019. The auction will be organised on the basis of the 'Nota Mobile Communication'[39] white paper to be published later this year, after the Ministry has finished processing the consultation responses to an earlier draft version.

Additionally, in 2018 the Netherlands government will evaluate the potential for opening up the 3.6 GHz band to mobile services. The 3.6 GHz band is currently restricted to military usage in certain areas of the country.

ComReg, Ireland

The Irish regulator (ComReg) has proposed to award blocks in the 26 GHz band for fixed links, as current fixed link licences are due to

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[36] RTR, "Spectrum Release Plan", December 2016

[37] RTR, "Consultation on the 3.4-3.8 GHz award procedure", 28 July 2017.

[38] Bundesnetzagentur, "Key Elements for the rollout of digital infrastructures and Identification of Demand for nationwide assignments in the 2 GHz and 3.6 GHz bands", 2017.

[39] Ministerie van Economische Zaken en Klimaat, "Nota Mobiele Communicatie 2017", 2017.

expire shortly. However, 10-year licences are proposed – shorter than the typical duration of licences – specifically so that future alternative uses, such as 5G, are not precluded given likely realistic timescales for 5G deployment.[40] ComReg notes that only about one-quarter of the entire 26 GHz band would be awarded in this process, leaving in excess of 1.2 GHz of currently unused spectrum available at the top of the band to meet future 5G needs.[41]

The 3.6 GHz band has already been awarded in Ireland.[42] Winners included the incumbent mobile network operators, an FWA operator - Imagine, who obtained spectrum only in rural areas - and a new entrant, Airspan. On the basis of its website, it appears that Airspan is interested in supplying wholesale network services to other operators.

Arcep, France

Arcep launched a public consultation on 5G in January 2017 on future uses of several frequency bands, including the 2.6 GHz and 3.6 GHz bands, and on the methods used to allocate these bands. Arcep will take an inventory of stakeholders' needs, identify the frequency bands best suited to each requirement, and explore appropriate spectrum allocation methods. The responses to consultation will be considered alongside the lessons learned from a number of trials underway in the 2.6 GHz and 3.6 GHz bands to determine how the 2.6 GHz and 3.6 GHz bands could contribute, in the short term, to ultrafast fixed access and PMR network rollouts and, in the medium term, to deploying 5G.[43]

MINETAD, Spain

In July 2017, Spain's Ministry of Energy, Tourism and Digital Agenda (MINETAD) launched a public consultation regarding the future introduction of 5G technology. Input is sought with regard to the current status of 5G technology, potential 5G services and applications, network deployment, radio spectrum, 5G prototypes and 5G research and development (R&D). Following the consultation, in December 2017, MINETAD released the 5G Plan for the 2018-2020 period.[44] The National Plan 5G aims to promote early implementation of networks 5G in Spain, as well as to contribute to the development of R&D in this area.

Within this Plan, Spain's Ministry for Energy, Tourism and the Digital Agenda has announced a series of measures designed to promote

[40] ComReg, "Response to Consultation and Draft Decision on the Proposed 26 GHz Spectrum Award", 23 February 2018, §4.82.
[41] Ibid, §2.26.
[42] ComReg, "Five Winning Bidders in ComReg's 3.6 GHz Band Spectrum Award", 22 May 2017. Available at: https://www.comreg.ie/five-winning-bidders-comregs-3-6-ghz-band-spectrum-award/
[43] Arcep, "Arcep launches a public consultation on "New frequencies for the regions, businesses, 5G and innovation"", 6 January 2017.
[44] MINETAD, "Plan Nacional 5G 2018-2020", 1 December 2017.

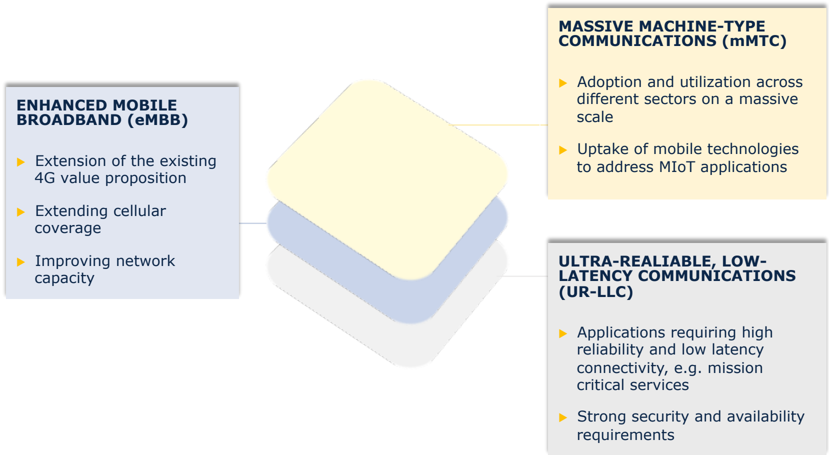
the deployment of 5G throughout the country, including a tender in the 3.6 GHz and 1.5 GHz bands “in early 2018”.

3 Overview of key 5G technologies

Although the final requirements for 5G have not been finalised yet[45], there is common agreement on the main families of usage scenarios and applications that 5G might support.[46] The three main uses are illustrated below:

- Massive mobile connectivity, that would enable **enhanced mobile broadband** (eMBB);
- Connectivity of millions of devices, that would enable **massive machine type communication** (mMTC); and
- Resilient, instantaneous connectivity, that would enable **ultra-reliable and low latency communications** (URLLC).

Figure 3: The main families of usage scenarios and applications 5G might support



Source: DotEcon and Axon

To effectively satisfy these use cases, 5G must combine a number of new technical capabilities and technologies. Therefore, 5G is far more than a faster radio access technology; it involves fundamental changes in network architectures.

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[45] However, in December 2017, 3GPP announced the completion of Release 15 NSA 5G NR specification, which introduced a relevant milestone to complete the first implementable specification for Non-Standalone 5G NR operation.
[46] identified by ITU-R M.2083 ¨IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond¨.

3.1 Technical capabilities that differentiate 5G

ITU-R has defined eight key technical capabilities for IMT-2020, which are summarised in the figure below:

Figure 4: Technical capabilities of IMT-2020

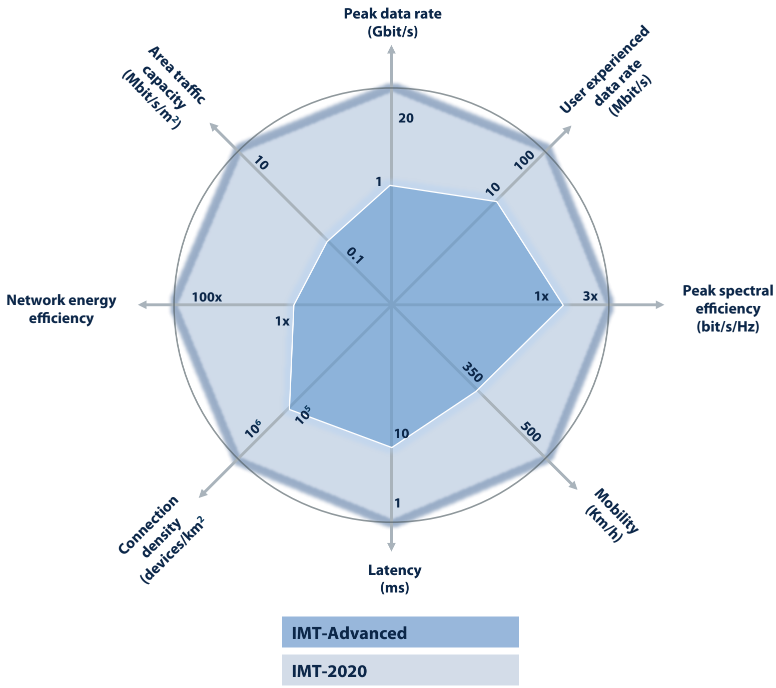
Peak data rate	**1-20 Gbps** *Total amount of traffic handled by a single cell*	Latency	**1-10 ms** *Round trip time for a packet of data*
User experienced data rate	**10 - 100 Mbit/s** *Total amount of traffic experienced by the end-user*	Connection density	**10k-1million devices/km²** *Number of devices fulfilling a certain QoS*
Peak spectral efficiency	**15 - 30 bit/s/Hz** *Information rate that can be transmitted*	Network energy efficiency	**90% more efficient** *Capability of a RIT (radio interface technology) to minimize energy consumption*
Mobility	**350-500 km/h** *Maximum mobile station speed at which certain QoS is achieved*	Area traffic capacity	**0.1– 10 Mbit/s/m²** *Total traffic throughput served per geographic area*

Source: Report ITU-R M.2410-0 (11/2017) Minimum requirements related to technical performance for IMT-2020 radio interface(s).

IMT-2020 defines an envelope of technical possibilities within which trade-offs can be made

Technical capabilities under **IMT-2020** present a significant enhancement vis-à-vis its predecessor (**IMT-Advanced** – sometimes referred to as 4.5G). The figure below shows the improvements in terms of peak data rates, spectral efficiency, mobility, latency, energy efficiency and connection density, amongst others. For the avoidance of doubt, there are trade-offs and not all network performance parameters can be pushed to the limits of the IMT-2020 capabilities simultaneously. However, a key aspect of 5G is that **virtual networks** can be created prioritising certain features (e.g. low latency or energy efficiency).

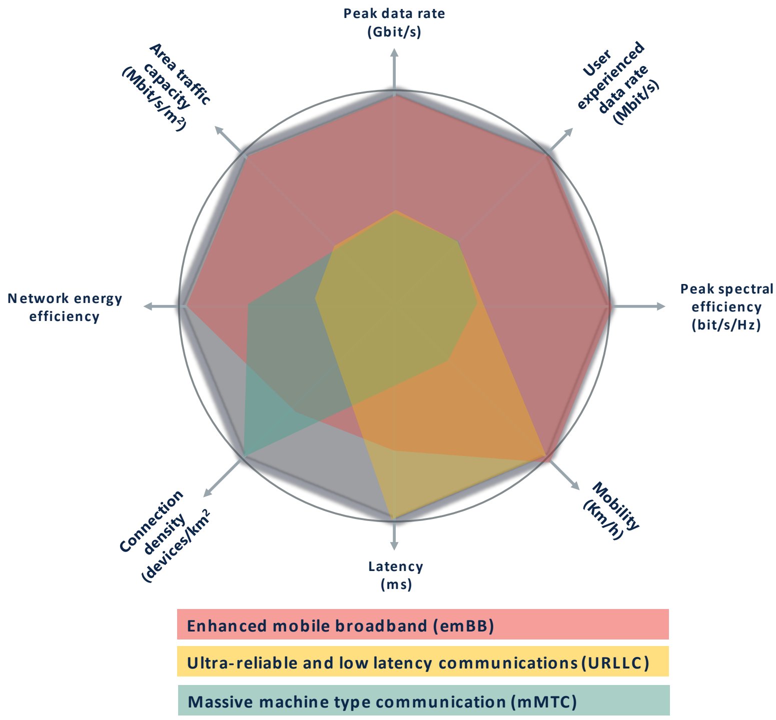
Figure 5: Enhancement of key capabilities from IMT-Advanced to IMT-2020



Source: Recommendation ITU-R M.2083-0

Although the final requirements for 5G have not been finalised yet, each of the three main families of usage scenarios (i.e. eMBB, URLLC, mMTC) are expected to have differing needs in terms of these technical capabilities, as shown in the figure below.

Figure 6: Enhancement of key capabilities from IMT-Advanced to IMT-2020



Source: Recommendation ITU-R M.2083-0

The charts above remind us that it is not possible to achieve peak values across all capabilities simultaneously and a trade-off will have to be made when defining a **differentiated service** to support a particular use case. These differentiated services can be implemented using **network slicing** to create a number of virtual networks with different performance characteristics hosted on a common infrastructure; within the overall constraints of that infrastructure, service characteristics of particular network slices can be varied agilely through software reconfiguration.

Defining 5G coverage if capabilities vary from location to location

Under this scenario, the concept of **5G coverage** is not as straightforward to define as for previous generations of mobile technology. 5G services at a given location will not have fixed characteristics, but rather represent a choice made within the overall range of possibilities defined by IMT-2020. In particular, we expect to see geographic areas that meet only part of IMT-2020 targeted technical capabilities despite a formal 5G standard (e.g. Release 15) being used to define what we mean by '5G'. Moreover, the choice of capabilities available at a location might be altered from time to time to meet changing user requirements.

For instance, there may be less densely populated areas that will be covered using 5G standard aimed at providing mMTC capabilities (e.g. to serve the needs of precision agriculture), but at the expense of reaching the data rates available from eMBB. Another example could be those areas that require significant upgrades to the network (e.g. edge computing) to minimise latency, which may not be required ubiquitously.

Massive system capacity

To support the dramatic surge in traffic loads for mobile communications systems in an inexpensive manner, 5G networks are expected to supply data with much **lower cost per bit** compared with the current networks. By deploying the most cost-effective combination of access technologies, operators can build massive capacity as and when it is needed. Operators will become able to intelligently steer, spread and load balance traffic to the user across multiple access technologies and theoretically achieve capacity greater than 10 Gbps.

Very low latency

Latency will be driven by the need to support new applications involving traffic safety, control of critical infrastructure and industry processes that would require very lower latencies. Future 5G infrastructure is expected to reduce end-to-end latency by a factor of 5, reaching 5ms (for instance, for tactile internet) and with radio link latency to a target of 1ms or less (for instance, for real time mobile control facilitated by mobile edge computing).

Very high data rates

5G should boost data rates by about 100 times with **peak data rates** in the order of 10 Gbps. However, peak data rates (which are the maximum attainable data rates under ideal conditions) are less relevant than user-experienced data rates actually achievable under real-life conditions. Ambitions for user-experienced data rates are:

- >10 Gbps data rates in specific scenarios such as indoor and dense outdoor environments;
- >100 Mbps data rates should generally be realisable in urban and suburban environments; and
- >10 Mbps data rates should be accessible nearly everywhere, including rural areas.

Ultra-high reliability and availability

Reliability refers to the capability of transmitting a given amount of traffic inside a fixed time duration with a high success probability. For critical services that 5G might cater to, loss of connectivity and deviations in quality of service should be exceptionally rare. A few industrial applications might even need a successful packet delivery guarantee of within 1ms at a probability higher than 99.9999%. 5G has the capability to allow terminal devices to be connected to multiple cells simultaneously; to the extent that failure risks at closely located cells are not strongly correlated, this should provide a reliability improvement.

Very low device cost and energy consumption

To enable the vision of billions of wirelessly connected sensors and devices, it is important to focus on lowering the device cost and **energy consumption**. 5G will enable low complexity receivers, even when scaling to higher bandwidths, lowering the device costs. It should be possible for 5G devices to be available at very low cost and with a battery life of over 10 years.

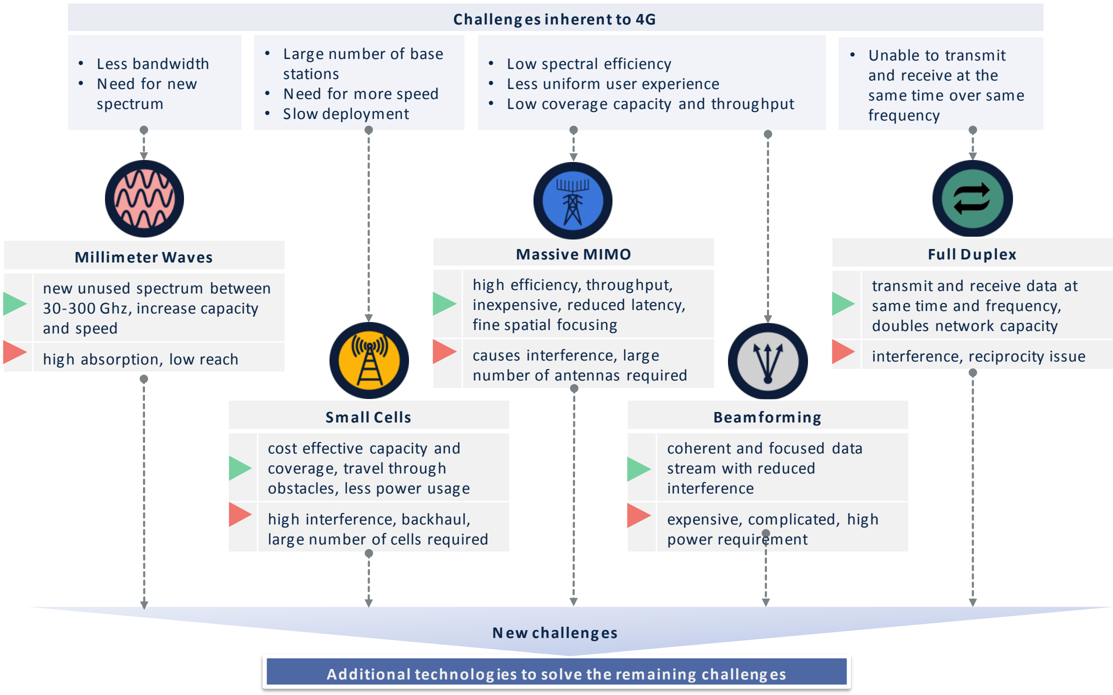
Energy-efficient networks

While energy consumption is a priority on the device side, energy efficiency is emerging as an important requirement on the network side as well. Network energy efficiency is the capability of a radio interface technology to minimise the radio access network energy consumption in relation to the capacity of traffic provided. Energy efficient networks will lower operational costs. They may even enable off-grid network deployments that are powered by solar panels, helping to reach the most remote areas.

3.2 Enabling 5G access using a combination of technologies

The front-running technologies and techniques that could potentially enable 5G networks are presented in Table 7 and explained in turn below.

Figure 7: Key technologies to enable 5G



Source: DotEcon and Axon

Currently wireless networks are typically spectrum constrained in geographical areas where there is a high density of users. This has resulted in less bandwidth for users, leading to a slower service and more dropped connections. A solution possible with 5G would be to use new spectrum that has never been used for mobile services – **mmWave**. This will massively increase the capacity of the networks, but has limited propagation[47] and is unable to travel through buildings and obstacles. To overcome this, carriers could install thousands of miniature base stations - **small cells**. Such a radically different network structure would provide more targeted and efficient use of spectrum.

Furthermore, two technologies that would prove critical in enabling 5G are massive MIMO and beamforming. By featuring dozens of antennas in a single array, massive multiple-input multiple-output **(massive MIMO)** could increase the capacity of mobile networks by a factor of 22 or greater[48]. **Beamforming** would allow a large

[47] Millimetre waves are known to have much lower coverage capacities due to higher absorption, which will be a challenge for telecom operators. Industry is currently struggling to model, understand and learn how to plan networks in cases such as rain, snow, changing foliage due to seasons, etc. for which the effect is negligible for bands currently used for mobile services.
[48] Nokia, "Beamforming for 4.9G/5G Networks – Exploiting Massive MIMO and Active Antenna Technologies."

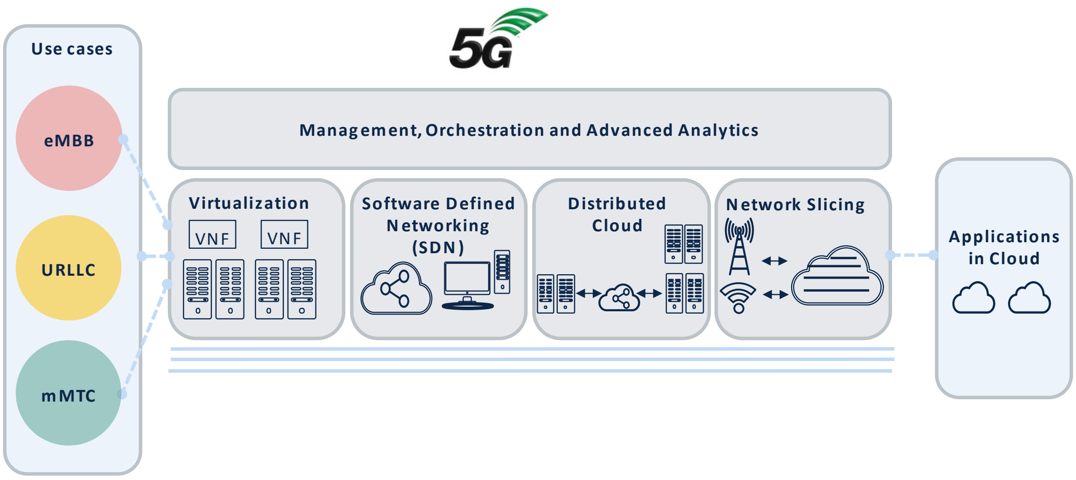
number of users and antennas on a massive MIMO array to exchange more information at once by improving signal to noise ratios. Moreover, it results in a coherent and focused data stream that can reach larger distances thereby increasing capacity of the cell towers in terms of number of subscribers served. While massive MIMO provides increased spectral efficiency, a new technology, so-called **full duplex**, is currently being researched. Although few field trials have been conducted so far, this technology is expected to increase throughput and reduce latency, both of which are critical requirements for 5G. It could double the capacity of wireless networks by enabling the transceiver to transmit and receive data at the same time over the same frequency.

3.3 A single network to serve multiple demands

5G also has potential to bring benefits over previous radio network technologies by allowing networks to be extremely agile and meet a potentially wide range of different demands for very low latency, bandwidth requirements, and device density (for example).

Stakeholders have identified key enablers that will help new services with diverse requirements to be accommodated efficiently and rapidly using a single network. These enablers are summarised in the figure below:

Figure 8: 5G virtual end-to-end networks tailored to serve application requirements



Source: DotEcon and Axon

Virtualisation of networks

Virtualisation renders network functions that typically run on dedicated and specialised hardware as software that can be run as virtual machines on commodity servers. Thus, it enables hardware resources to be managed as a common resource pool. **Network function virtualisation** (NFV) enables the creation of new network functions on-demand.

Software Defined Networking (SDN)

To make the most of virtualisation, **software defined networking** (SDN) is able to adjust the network in software, enabling network programmability and sequencing of functions. The convergence of NFV and SDN will permit operators to be more responsive to customer demands, both by being able to tailor bespoke services (within reasonable time and cost) and through on-demand provisioning by customers themselves via self-service portals.

Distributed Cloud

Once networks are virtualised and made programmable, it becomes possible to shift computing resources to the most appropriate location. Some use cases might require low latency responses, for which **mobile edge computing** (i.e. cloud computing resources within the network itself located close to the user) may be appropriate.

Network Slicing

Network slicing will enable operators to deliver networks on an as-a-service basis and meet the wide range of use cases that the 2020 timeframe is expected to demand. With this technology, a single physical network can be separated into multiple virtual networks letting the operators to offer optimal support for the different services for different user segments.

Management, Orchestration and Advanced Analytics

This layer is expected to act as the glue that holds together the entire network. Once the network is enabled, it is important to deliver the service in an efficient way to the end user. This needs smart management, smart orchestration and advanced analytics to expose the network in an abstract way.

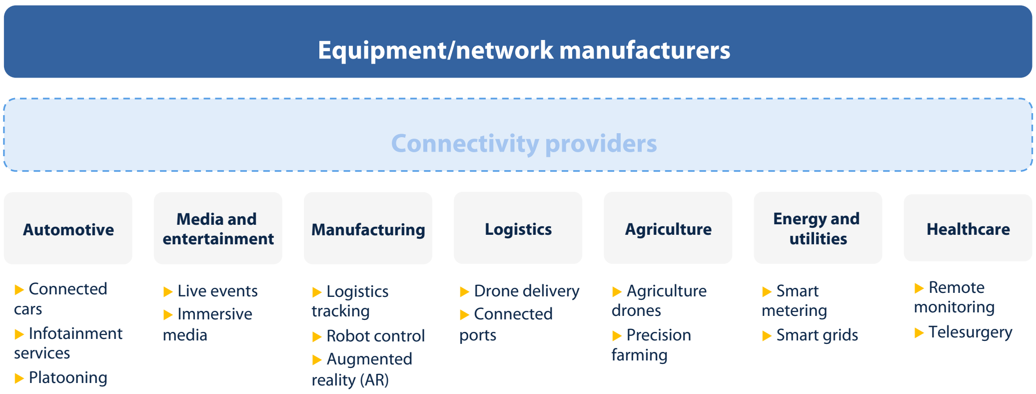
4 Use cases for 5G

Much has been said in the public domain about the potential use cases that the enhanced technical capabilities of 5G could support, from improvements in mobile broadband services to futuristic sounding services such as fully autonomous vehicles. However, the realisation of 5G use cases will be a step-by-step process and many potential uses are currently at very early stages of development; many use cases that may eventually prove important once 5G is widespread may not even have been identified yet.

Whilst we might expect that early 5G deployments will be focussed on improving existing mobile broadband propositions, there may be other use cases for 5G enabled by its distinctive new capabilities over previous radio access technologies.

To this end, much of the public discussion of 5G to date has considered eye-catching use cases in specific industries where 5G is expected to trigger new business opportunities or bring significant additional value to existing services. For example, 5G use cases are often discussed in sectors such as automotive, healthcare, manufacturing and agriculture (amongst others). The figure below illustrates the potential verticals and horizontals (the equipment manufacturers and connectivity providers) that attract the most attention (together with some illustrative case studies under each). As we discuss later in the report, connectivity providers may not always be telecoms operators, as verticals may use private networks or source a solution from equipment manufacturers. Therefore, there may not always be a role for traditional telecoms operators (such as MNOs) within the value chain.

Figure 9: Overview of proposed verticals and illustrative case studies



Source: DotEcon and Axon

Beyond eMBB, in the short-to-medium term there may be few use cases entirely dependent on 5G

Whilst there be some particular use cases for which 5G availability will be critical, we are somewhat sceptical that, at least in the early years, there will be use cases dependent on 5G that will create sufficient incremental revenue that this could significantly affect 5G deployment incentives. Indeed, many use cases are unlikely to emerge with any clarity in the short-to-medium term, due to lack of demand, commercial risk, lack of suitable hardware, or simply due to the large amount of research and development that must be conducted beforehand.

Whilst the EU, and other countries, have in place a number of initiatives to support research and promote trials, to date these have focussed on showing what is technically feasible and determining exactly how particular use cases may be supported by technology and standards setting, but there has been limited attention given to how (or whether) such services will be commercially viable.

Commercial services and products wishing to use mobile connectivity to provide a ubiquitous service will likely use a mixed connectivity approach

When considering products and services that might be enabled by 5G (and also improvements to companies' internal processes that might be enabled by 5G), there is clearly a high level of risk for developers. It cannot be assumed that 5G will be ubiquitously available. It is reasonable to expect that - for a considerable time - there will be a mixed connectivity environment, with 4G available and Wi-Fi often providing indoor connectivity. Initial 5G deployment is likely to be focussed on urban areas. Therefore, commercial services and products using mobile connectivity wishing to provide a ubiquitous service will need to have fall-back options rather relying entirely on 5G. We should expect that a developer wanting to offer an application or service, or to embed connectivity in a product, and market this across Europe, or even globally, will want to reduce its exposure to 5G rolling out at different rates in different countries by being able use whatever networks are available.

5G will need to be attractive relative to other technological solutions

The relevant alternatives will depend on the details of the connectivity requirements (as we discuss below in a number of case studies). Whilst 5G will provide significant enhancements and also much more flexibility, where there are alternatives this will limit what users will be prepared to pay additionally for 5G functionality.

Pricing models for 5G will be an important factor in providing the correct incentives for adoption

There will also need to be models that allow verticals to pay for 5G connectivity in a manner that is efficient and does not create poor incentives for the user. To take a specific example, a sensor network might benefit from using 5G due to the low power requirements and the flexibility that using a public mobile network might provide in locating those sensors and deploying them without needing any additional infrastructure. However, payments to the network operator need to reflect an appropriate balance between the benefits to the user and the costs to the network operator. Paying on a per device basis might be unattractive to the user and provide incentives to reduce the density of its sensor network or switch to an alternative way of connecting those sensors. However, if little data is transferred by each sensor, the *marginal* cost to the network operator of additional sensors may be close to zero; nevertheless, the network operator needs to price to recover the *fixed* costs of its network infrastructure whilst trying not to discourage such users. Therefore, to recover fixed costs, the network operator needs to create a pricing structure that somehow reflects the benefits to the user, which suggests that a pricing structure that charges a fixed sum regardless of how many sensors were deployed at that location would not be appropriate. However, there is a conflict, as charging more to users with more sensors might cause some of those users to switch to alternative technologies if they were cheaper at some density.

This is just a hypothetical example, but it shows the general problem of creating pricing menus for differentiated services that both reflect the benefit that different users enjoy and yet does not create poor incentives for users. These two aims cannot always be easily aligned. As a result, there may be opportunities for individual users to form partnership arrangements of various types with connectivity providers – which might be a joint venture or even a payment-by-results type of contract – in order to better align incentives. In effect, the connectivity provider is integrating to some degree into the services and products that embed that connectivity.

Our assessment of use-cases in the key verticals takes into account the extent to which alternative technologies could be used to meet the requirements and the enhancements 5G might bring

In this section, we consider some of the key sectors where the 5G debate has been focussed to date and consider the opportunities 5G could bring. At the same time, we also consider the extent to which some of these use cases could be supported by existing technologies and how these alternatives could limit the incremental value that 5G could bring in each of those cases.

We consider that it is very difficult to say at this stage whether any one sector/vertical as a whole, or any one specific use case, will or will not need 5G. Many examples of use cases requiring wireless connectivity are able to be served by alternative technologies. Therefore, 5G will be competing with these alternatives. End users will make adoption decisions based on cost effectiveness, additional functionality and the flexibility that 5G provides. Many use cases may simply evolve towards reliance on 5G as and when it becomes available, using it as a complement to existing technologies.

For each sector, we seek to identify the specific requirements of that sector and any potential issues that are likely to influence 5G adoption. We will draw together the common features subsequently.

4.1 Automotive

The automotive industry has been an early adopter of various connectivity technologies. There has been a significant push by car manufacturers in developing connected-ready cars, with a view to improving the in-car experience, helping traffic flow and overall safety on the road, and obtaining information about the performance of their vehicles and to assist maintenance. These are small steps forward within a long-term vision of autonomous vehicle control.

Opportunities for 5G

5G could bring improvements to services in the automotive industry in the form of improved in-car 'infotainment' and improvements to vehicle-to-everything (V2X) communications on an evolution path to autonomous driving in the future. Furthermore, as cars become more 'connected' and collect a larger amount of data on location, usage, performance and other telematics, opportunities open up for remote diagnostics, and opportunities for developing emerging insurance models such as 'pay-as-you-drive'.

Potential use cases

The wide range of use cases considered within the automotive sector range from infotainment services such as on-demand entertainment and trip advisory services in the vehicle, traffic management, weather and location-based services while the vehicle is moving, to road-side assistance and use-based insurance and services including enhanced GPS and collision avoidance (with a view to autonomous vehicles in the future). It is possible that 5G services will be used to complement vehicle-to-vehicle (V2V) communications, for example, to add to the information available to the car including interaction with mapping data and infrastructure to provide information about the route and the environment beyond the 'line of sight' of V2V communications. Table 2 below provides an overview of these use cases.

Table 2: Potential use cases in the automotive industry

Use cases	Impact on industry	Critical requirements	Estimated value
Improvements in Vehicle-to-everything communications (supporting the move to autonomous vehicles) and allowing for features such as collision avoidance, emergency braking, intelligent traffic systems	Improved safety	Latency Connection density Mobility	< 5 ms > 10,000 /km2 > 200 km/h
Infotainment services	New opportunities for the provision of in-car entertainment and information services of value to the driver and passengers	Data throughput Connection density Mobility	> 10 Mbps > 10,000 /km2 > 200 km/h
Platooning	Improved safety and efficiency	Latency Reliability	< 5 ms > 99.99999%
Data collection	Generation of large amounts of telemetry data opens up opportunities for new charging and insurance models	Data throughput Connection density Mobility	> 10 Mbps > 10,000 /km2 > 200 km/h
Remote monitoring and predictive maintenance	Efficiency improvements	-	-
Driver assistance - 'see through' the front vehicle, in-dash junction cameras (for HGVs for example)	Improved safety	Latency Data throughput Mobility	< 5 ms > 10 Mbps > 200 km/h

Source: DotEcon and Axon based on publicly available information

Enhanced capabilities of 5G that could support these use-cases

It may already be possible to meet some of these use cases with existing technologies and others may not be 5G critical. For example, predictive maintenance might not require real-time, low latency exchange of data, but rather uploading/sharing of information intermittently. However, other aspects – such as features associated with fully autonomous driving that rely on more than just vehicle-to-vehicle communications or the increasing demand for in-car infotainment - can expect to see improvements from 5G. Although some of these use cases have been demonstrated to work using 4G (for example, some infotainment services), 5G could support improvements, especially if demand increases and requirements on device density, mobility, and data throughput become increasingly important.

Although use cases seen as stepping-stones to fully automated driving are often thought to require 5G, we must be clear that some of those services only require basic vehicle-to-vehicle communication and are not necessarily reliant on advanced wireless technologies. For example, dedicated Short-Range Communication (DSRC - a short-to-medium range, two-way wireless technology for V2V communication) and Intelligent Transport Systems (ITS) based on a set of standards relying on IEEE 802.11p[49] within the dedicated 5.9 GHz band can be used. These technologies allow for direct communication between source and destination endpoints and can operate independent of a cellular network and do so in a fully distributed fashion.[50][51]

However, these technologies focus on short-to-medium range V2V communications which are subject to limitations of distance and in communicating with cars or infrastructure that are further ahead[52], as might be needed, for example, for the sharing of expected paths of all surrounding vehicles in an autonomous world. Therefore, taking this approach may be insufficient if the requirements of the 'connected car' extend beyond simple vehicle-to-vehicle communication and require communications between other factors such as vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) communication, typically referred to together at Vehicle-to-everything communications (V2X). For example, vehicles may also need to communicate with infrastructure to allow vehicles to receive and send information to traffic lights, roadside signs or traffic control centres; and with other road users such as pedestrians or cyclists etc. Depending on the type of data being transmitted and the need for computations, information may also need to be exchanged with a backend server for processing (such as aggregation with other information and summarisation).

For V2X communications, one increasingly relevant solution is Cellular-Vehicle-to-Everything (C-V2X), which provides a solution for integrated V2V, V2I and V2P in operation with V2N by leveraging existing cellular network infrastructure. C-V2X allows for two modes of communication: a direct vehicle-to-vehicle mode and a network communications interface for vehicle-to-network communication via mobile networks.

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[49] IEEE 802.11p represents an amended version of the IEEE Std 802.11 for wireless local area networks (WLANs) and specifies the extensions for the provision of wireless communications while in a vehicular environment. See: https://standards.ieee.org/findstds/standard/802.11p-2010.html.
[50] 5G-PPP White Paper on Automotive Vehicle Sectors.
[51] We understand that from 2019 the Volkswagen group will use the WLANp standard for communications between vehicles. See: https://www.volkswagenag.com/en/news/2018/02/volkswagen_group_rapid_road_safety.html
[52] Arthur F. Little for Vodafone Group Plc, "Creating a Gigabit Society – The role of 5G". Available at: https://www.vodafone.com/content/dam/vodafone-images/public-policy/reports/pdf/gigabit-society-5g-14032017.pdf.

The global cellular standard is now LTE-4G, which is seen as an essential foundation to powering C-V2X. However, 5G offers a further (and improved) option for C-V2X communication and is seen to be more 'future proof' in the shift towards fully autonomous driving in future. For example, although the 5G Automobile Association (5GAA) acknowledges that forms of C-V2X technology are available at present, they indicate that "…*to support the autonomous vehicles of tomorrow, the technology must evolve to meet more demanding safety requirements. 5G will facilitate this evolution. Its extreme throughput, low latency, and enhanced reliability will allow vehicles to share rich, real-time data, supporting fully autonomous driving experiences.*" [53]

Expected role of the automotive industry in driving 5G development

According to the latest Ericsson '5G Readiness Survey'[54] the automotive sector is one of the most important industry sectors that telecoms operators are focusing their 5G activities on, second only to the Media and Entertainment sector.

By design, the C-V2X standard includes the possibility of direct communication rather than communicating via networks due to the high safety requirements and the high risks of being over-reliant on a network that may have poor coverage in some areas; therefore, vehicles would not be solely reliant on 5G mobile networks. There is also demand for cellular connectivity for the provision of improved infotainment services and performance diagnostics in the near future,[55] irrespectively of the rate of development of future 5G networks. Therefore, we expect that this industry will be an early adopter of 5G, but:

- for infotainment services 5G will represent an evolution of services already provided over existing 4G cellular networks;
- for C-V2X communications, 5G will complement existing cellular and short-range communications between vehicle and infrastructure.
- 5G might also support some features of fully autonomous vehicles in the long-term. However, the technology is unlikely to be solely reliant on 5G given the safety aspects and the need for 100% coverage and service guarantees.

In this context, the extent to which 5G will be adopted in the automotive sectors will depend on sufficient coverage and an

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[53] 5GAA, "Paving the way towards 5G". Available at: http://5gaa.org/5g-technology/paving-the-way/

[54] Ericsson, "5G Readiness Survey 2017 – An assessment of operators' progress on the road to 5G"

[55] In fact, a large number of vehicle manufacturers are already providing cellular modems to, for example, allow the cars to act as Wi-Fi-hotspots.

alignment of incentives between the equipment manufacturers who will 'embed' the connectivity technology within the vehicles and the provider of the mobile network. This raises a number of interesting questions:

- Who will support the network investment that would be necessary for automotive sector to be able to rely on widespread 5G coverage?
- Will there be bilateral deals between individual manufactures and telecoms operators to provide a pan-European service or will there be a role for intermediaries to help facilitate deals with a number of operators depending on network coverage?[56]
- Will there be scope for joint ventures/co-investment models or risk sharing between the telecoms and the automotive sector to share the burden of network deployment (particularly in costly deployment areas such as rural areas)?
- Who will be expected to pay for the connectivity - for example will OEMs bundle in the price or will they expect consumers to contribute to the connection costs through a subscription?

4.2 Media and entertainment

Consumption of media and entertainment content on the move and the increase in user-generated content has led to increased demands on mobile data networks in recent years. High quality and high-resolution audio-visual services will continue to drive increasing demand for higher downlink data rates, whereas user generated content such as sharing of live-video over social media are driving demand for increased uplink data rates. For example, according to the latest Ericsson mobility report, "*[m]obile video traffic is forecast to grow by around 50 percent annually through 2022 to account for nearly 3 quarters of all mobile data traffic. Social networking is expected to grow by 38 percent annually over the next 6 years.*"[57]

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[56] For example, where car manufacturers are reliant on cellular networks for connectivity opportunities may arise for new intermediaries who help car manufacturers to negotiate deals with multiple operators across multiple regions to ensure high coverage across countries and boarders, providing a 'one-stop-shop' for 5G connectivity.

[57] Ericsson, "Mobility Report", June 2017. Available at: https://www.ericsson.com/assets/local/mobility-report/documents/2017/ericsson-mobility-report-june-2017.pdf

Opportunities for 5G

To the extent that media and entertainment will continue to drive the significant increases in mobile data usage, a key challenge will be to provide ways of supporting this growth and guarantee a high level of quality. This might be particularly relevant at large public events or stadia where video content is being consumed or created. 5G may help support these requirements in a cost-effective manner. It might also allow of new, data hungry services. For example, spectators at events might be encouraged to enhance their viewing experience through virtual reality headsets, augmented reality services, or by allowing spectators to view video replays and live video streams from different camera angles on their mobile device.

5G's role in supporting high-quality streaming is not limited to supporting high data rates in dense areas; it might also have a role to play in the development of broadcast and media distribution platforms. For example, as consumer habits change from watching linear TV on a stationary set at home, we have already seen an appetite for catch-up TV and a greater number of devices used for viewing such services. This has required broadcasters to rely on various forms of local caching to distribute content cost effectively (for example, through the use of commercial content distribution networks).

There will be increased need for the seamless integration of different network technologies, so consumers can move between them and consume video content without disruption. Whilst at present, distribution networks might largely be considered separate and independent (for example, distribution over cellular, satellite, broadcast airwaves, digital terrestrial television etc.), 5G may facilitate the development and provision of a single solution that can "*exploit delivery modes for unicast, multicast, broadcast as well as local caching.*"[58]

Whilst there are some uncertainties in how future media production and broadcast will evolve, 5G networks may bring advantages to the broadcasting sector that help remove production from resource heavy, on-site, outside-broadcast units to a central location where video streams gathered from multiple cameras to be compiled. Whilst this may, in part, rely on fixed infrastructure, 5G might help where infrastructure is lacking, or where wireless connectivity provides a more cost-effective solution.

Potential use cases

Table 3 below gives some examples of use cases for the media and entertainment sector, the expected impact and the critical requirements for connectivity.

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[58] 5G-Xcast website. Available at: http://5g-xcast.eu/about/

Table 3: Potential use cases in the media and entertainment industry

Use cases	Impact on industry	Critical requirements	Estimated value
Supporting high quality data services in dense areas for improved viewing experiences and sharing of user and machine generated content	Will allow users to engage with media services at large events and may support the emergence of new, data hungry services which spectators at events will be encouraged to use to enhance their viewing experience	Data throughput Connection density Latency	> 15 Mbps > 150000 /km2 < 10 ms
Immersive media	Support the emergence of interactive media and improved, immersive video	Data throughput Latency	> 30 Mbps < 10 ms
New distribution technologies	Allows for a shift away from traditional distribution towards IP and to explore the use of multicast and broadcast modes over wireless networks	Data throughput Reliability Latency	> 10 Mbps > 99 % < 10 ms
Cooperative/off-site media production	Helps to remove production from resource heavy, on-site, outside-broadcast units to a central location potentially bringing cost savings and more efficient use of resources	Data throughput Reliability Latency	> 15 Mbps > 99.9999 % < 10 ms

Source: DotEcon and Axon based on publicly available information

Enhanced capabilities of 5G that could support these use cases

For provision of high quality mobile data services in dense areas (such as events or stadia), 4G has proved to be significantly better than 3G. However, if data requirements continue to increase, especially when we might expect to see the emergence of new, data hungry services (for example, virtual reality headsets, augmented reality services, live replays or video streams from different cameras at an event) 5G's ability to accommodate high data rates and a high density of devices might be valuable.

Furthermore, broadcasters want to explore new distribution and production methods taking advantage of transfer of information over IP (rather than traditional broadcasting technologies). Fixed Ethernet infrastructure may provide some solutions. However, 5G might allow for a much greater reliance on wireless technologies and facilitate the migration of media content and services from legacy systems by facilitating improvements in the physical, transport and application layers of the radio network.[59]

In particular, for broadcasters 5G may help with delivery of broadcast over cellular networks at the radio level within the core. Whilst broadcast mode exists for 4G it is time sliced with unicast traffic. We understand that in 3G-PPP, under Release 14, there was work to support a standalone broadcast mode.[60] 5G may allow for the possibility of transmitting broadcast and unicast data simultaneously which could have efficiency benefits, however the technical work to determine this possibility is still in the early stages. In any case, broadcasters (especially those public service broadcasters under a universal service obligation) must ensure that their content remains available to all, so at least in the short-to-medium term where 5G availability might be limited to certain areas, other available broadcast technologies must continue to be available.

Expected role of the media and entertainment industry in driving 5G deployment

5G's ability to accommodate high data rates will be particularly valuable in the media and entertainment sector. In the short-term we consider that the desire for improved data rates for consumption and generation of media and entertainment, coupled with the potential for the emergence of even more data-intensive services could be one of the key drivers behind the 'advanced mobile broadband' use-case for 5G. According to the latest Ericsson '5G Readiness Survey'[61] *"Media & Entertainment is the top industry sector that operators are focusing their 5G activities on"* and *"[h]igh-quality streaming to mobile devices stood out as the single most important use case in the Media and Entertainment sector."*

We explore some example use cases in more detail in Annex C with a focus on enhanced mobile broadband to support on-site live event experiences with significant data rate and device density demands. Annex C also considers broadcast and multicast communication enablers for 5G, based on the lessons from the so-called "5G-Xcast" project.

To the extent that the media and entertainment industry requirements are supported by eMBB, the key issues are around

[59] 5G-Xcast website. Available at: http://5g-xcast.eu/about/#concept.
[60] For example, we understand that that advances in 3GPP Release 14 will include a standardised interface between mobile network operators and service providers and to the 3GPP system itself – for media delivery and control, radio enhancements for improved broadcast support and system enhancements to allow delivery of free-to-air receive-only services.
[61] Ericsson, "5G Readiness Survey 2017 – An assessment of operators' progress on the road to 5G"".

how networks are deployed to meet the significant demands that might be created by a mass-market service using high data rates. This is likely to create a need for network densification in urban areas or areas with high capacity demands (such as stadia). In the longer run, the use of high frequency mmWave bands and the installation of small cells will be crucial for meeting these capacity requirements.

4.3 Manufacturing

In 2012, Europe set a target of a GDP contribution of 20% from the manufacturing sector but is some way from realising this[62]. Therefore, in recent years, the European manufacturing sector has been trying to use ICT enhancements to improve productivity. The digitisation of manufacturing is sometimes referred to as the 'fourth industrial revolution' and is expected to be fuelled by **cyber-physical-systems** (CPS) and the **Internet of Things** (IoT) to enable effective, connected and flexible factories of the future.

Opportunities for 5G

5G could contribute to further developments in the manufacturing sector by enabling improvements in wireless data rates through the evolution of mobile broadband networks. For example, there is scope for the sector to take advantage of improvements in connection density and lower latency as it will enable multiple devices and machines to communicate. This could facilitate new ways of working, bring significant efficiency gains and disrupt traditional manufacturing methods.

The growing importance of CPS production has created a demand for increased connectivity and information exchange over a larger, more diverse set of devices, at new scales and requiring fast response times. 5G could help the manufacturing sector to realise the concepts of the connected factory and connected products, and to participate in connected value chains.

Potential use cases

A number of potential use cases for 5G have been identified[63] within the industrial sector, covering both the manufacturing processes within the walls of a single factory and integrating processes across different factories. We present the most widely reported use cases

[62] The European House – Ambrosetti, Italy - ¨European manufacturing between structural trends and future perspectives: Taking up the challenge¨, Industrial policies for global manufacturing, World Manufacturing Forum, 2014.
[63] Based on 5G-PPP's White Paper: 5G and the factories of the future, 2015.

in Table 4 below. Many of these fall under the larger umbrella of mMTC or the IoT.

Table 4: Potential use cases in the manufacturing industry

Use cases	Impact on industry	Critical requirements	Estimated value
Cell automation: devices in an assembly line and control units communicate wirelessly	Flexible and highly efficient production	Latency Reliability	< 0.5 ms >99.99999%
Automated guided vehicle: autonomous vehicles to transfer goods in a factory	Increased safety, efficiency	Mobility Reliability	> 10 m/s > 99.999%
Process automation: a high number of low maintenance sensors and actuators communicate wirelessly with control units	Increased efficiency, flexibility, lower inventory	Reliability	>99.99999%
Logistics tracking: track flow of goods from raw material to delivery	Increased efficiency (cost and time)	Connection density	> 1000000 /km^2
Remote assistance and robot control: remote control of robot to fulfil operations such as measurements, digging	Increased product/process quality	Reliability	> 99.999%
Augmented reality (AR): live direct or indirect view of a physical environment for training and maintenance	Increased efficiency, worker satisfaction, safety	Data throughput	> 500 Mbps

Source: DotEcon and Axon based on publicly available information

Enhanced capabilities of 5G that could support these use cases

We consider, in the short-to-medium term (the timeline over which we are concerned in this study) the requirements for a number of these use cases primarily arise from an increasing number of IoT or M2M-enabled devices. To some extent, these requirements for wireless connectivity within an enclosed environment (for example a factory) may be met using existing technologies (such as NB-IoT, Lora, SigFox etc.) possibly complemented by RLAN solutions such as Wi-Fi. Wi-Fi networks are continuing to evolve, and advances may be sufficient to support some applications. For example, work is underway to allow for "*a more intelligent wireless network [that] will be introduced by bringing 3G and 4G cellular concepts to Wi-Fi*" [64]. There are possibilities for the standard to allow integration with 5G networks (e.g. the IEEE 802.11 ax Wi-Fi standard). Wi-Fi Certified WiGig allows for multi-gigabit, low latency connectivity.[65] The Wi-Fi Alliance is introducing Wi-Fi power saving features to enable use for IoT scenarios with battery-powered devices.[66]

However, if the number of connected devices grows strongly and the connectivity requirements of those devices increase with respect to data throughput or low latency, it is possible that existing technologies may fail to meet these requirements cost effectively. 5G may become a superior alternative at some point. For example, where IoT devices must be cost and energy efficient, ultra-reliable and deliver very low latencies, while also supporting a dynamically configured factory floor, 5G has the potential to provide power saving techniques to reach 10 to 15 years battery lives, and more flexibility in terms of target performances (with reliability of up to 99.9999%) and ultra-low latency. This could ensure the same level of reliability as offered in current wired architectures.

5G may also be attractive for manufacturers who would otherwise need to ensure that diverse wireless IoT systems work well together. To manage coexistence of wireless technologies and assure interoperability between communication systems, either protocols are required to manage the cooperation of technologies working in the same frequency bands (which may be risky) or usage must be spread over multiple frequency bands. In contrast, self-organizing 5G technology can allow a large number of sensors to be operated in close proximity without compromising availability and without needing complex planning.

Furthermore, machine interactions might still be executed using wired technologies if there is a lack of technology to orchestrate, monitor and optimise wireless networking. Such orchestration might be difficult or costly if manufacturers adopt a diverse set of wireless technologies, protocols and data formats. In contrast, using 5G for all of a manufacturer's connectivity requirements would meet this need; furthermore, management capabilities can be extended beyond networking aspects to include services for security, data analytics and cloud/edge computing.

[64] https://blogs.cisco.com/wireless/a-glimpse-into-your-future-802-11ax
[65] https://www.wi-fi.org/discover-wi-fi/wi-fi-certified-wigig
[66] https://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-introduces-wi-fi-power-saving-features

Expected role of manufacturing industry in driving 5G development

The sheer diversity of manufacturing use cases, as outlined above, represents a challenge as well as an opportunity. The diversity of manufacturing use cases creates a need for information sharing in order for providers to understand better what particular sectors might require. However, manufacturers are taking an interest in the development of 5G and active partnerships are being formed between industry and ICT players, such as the I4MS (ICT Innovation for Manufacturing SMEs) of the European Commission, to drive innovative technology adoption in manufacturing. Thus, the manufacturing sector is one where the stakeholders involved, from the industry players to equipment manufacturers and operators, are likely to consider the ways in which 5G deployment can help support the industry. However, questions remain about who might provide connectivity in controlled private spaces such as factories and how this might be charged for.

4.4 Logistics

Logistics and Supply Chain Management (SCM) are concerned with the flow of products and information between various points of the distribution chain – typically from manufacturers to distribution centres, from distribution centres to retailers and from manufacturers or retailers to consumers. IoT is expected to have a great impact in the way companies approach logistics and SCM.

Opportunities for 5G

Technology is currently having a significant impact on the logistics sector. The key trends are shown in Table 5 below. These are likely to have a substantial impact on the industry in the long term and create opportunities for 5G to be used. Even though most of the upcoming requirements of the logistics sector can be satisfied by the existing technologies, 5G may have a role in the sector in the future by providing more efficient fleet management and delivery solutions.

Table 5: 5G Opportunities via convergence of technology and logistics trends

Technology trends	Impact on Logistics	5G Opportunity
High speed Internet	Improved supply chain transparency, safety, efficiency, and efficient resource planning	High
IT standards	Horizontal collaboration, more efficiency and transparency	Low
Data analytics	Improved customer experience, inventory management, and predictive maintenance	Medium
Cloud	New platform-based business models, increased efficiency	Medium
Blockchain	Supply chain security, reduction in bottlenecks and errors	Low
Robotics & automation	Improved delivery and warehouse management, lower costs	High
Autonomous vehicles	Increased delivery efficiency	Medium
UAVs (Drones)	Cost and delivery efficiency	High
3D Printing	Transportation efficiency	Low

Source: DotEcon and Axon

Potential use cases

The logistics industry was among the first adopters of the IoT within operations, from the introduction of handheld scanners to sensors that monitor cargo integrity and transportation performance. However, this is just the start, with many more specific use cases expected, as shown in Table 6 below.

Table 6: Potential use cases in the logistics industry

Use cases	Impact on industry	Critical requirements	Estimated value
IoT driven smart inventory management: Use of pallet tagging, cameras, sensors, automation to achieve damage detection, real time visibility and accurate inventory control	Enhance warehouse efficiency, ensure service quality	Connection density Battery life	> 1000000 /km^2 > 10 years
Optimal asset utilisation: Connecting machinery and vehicles to a central system to monitor all assets in real time and to enable predictive maintenance.	Reduce errors, increased workforce efficiency	Connection density Mobility	> 1000000 /km^2 > 100 km/h
Fleet and asset management: Use of sensors and wireless connectivity to create fleet efficiencies	Optimised routes, improved fuel economy, reduce deadhead miles	Connection density Battery life	> 1000000 /km^2 > 10 years
UAVs or Drone delivery: Use of drones to deliver packages by using a remote-control system	High speed delivery, access to low population zones	Reliability Latency	> 99.999% < 5 ms
Truck platooning: Platooning of delivery trucks equipped with mutually connecting smart technology.	Increase capacity and cost efficiency	Latency Reliability	< 5 ms > 99.99999%
Connected Ports: Devices, machines and humans sharing real time information to enable ports to work in a smarter way	Increase in trade, accurate tracking, secure ports	Connection density Battery life	> 200000 /km^2 > 10 years

Source: DotEcon and Axon based on publicly available information

Enhanced capabilities of 5G that could support these use cases

The demand for real time information and delivery predictions has put the ICT sector at the centre of the logistics industry. Highly automated systems are required to meet the demands of the industry. Existing technologies already have the potential to enable many of the use cases in Table 6, but 5G is likely to offer certain enhancements. In particular, IoT applications in large warehouses and logistics hubs might have high device densities, with a need for lower power sensors to tag items; 5G would be able to meet these requirements. There may also be some need for high reliability connections for real-time control of automation such as drone deliveries.

Expected role of the logistics industry in driving 5G development

The logistics industry could be an early adopter of 5G as it becomes more widespread. However, the industry is not likely to drive the development of 5G because, as previously stated, most of the use cases can be realised with the existing network technologies. There is significant push, however, on use cases such as drone delivery, truck platooning, smart ports, etc. through partnerships with adjacent players who are relevant stakeholders in the value chain. Amazon and Google are working on drone delivery projects, and automotive players such as Scania are driving projects on truck platooning.

The key requirement of the logistics sector is the need for connectivity 'on-the-go'. Therefore, the key questions are whether 5G applications within the logistics sector will just rely on public 5G networks or rather fall-back to use other forms of connectivity such as 4G.

Real-time control of delivery drones would require extensive 5G networks, covering the entire area of operation. Therefore, such applications are unlikely within the near term and, in the longer term, potentially limited to areas such as cities with large swathes of contiguous 5G coverage. Even then, there is a question about how the reliability and security of such services would be assessed given the possibility of significant harm to the public if they failed. Larger area 5G roll-out would be necessary for widespread use. In the absence of low latency 5G connectivity allowing real-time control, it might be possible to command drones over less capable networks by relying to a greater degree on autonomous behaviour. In this sense, many of the key issues are very similar to those in the automotive sector. The pace of such developments is likely to be highly dependent on how specific sectoral regulations (e.g. safety rules for drones) evolve.

4.5 Agriculture

Agriculture is rapidly adopting technology, as it evolves from an industry entrenched in tradition to one that is fast embracing change. Technological innovations are automating labour-intensive tasks and providing farmers with greater knowledge and insight into their crops and environmental factors that can be used to increase efficiency and yield. The agricultural sector has already started to embrace ICT and wireless connectivity to increase productivity and efficiency. IoT can help achieve smart farming and 'precision agriculture' that will be vital to achieve improved crop yields. For example, according to the UN Food and Agriculture Organisation, farmers across the globe will have to grow 70% more food in 2050 than they did in 2006, so technology's ability to support increases in efficiency could be particularly valuable. Data collected from agricultural machinery (e.g. combined harvesters) can be wirelessly backhauled to allow for detailed analysis, creating location-specific plans for dosing of fertilisers that can be uploaded to tractors. IoT can also be used to keep track of livestock and monitor farm assets.

To the extent that precision agriculture can reduce use of fertilisers and pesticides, applying only where necessary, this could have significant environmental benefits. For example, run-off into water courses from excessive use of nitrogen fertilisers could be reduced.

Opportunities for 5G

The global trends in the industry suggest that the opportunities for 5G include:

- **Expansion of smartphone and internet penetration:** Farmers are becoming increasingly reliant on smartphones and other intelligent mediums to stay updated and participate in industry-specific knowledge sharing initiatives. Smartphones and tablets are likely to be important in accessing analytical and other services for precision agriculture. 5G could provide improved capabilities to meet the growing demand of broadband connectivity for the farmer community, where alternatives are not already available or cost effective. 5G is likely to be used as the technology for future FWA deployments.
- **Increasing adoption of technologies:** Farmers, as well as the farming processes, are increasingly becoming dependent on technology. Low power wide area networks using Zigbee or LoRa, Wi-Fi and various other wireless sensor technologies enable farmers to collect data to streamline numerous agricultural operations, such as purchasing, inventory control, planting, monitoring, and harvesting. 5G can provide improved capabilities, bandwidth and provide a platform for advanced processes such as precision farming, drone-based crop monitoring etc. which could prove valuable and cost efficient to the farmers.

However, the extent to which the agricultural sector (located mainly in rural areas) could use 5G will of course depend on penetration in those areas.

Potential use cases

Table 7 summarises the main use cases that are emerging in the agriculture sector. They are largely applications requiring networks of sensors. However, there is also the potential for the use of drones for remote sensing, which raises similar issues to the use of drone from deliveries. Such applications either need low latency connections to allow real-time closed-loop control (for which 5G would be appropriate), or else drones need to be autonomous to some degree, using a higher latency network for command data. In either case, safety issues and sectoral (i.e. aviation) regulation are likely to constraint the speed of adoption of these new technologies.

Table 7: Potential use cases in the agriculture industry

Use cases	Impact on industry	Critical requirements	Estimated value
Precision farming: Use of sensor data to measure crop yields, moisture levels and terrain topography	Ensure profitability and sustainability, protect environment	Connection density	> 100 /km^2
Smart Irrigation: Use of IoT to measure humidity, soil moisture, temperature etc. to calculate precise requirements for water	Higher irrigation efficiency	Connection density Battery life	> 100 /km^2 > 1 year
Agriculture drones: Use of UAVs to monitor crop health, scan areas, agriculture photography etc.	Enhanced protection, Efficient inspection and monitoring	Reliability Latency	> 99.999% < 5 ms
Soil and Crop monitoring: Use of sensors to monitor moisture and identify issues such as diseases or insects	Enable informed farming decisions, minimise erosion	Connection density Battery life	> 100 /km^2 > 1 year
Precision livestock farming: Real-time monitoring of productions, health, and welfare of livestock	Ensure optimal yield, enable informed farming decisions	Connection density Battery life	> 100 /km^2 > 1 year

Source: DotEcon and Axon based on publicly available information

Enhanced capabilities of 5G that could support these use-cases

In order to realise smart farming and monitoring, IoT platforms require a wireless internet connection that is both fast and reliable. Although it is true that 5G could bring enhanced capabilities in terms of fast and reliable connections, current technologies, which are continuously evolving, have the capabilities to enable most use cases expected in the agriculture industry. For instance, farmers can already implement IoT-based precision farming solution comprised of sensors and gateways using existing NB-IoT standard technologies or long-range communication technologies such as LoRa, to meet the demands in a cost-effective manner.

There are various ways of creating narrowband sensor networks without needing 5G (or even any cellular connectivity). For example, suppose that a large farm might want to remotely monitor sensors that can detect soil moisture, crop growth and livestock feed levels, so that actions such as watering or applying crop fertiliser can be optimised. This could be done by deployment of a number of 'slave' devices connected to a master 'hub' using low power wide area networks such as LoRa, with only that hub device being connected to the mobile network using a normal SIM to 4G or 3G network or even a fixed connection. The hub then sends the data to servers to be analysed and interpreted. In areas with very challenging connectivity, backhaul of a hub might even use a satellite connection. Clearly such models become increasingly unattractive as the amounts of data flowing from sensors become greater; for example, the widespread use of high quality video feeds would probably not be feasible on that basis.

It is expected that equipment and machinery in farming will become autonomous moving forward. Real-time control of such equipment over a wireless network would require a low latency connection and ultra-secure connectivity and control platforms. Thus, even though currently the existing technologies are sufficient to cater to the needs of the industry, in the long-term - beyond the timeframe of this study - some agricultural use cases could become dependent on 5G. For example, agriculture drones that monitor crop health, scan areas, agriculture photography and so on might benefit from the capabilities of 5G.

We understand that operators such as Vodafone are already working with partners on the use case of automatic drones for precision farming. We expect 5G-based use cases such as agricultural drones, despite considerable current interest, to be realised beyond the timeframe of 2018-2022.

Expected role of agriculture in driving 5G development

Within the timeframe of this study, we would not expect the agriculture industry to be a key driver of 5G deployments, mainly due to the sufficiency of existing networks to fulfil the required needs for low data rate sensing, and also potential coverage issues in the short-to-medium term, with 5G deployments likely to be focussed on urban areas initially. We expect markets for various agricultural support services based around collection and analysis of data to develop on the basis of a mixed connectivity model (i.e. various fall backs to less capable networks as discussed above) rather than 5G availability being a prerequisite for these developments.

Nevertheless, as we discuss in the latter sections of this report, there may be some examples where 5G, if priced attractively, could provide a more cost effective and flexible solution to providing connectivity for agricultural applications in certain cases.

For example, for dense sensor networks, existing solutions can, in some cases, have some disadvantages that could be addressed by 5G. For example, using a spoke-hub or master-slave configuration might require professional design/configuration of the topology or at the very least significant configuration by the installer.

Furthermore, as the number of devices increases there may be some problems regarding device density, since increasing the number of devices hinders the topology design, organisation of communication of all devices. In contrast, deployment of dense sensor network – even if data rates are modest – might be much easier using a public 5G network. The pricing and charging structure of the 5G 'solution' will be an important factor in generating demand for using 5G networks for such purposes, especially where the incremental benefit of 5G may be limited (i.e. not essential for the provision of the service).

4.6 Energy and utilities

Energy systems are currently facing the following challenges:

- Increased consumption of electricity creates challenges for management of the grid, especially where demand is unpredictable. This may be made worse in the short-term by increasing electrification of transport, leading to an increased demand on energy consumption at potentially unpredictable locations and times;
- Variable generation technologies - renewable energy generation such as wind turbines whose output is not controllable - make up an increasing proportion of the overall supply due to decarbonisation, creating a growing need to manage the transmission network flexibly. This includes being able to control energy storage facilities such as batteries.

In addition, issues with the current infrastructure are emerging, which suggests they may not be fit for purpose. Increasing demands are likely on transmission grids given that new renewable generation capacity is often far from the centres of most demand. Where infrastructure is aging and possibly more susceptible to faults, which will need to be identified quickly. Where systems have been dimensioned to meet peak demand, such that during non-peak times the system may be underutilised, there is a clear role for improved capacity management to make the most of such redundancies as and when required. Overall, this potentially increases the need for monitoring and control within supply grids. Some new transmission infrastructure is also likely to be needed in many EU Member States to respond to these changes in both demand and supply.

Opportunities for 5G

5G could help provide the necessary support for critical machine type communication (MTC) applications for energy grid monitoring and control and support the massive volume of MTC type applications emerging from increased use of smart metering. According to the 5G-IA: *"the anticipated performance and flexibility of*

5G will enable a communication infrastructure which is able to support the emerging energy use-cases…the ongoing evolution of the power grid into a grid supporting a much more distributed generation and storage of power as well as micro-grids would be a clear beneficiary of the high performance, but still very flexible communication architecture provided by 5G."[67]

Potential use cases

A number of 'smart' or 'connected' use cases for 5G have been put forward to try and address some of these issues in the electricity sector, with the main focus being on 'smart meters' and 'smart grids'.

'Smart metering' could be used to provide customers with greater information about their energy use, in near real time, allowing them to make more efficient decisions. This could help smooth peak demands, especially if consumers can respond to real-time market price information. Furthermore, by informing the supplier of exactly the energy they use, removing the need for manual meter readings, customers will get more accurate bills and suppliers can better manage activities and investments based on the improved information.

'Smart grids' refer to everything in the grid being connected, monitored and controllable. They have been proposed as a way of better managing the energy grid, to react to the challenges of unpredictable energy generation (e.g. from renewal technologies which may begin to replace "*dispatchable and controllable base load generation*"[68]) and as demand for energy and patterns of use evolve as well. For smart grids, there will be a need for an ultra-reliable and secure network to connect power generation, transmission and distribution assets and management systems. Even where grid or distribution operators have fixed (data) network connections to facilities for monitoring and control, in some cases they may need a second backup connection for reliability.

Enhanced capabilities of 5G that could support these use-cases?

Whilst 'smart metering' could be considered as part of the IoT category and mMTC applications, such services are already available and in use and functioning without the need for 5G given their relatively low data volumes and no requirements for extremely low

[67] 5G Infrastructure Association, "5G and Energy – version 1.0", 30 September 2015.
[68] 5G Infrastructure Association, "5G and Energy – version 1.0", 30 September 2015.

latency.[69] Smart metering is not mission-critical – unlike monitoring and control of the power grid – and can use shared spectrum. Therefore, we do not expect smart metering to be a key use case for 5G.

For smart grids, a large number of connections within the energy grid are already in place, often relying on Local Access network Solutions based on Ethernet infrastructure.[70] However, as the grid is required to become ever 'smarter' there will be an increasing need for communication between sensors, control systems and energy generation and storage transmission assets[71]. As more and more elements of the energy grid need to be connected and controlled, the demands on the communication networks to support this will increase. These connections need to be highly reliable and secure. There is currently considerable concern about the possibility of cyberattacks on key national infrastructure, such as power grids and other utilities.

The 5G-IA, considers that for those assets in a smart grid network that currently have no communications or measurement equipment 5G could provide an economically viable wireless solution compared to full-fibre fixed connections but with the added advantage of improved resilience compared with existing mobile technologies.[72] This view is supported by Vodafone that consider *"5G networks can be used for monitoring and control of the grid in places where fibre networks have not been rolled out yet or where this would be too costly (e.g. rural areas). The resilience and reliability of 5G will give utility providers the confidence to push the technology deeper into the generation and distribution networks. It is also expected that the benefits of more control deeper down the network will trigger efficiency gains."*[73]

[69] However, the 5G-IA considers there application might have greater requirements in the future: "*They will reach near real time application in coming years, enabling near real time optimisations of sections of the low and medium voltage infrastructure with impacts on the communications requirements of utilities towards the customers (residential and business) particularly in urban areas where 5G will become available and can address the communication needs of smart meters if the design targets are accordingly set.*" 5G Infrastructure Association, "5G and Energy – version 1.0", 30 September 2015.

[70] The 5G IA gives a more complete overview of the various smart grid communication domains and the types of networking they rely on. See 5G Infrastructure Association, "5G and Energy – version 1.0", 30 September 2015.

[71] Huawei, "5G Opening up New Business Opportunities", August 2016. Available at: http://www.huawei.com/minisite/hwmbbf16/insights/5g_opening_up_new_business_opportunities_en.pdf

[72] 5G Infrastructure Association, "5G and Energy – version 1.0", 30 September 2015.

[73] Vodafone: https://www.vodafone.com/content/dam/vodafone-images/public-policy/reports/pdf/gigabit-society-5g-14032017.pdf

Expected role of the energy and utilities industry in driving 5G development

The question is when these requirements will be realised and whether we can reasonably expect 5G to be used in the energy and utilities sectors before 2022 (the time-period covered in this study).

Although there does not appear to be a coordinated approach or roadmap for the emergence of 'smart-grids' in Europe there are roadmaps for some countries. For example, the Sustainable Energy Authority of Ireland has set out a roadmap to explore how a smart grid could be operational in Ireland by 2050, part of which includes the establishment of a 5G test bed facility in the run up to 2020 and engagement with large scale technology R&D projects from 2020 onwards.[74] This suggests that the emergence of smart grids reliant on 5G may still be some time away.

According to Ericsson's '5G Readiness Survey', which asked telecoms operators about the industries and use-cases they were considering and pursuing, less than a third of those surveyed included "*Energy and Utilities*" within their top three industry sectors being pursued.

Furthermore, as highlighted by Vodafone, there are some additional challenges to be overcome in this industry, which may limit the scope for the emergence of 5G-use cases within the timeframe of the study (or at least suggest that energy and utilities will certainly not be a driving force behind 5G deployment). For example, the industry may be slow to adopt due to the fact that "*the energy industry is generally considered as being risk averse and conservative, meaning 5G will have to be stable and technology proven before take-up*"[75]. A further challenge arising in this sector due to the integrated grid system is the focus on security of the power system, which would require any new technology to meet the security standards. Grid operators can be expected to have a preference for deploying their own wireless networks (for example using LTE-M in the 410-420 MHz range) given concerns about whether mobile operators public networks will fully meet their needs.[76] A move towards reliance on external 5G networks may require a significant cost advantage to be demonstrated to outweigh these concerns.

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[74] See Sustainable Energy Authority of Ireland, "Smartgrid Roadmap 2011-2050". Available at: https://www.seai.ie/resources/publications/Smartgrid-Roadmap.pdf
[75] Vodafone: https://www.vodafone.com/content/dam/vodafone-images/public-policy/reports/pdf/gigabit-society-5g-14032017.pdf
[76] For example, see ESB's response to ComReg's consultation on the proposed release of the 410-415.5/420-425.5 MHz subband, December 2017, available at https://www.comreg.ie/publication-download/non-confidential-submissions-comreg-document-1767-proposed-release-410-415-5420-425-5-mhz-sub-band

Therefore, although there may be some prospects for 5G uses in the energy sector, they may not be forthcoming, especially given that in the short-medium term, it may be that 5G finds itself competing with existing wired/fibre solutions or with self-supplied wireless solutions with regards to reliability, performance, cost and usability. There may be some situations where 5G becomes an attractive option for connectivity within the grid, however, we anticipate that the utilities sector may be slow to transition and that it will be very unlikely to be a key driver being 5G deployment. Rather, utilities are more likely to look at 5G as an alternative once infrastructure is in place and reliability has been proven.

4.7 Healthcare

Health systems are faced with significant challenges from constantly increasing healthcare demand due to growing and ageing populations. Cost of healthcare as a percentage of GDP continues to grow faster than average economic growth.[77] New opportunities to improve the cost efficiency of healthcare delivery are extremely valuable to the industry.

Opportunities for increasing efficiency and reducing costs will arise from applications that allow for the collection and management of more data and opportunities such as improved health monitoring, smart medicine and remote diagnosis and surgery. Big data management and sharing could be a key driver of more informed medical decisions and help prevent illnesses.[78] The use of remote healthcare ("Telehealth") could also significantly reduce costs by enabling the decentralisation of medical care, which will be particularly advantageous in rural or hazardous areas.

It is likely that these applications will rely on a range of technologies depending on the specific requirements. For example, some could rely on fixed connections whilst others might be able to rely on low data rate wireless technologies (2G or 3G) or even over Wi-Fi for example. It is possible that some use-cases might also see potential in 5G.

Opportunities for 5G

Healthcare providers believe 5G has a role to play in bringing improvements and significant benefits to the sector. For example, in a study by Ericsson, almost three quarters of surveyed healthcare

[77] 5G-PPP, White paper on 5G and e-Health, September 2015.
[78] Tech4i2, Real Wireless, Trinity College Dublin, InterDigital, "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe, A study prepared for the European Commission", May 2015.

executives expect 5G to enable new services and products that will improve quality of life.[79] Implementing 5G technologies is expected to enable digitalisation and virtualisation of healthcare, bringing benefits through reducing costs of healthcare provision and through greater access to patient information.

Potential use cases

Table 8 below presents examples of use cases for the healthcare sector,[80] the expected impact within the sector and critical requirements for connectivity.

Table 8: Potential use cases in the health sector

Use cases	Impact on industry	Critical requirements	Estimated value
Remote monitoring of health or wellness data through wireless devices	Could provide new opportunities for monitoring well-being remotely and for providing better medical information to healthcare providers, including medical data/information.	Battery life Connection density Coverage (indoors)	> 15 years - -
Smarter medication	Linked with health monitoring devices, medication could be administered immediately when required.	Battery life Connection density Coverage (indoors)	> 15 years >1000/km2 -
Wireless tele-surgery	May allow specialists to join a local surgeon remotely, or allow for surgery to take place for those patients in remote or dangerous locations.	Latency Reliability Data throughput Coverage Security	< 1 ms > 99.999% > 10 Mbps - -
Assets tracking and management in Hospitals	Cost savings and efficiency benefits through improved tracking of valuable assets within the hospital and management of pharmaceuticals e.g. tracking those coming to end of expiry data and/or having automated ordering systems in place to re-stock key items.	Connection density Location accuracy Seamless handover between different access technologies throughout the hospital	>1000/km2 < cm -

Source: DotEcon and Axon based on publicly available information

[79] Ericsson, "Opportunities in 5G: The View from Eight Industries".
[80] Based on information presented in the 5G-PPP, White paper on 5G and e-Health, September 2015.

The use of 5G to support wireless robotic assisted surgery is widely expected to bring a major breakthrough in tele-surgery, which would create requirements for data speed, latency, reliability and security[81]. In particular ultra-low latency will be crucial to ensure there is zero perceived delay.[82] However, many remote surgery cases would likely rely on fixed networks with wireless 5G being the exception for very particular circumstances (discussed below).

One eHealth application that stands to drastically increase 'big health' data flows is 'smart wearables'. Smart wearables will consist of multiple low power, waterproof devices and sensors that can be integrated into clothing. These sensors might collect data on a number of environmental and health attributes such as atmospheric pressure, temperature, blood pressure, blood glucose, etc. [83] With the introduction of wearables, healthcare providers will be able to collect data from more locations and larger populations. Monitoring of biological data has potential to be broadly beneficial. While monitoring patients can help to avoid non-adherence to medical treatment, the capture and analysis of data will benefit healthy consumers by helping promote a healthy lifestyle and preventing diseases. The capture and analysis of data will also help ensure that patients get the most appropriate treatment available through the increased tailoring of treatment to genomes possible with better data on medical outcomes.[84]

Enhanced capabilities of 5G that could support these use-cases

Although remote diagnosis and surgery is already available today through fixed networks, the surgeon currently has to rely on visual feedback, as haptic feedback[85] is not available over current technologies. 5G is reported as having the capability to be the only wireless technology able to provide the low latency and high availability required for enabling particular features of wireless tele-surgery, such as allowing the replacement of the doctor's hands

[81] Maria Lemas et al, "5G Case Study of Internet of Skills: Slicing the Human Senses", IEEE 2017; Ericsson, "From Healthcare to Homecare"; IEEE, IEEE 5G and beyond technology roadmap white paper".
[82] Maria Lemas et al, "5G Case Study of Internet of Skills: Slicing the Human Senses".
[83] NGMN, NGMN 5G White Paper, 17th February 2015.
[84] Tech4i2, Real Wireless, Trinity College Dublin, InterDigital, Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe, A study prepared for the European Commission.
[85] Haptic feedback refers to feedback that confirms a sense of touch for the action performed. In remote surgery, it will give the surgeon a sense of touch while using tele-surgical devices with robotic probes.

with robotic probes, while providing the same sense of touch.[86] Substantial delays in either visual data or haptic feedback can lead to cyber-sickness, which may occur when there is a discrepancy between the visual feedback and the feedback received by the sensory system.[87] Furthermore, where fixed connections are not feasible (e.g. ambulances, hazardous areas, etc.) 5G would be the only technology capable of enabling wireless remote surgery.[88]

For remote monitoring and big data capture through widespread use of smart wearables, 5G may bring some incremental improvements over existing technologies. For example, whilst bedside monitoring devices are already in place in a number of hospitals [89] the next step is to monitor consumers outside of the hospital. Although some smart monitoring devices can already be delivered over existing technologies, the use of 5G for these wearables could provide incremental enhancements. For example, 5G will be able to provide low power wide area machine type communication and "*has the ability to support a plurality of devices and sensors, and to translate information from these devices and sensors into critical and meaningful data points*"[90].

Furthermore, to protect consumer data, security is of extreme importance in eHealth, 5G could offer assurances to safeguard identity, privacy and authentication management for every single device[91] given 5G's capability to support managed secure network slices.

In cases where monitoring is life critical, these services could benefit from 5G, as it will be able to ensure reliability and reserve the necessary network capacity.[92] However, one would expect that there would have to be fall-back technologies to ensure that monitoring is still possible outside of 5G coverage.

Expected role of healthcare industry in driving 5G development

A particular challenge with enabling 5G in the healthcare sector is that, in contrast with M2M environments such as automotive and

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[86] (This sense of touch is received through two elements of haptic feedback, one is tactile feedback which is touch felt on the skin such as heat and vibration, the other is kinaesthetic feedback which is touch felt in muscle and bone such as force and motion.)

[87] Nokia, "Translating 5G use cases into viable business cases", White Paper.

[88] NGMN, NGMN 5G White Paper, 17th February 2015

[89] For example, see Phillips Press Release: "Philips and VU University Medical Center Amsterdam sign agreement on patient monitoring systems". Available at: https://www.philips.com/a-w/about/news/archive/standard/news/press/2013/20130530-Philips-and-VUmc-Amsterdam-sign-agreement-patient-monitoring-systems.html

[90] David Teece, "5G Mobile: Impact on the Health Care Sector", 26 October 2017.

[91] NGMN, "NGMN 5G White Paper", 17 February 2015.

[92] Huawei, "5G – Opening up New Business Opportunities", August 2016.

industry, the applications will directly involve consumers (i.e. patients)[93]. This means that before implementing any new healthcare applications these will need to be tested and certified and meet all of the strict regulatory requirements of the health-care system. There will also be very strict requirements on standardisation across any devices or technologies used (for example, to ensure security and privacy of health information, audit trail support and reliability). Reliance on 'connected devices' or 'robots' to administer care also raises significant issues in terms of determining liability where things go wrong. Given these (largely exogenous) barriers, the adoption process of wireless surgery within the healthcare sector will likely be slow and we may not reasonably expect to see 5G widely adopted within the healthcare industry within the timeframe of our study. We see these as the most significant barriers for adoption of new technologies within healthcare and for these reasons would expect that the introduction of 5G in this sector will be slower than in other sectors.

Of all the use-cases discussed for this sector the 5G use case for smart wearables has scope to be realised earlier than some of the other examples discussed as they will be used to provide additional information to the patient and healthcare professionals without being a critical component of the healthcare delivery process. So safety-critical issues should be raised by smart wearables. However, the key issues here (as with many use-cases reliant on devices with 'embedded connectivity') revolve around whether - despite potential incremental improvements brought by 5G - it is attractive relative to other technological solutions in terms of the connectivity requirements and the extent to which the availability of alternatives will limit what users will be prepared to pay additionally for 5G functionality. For example, devices might log data and then download it over a Wi-Fi network once available, as it is unlikely that there will be a tight timing requirement. There may be few examples where 5G is really the most cost-effective solution for such devices which may have relatively limited demands that absolutely require 5G.

[93] Tech4i2, Real Wireless, Trinity College Dublin, InterDigital, "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe, A study prepared for the European Commission" May 2015.

5 Business models and value chains

In the previous section we considered specific use cases within a number of vertical industries that have been widely identified as potentially benefiting from 5G. Some of these use cases can be considered as extensions of mobile broadband (for example the media and entertainment cases and the infotainment in cars). Other use cases take advantage of 5G's distinctive technical capabilities in terms of being able to handle a large number of devices at once (dense sensor networks for IoT or mMTC), low latency (remote control services) or particularly high data throughput (such as augmented or virtual reality applications).

Whilst it is difficult to identify any single particular use case that could, at this stage, be considered to significantly drive demand for 5G and support the investment case, it is clear that there are potentially a number of different use cases that *could* be supported by 5G.

5G's potential to serve such a wide range of requirements relative to that made possible by previous radio technologies, comes from the increased flexibility 5G will allow. Network operators will be able to configure networks in different ways to offer bespoke solutions, which in turn opens up the prospects for telecoms operators to provide differentiated services for a number of different verticals simultaneously. SDN and NFV will also allow a more cost-efficient approach to adapting networks rapidly to meet new demands/requirements. Therefore, service innovation should become faster and less costly; experimenting with new services should become less risky, as little sunk investment will be needed (at least within the network).

For this reason, the emergence of 5G could lead to significant changes within the value chain for mobile data connectivity, both modifying traditional business models of telecoms operators and opening opportunities for intermediaries of various types. There is potential for creating new "merchant markets", where various connectivity services are traded at a wholesale level between operators and then different physical networks orchestrated to create a unified 'connectivity service' for customers.

In the remainder of this section we consider the potential changes to the value chain and business models that could be enabled by 5G. However, it is important to remember that, the extent to which these will be realised in practice will depend on widespread deployment and take up of 5G services. We consider (in Section 6) the drivers and obstacles to the 5G business case, focusing on what will be the immediate drivers of 5G, and potential difficulties 5G providers may face.

5.1 How might 5G enable new business models?

We have identified a number of key changes to the traditional service provision and network deployment models that could occur due to the emergence of 5G. Each raises potential issues that will need to be considered in more detail by telecoms providers, service providers and NRAs in terms of determining how best to support the business case for 5G investment.

Service related

Differentiated services

The technological capabilities of 5G - including NFV/SDN and network slicing - open the possibilities for a larger number of differentiated services (and various associated charging models) to be offered. This may facilitate changes to the traditional model of offering standardised, largely undifferentiated "mobile broadband" services to customers in the form of a package of "minutes and data" for a subscription fee, or charges on a per device basis based on the data usage. For example, operators could offer different 'services' depending on whether customers want low latency and high data throughput, or a service to support connectivity of thousands of devices simultaneously.

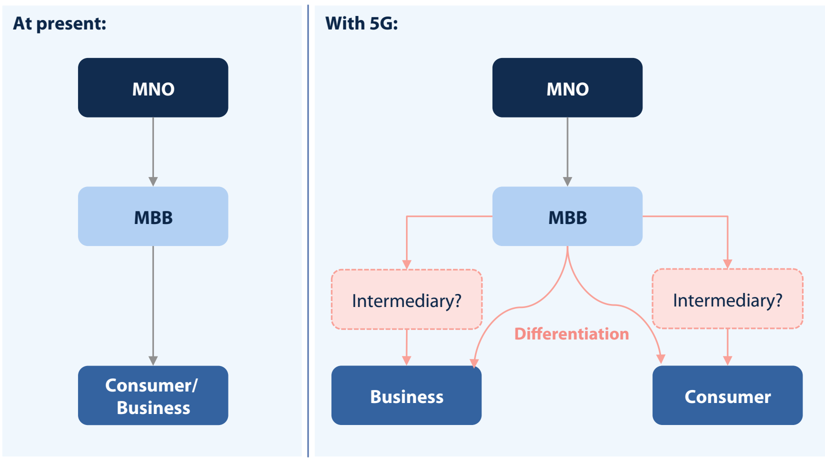
The extent to which 5G services could be successfully marketed in this way will depend on:

- whether MNOs (or connectivity providers more generally) will be able to successfully identify all the relevant niches where 5G might be useful, as these depend on the precise requirements of the customer, the alternative feasible technologies (especially if connectivity might be required in areas where 5G is not available initially) and the relative pricing of 5G and those alternatives;
- whether MNOs will be able to develop a range of standardised tariffs to attract these various new users of 5G (i.e. offer differentiated services and tariffs and hope demand comes) or whether these new users may need bespoke negotiation of pricing and service characteristics to meet individual requirements.

Given the possibility of a number of specialist requirements, there may be a role for intermediaries in identifying new applications for 5G and facilitating agreements between the connectivity provider and end user (discussed below).

Therefore, there is scope for the value chain to change relative to the status quo, with differentiated services being provided, possibly with the help of intermediaries, as illustrated in Figure 10 below.

Figure 10: Value chain with service differentiation under 5G



Source: DotEcon and Axon

Being able to differentiate services could have a number of consequences:

- Differentiation may expand demand for mobile connectivity. For example, a business wanting to deploy augmented reality support on mobile in its factories may be able to purchase a package that includes high data rates and low latency to support this feature. In our view, this demand expansion due to 5G is likely to come from a large number of specialist, niche applications across many sectors of the economy;
- Charging models need to become more complex, as pricing will need to match the particular characteristics of the service being offered. This might mean charging a premium for certain services or using very different charging models;
- Differentiation by price may allow niche services to develop and be paid for by users with specific needs, whilst avoiding price increases for users not making use of this additional functionality.

New opportunities from increased demand for 'connectivity'

As the number of connected devices increases (for example for IoT and/or M2M applications), there will be increasing demand for individual devices to connect both to each other and to the internet. Whilst the data requirements for an individual device may be small, the large number of devices and, in some cases, the need for low power requirements could be facilitated by 5G. However, whether or not these services rely on 5G networks will rely, in part, on the charging models for such 'connectivity'.

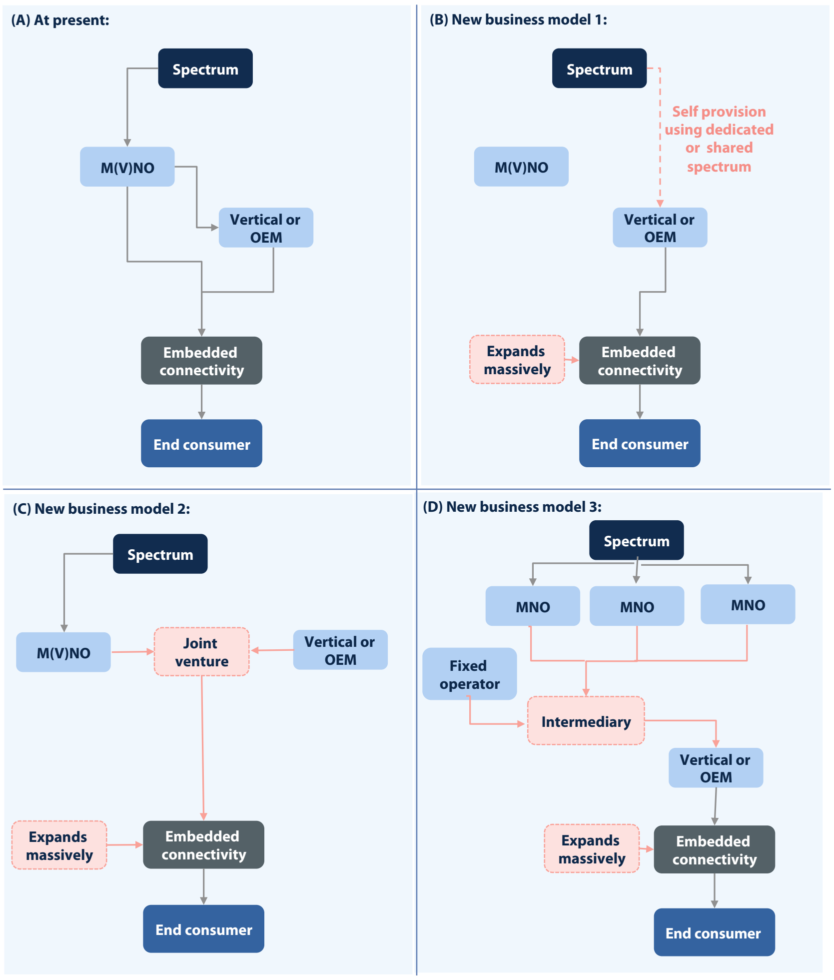
At present there are no common models for charging for such services and it would appear unlikely to be cost effective for each device to have a separate subscription to the network. To give appropriate incentives for different types of users, connectivity providers (MNOs, but possibly other providers too) may have to develop new charging models to provide an attractive proposition relative to alternative technologies for many different forms of use cases.

In addition to questions around who and how this 'connectivity' will be paid for, there are also interesting questions about the different options for how this 'connectivity' will be provided and the parties involved in the service provision value chain. For example:

- The MNO may continue to provide the connection and negotiate with individual verticals and/or equipment manufacturers (OEMs) on a bilateral basis to provide bespoke connectivity (option A in Figure 11 below);
- In some cases it may be that a self-supplied (i.e. private 5G network) solution is preferred by the vertical where the requirements are relatively well-defined by area and/or where there may be concerns associated with relying on a public network (option B in Figure 11 below);
- There may also be scope for joint ventures between the vertical and/or equipment manufacturers and the network operators (option C in Figure 11 below).
- There may be opportunities for new intermediaries to enter the market who can negotiate deals with a large number of mobile operators (and maybe fixed operators depending on the specific requirements)[94] and across borders and then market a single 'connectivity solution' to that vertical (option D in Figure 11 below and discussed with an example in the box below).

[94] For example, where there may be products and services that make use of different forms of connectivity, such a 5G, 4G and WLANs. Sensor networks and the IoT can use technologies other than 5G (indeed not even mobile networks). There may be opportunities to create connectivity offerings that integrate these alternatives. This is an area where mobile network operators could become active, but there is also a need to understand the requirements of particular industrial users, which should create opportunities for specialist services.

Figure 11: Business models to support embedded connectivity



Source: DotEcon and Axon

Role of intermediaries in service provision

Option D highlights a potentially new role for intermediaries in the value chain, downstream of network operators. There may be new opportunities for intermediaries or aggregators who can offer a single solution to those demanding connectivity, taking on the role of the negotiator to ensure issues such as securing connectivity across borders, roaming and billing are all taken care of.

We already see aggregators who put together such trans-national connectivity packages for particular industries. For example, there are aggregators offering connectivity services to car manufacturers that remove the need to make individual deals with mobile network operators in multiple countries (described with an example in the box below).

Example: 5G Networks to support automotive applications

Where cellular connectivity is embedded, there will need to be a deal between network operators and device manufacturers in terms of who pays for connectivity and data use.

This might require specific car manufacturers making deals with specific operators to secure connectivity. For example, a partnership between Ford and Vodafone in Europe has been struck to secure 4G data services within its cars.[95]

However, there will be requirements for such services to work across all regions and across borders. Therefore, deals may be needed across a number of operators or a number of countries, while the costs of network roll-out to support this use case may be particular high, especially for those areas already falling outside 5G deployment for other services such as eMBB (for example in rural areas). In this case, if the car manufacturer believes there is a large private value for connectivity, they may be able to fund some of the roll-out to get coverage through co-investment models.

There is also potential for new companies to provide solutions and help facilitate deals between the main parties. For example, one company "Cubic Telecom" has built a virtual networking solution to allow connected vehicles to automatically connect to service providers in whichever country they are in.[96] By working with over 26 mobile operators around the world, Cubic can remove the need for a manufacturer to agree separate deals with multiple operators who might each have different protocols. Car manufacturer Audi made a deal with Cubic in 2016 to support its connected car roll out.[97]

There are a number of other difficulties that may also need to be overcome in this example, such as billing complexity – who will pay for the connectivity at the point of use?

To the extent that connectivity is "necessary" for the car or is included for the manufactures benefit (for example remote diagnostics), then the manufacturer might have to pay for some of the costs of the connectivity. For those services that are purely add-ons (e.g. some infotainment services like using data for in car streaming of entertainment), then the consumer might have to pay extra on a regular basis for the data it uses.

To the extent that 5G creates services and products with embedded connectivity that will be sold trans-nationally, there will be similar opportunities for such aggregators in other industries too. This might reduce transaction costs and also enhance the bargaining power of users relative to network operators by combining the demand of several users. These trans-national aggregators are probably unlikely to be network operators given that none currently have truly global reach, and could be considered somewhat similar to a pan-national MVNO.

Given the potentially diverse needs of different sectors and users, this is just one possible role for intermediaries downstream of network operators. For example, 5G may create new business opportunities for intermediaries to bundle and repackage connectivity. There may be further opportunities for partnerships

[95] Wired, "Ford links-up with Vodafone to bring 4G to European cars", 27 February 2017. Available at: http://www.wired.co.uk/article/ford-in-car-wi-fi-modem-vodafone-europe
[96] See http://www.cubictelecom.com/
[97] Cubic Telecom, "Audi and Cubic. Driving in-car connectivity". Available at: http://www.cubictelecom.com/Projects/Audi

between providers and users both to allow development of niche services; this may help in understanding users' particular requirements and also overcoming the difficulty of creating charging structures that work efficiently for different types of users. If 5G opens up many niche applications, there may also be a role for intermediaries with specialist knowledge of the specific connectivity requirements of particular sectors. This could have important consequences in terms of the kind of players regulators will have to deal with in the future.

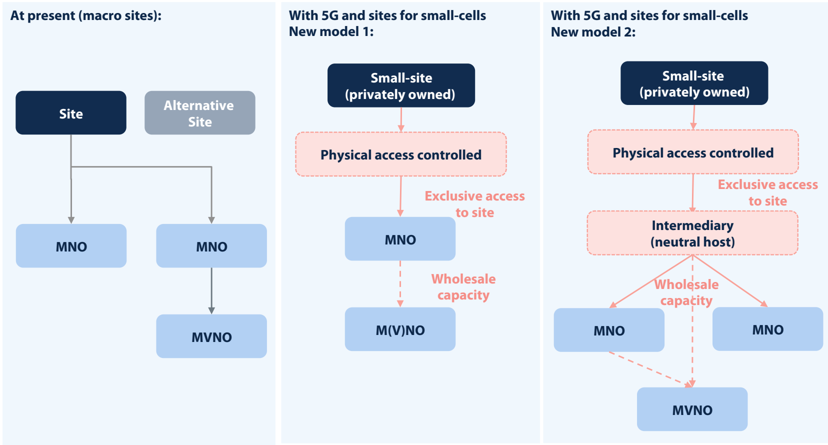
Network related

Network densification

Typically when deploying a mobile network there may be a number of alternative sites where operators could deploy their infrastructure and still meet coverage and capacity requirements. However, for the deployment of 5G networks, a greater number of small sites within urban areas are likely to be needed (especially where mmWave bands are used to support greater speed and capacity, but for which the propagation characteristics of the spectrum mean only relatively small areas can be covered per cell site). There will also likely be a need for small-cells to be deployed within buildings to serve indoor public spaces or privately controlled quasi-public spaces (for example within shopping centres or at large stadia). These sites will likely be privately owned and might be scarce, which raises interesting questions around who will install the infrastructure and how access will be granted (by which we mean access to the physical site, and potentially also wholesale access to the cell infrastructure).

For example, individual MNOs might deploy their own infrastructure (i.e. small cells) in private sites. However, the likelihood of multiple operators deploying in a single site might be challenging given the need to reach agreements on access to private sites (e.g. agreements with councils) and the practical difficulties of providing power and backhaul to each site. Therefore, there may only be scope for a single operator to gain access (or the site owner may only offer exclusive access). The operator may (or may not) then offer wholesale access for other operators. This is illustrated in 'New model 1' in Figure 12 below.

Figure 12: The value chain considering cell densification and access to small sites



Source: DotEcon and Axon

However, there may also be opportunities for new players upstream of traditional mobile networks. Such intermediaries may wish to acquire sites in dense urban areas and indoor public spaces, deploy their own 5G infrastructure and offer wholesale services providing patches of connectivity to 5G operators This is illustrated in 'New model 2' in Figure 12 above.

We are already seeing businesses forming with such strategies aimed at creating wholesale 5G capacity to sell to MNOs in order to aid cell densification. For example, an operator called Airspan recently won spectrum in the Irish 3.6 GHz award, apparently with a view to providing small-cells and offering wholesale access.

In the case of gaining access to private sites for deployment of cells, the role of the site owner in the value chain will be increasingly important. There is a potential for the site owner to leverage its bottleneck control in some cases where it might not be feasible or cost effective for all public networks to place networks within that space. To the extent that such issues might be a barrier to 5G deployment we discuss them in more detail with the help of some illustrative examples in Section 6 and consider the regulatory implications in Section 7.

Convergence of PPDR[98]-MNO-FWA provision

Typically, MNOs have served mobile broadband customers over commercial radio access networks, with other specialised providers servicing the Fixed Wireless Access (FWA) Market to serve rural areas with fixed broadband. However, given the enhanced capabilities of 5G offering a viable substitute to fixed networks, we

[98] At present a separate network may be needed given for higher quality in terms of redundancy, uninterruptable power supply, outage periods and coverage,

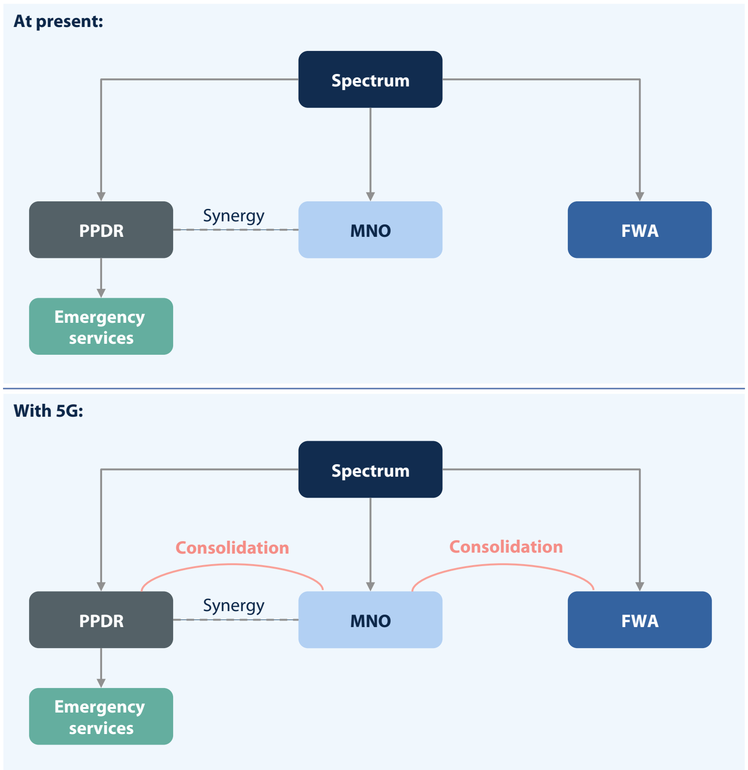
may see MNOs extending into the FWA market, especially where this provides the opportunity for a new revenue source that could help support the 5G business case.

This could be an important factor in countries where fixed broadband is particularly expensive or difficult to deploy due to rural populations or challenging geographies (e.g. Ireland, Switzerland). As mobile broadband speeds increase relative to fixed connections, consumers may increasingly substitute fixed broadband services with mobile broadband services; this may fundamentally change the nature of competition, eventually necessitating a re-think of regulation of fixed services, as the local loop could for the first time become contestable by wireless services.

Furthermore, for Public Protection and Disaster Recovery (PPDR) services currently offered over an independent network infrastructure may be offered over the same network infrastructure as commercial networks using SDN and NFV to effectively allow for the creation of separate networks that share one physical infrastructure, with each network designed to meet its own specific requirements. This would allow for significant cost savings to the MNOs through reduced infrastructure duplication. Therefore, 5G may affect the strategy for future PPDR services.

As illustrated in Figure 13 below, we may see some consolidation across these sectors.

Figure 13: Convergence of PPDR-MNO-FWA provision



Source: DotEcon and Axon

Infrastructure sharing

For some use cases, it may also be attractive for 5G providers to enter into infrastructure sharing agreements to lower the costs of deployment and avoid unnecessary and costly infrastructure duplication. This might be made easier in a 5G world if SDN and NFV could be used to "*effectively create separate networks that are housed within one physical infrastructure in a way that is tantamount to them being situated on separate physical infrastructures. In this way, each 'physical network' will be able to host multiple service providers who provide specialist niche services over that network*"[99]

Cost and benefit sharing...

There may be scope for agreements between network providers and verticals requiring connectivity to share costs and risks. More broadly, if there are incentive misalignments between verticals and network operators, these might be addressed through co-investment or Joint Ventures. These partnerships may be needed to support network development or service development

…to support the network investment

For example, where network investment and 5G deployment would be very costly or unattractive, but verticals foresee significant advantage associated with 5G connectivity (i.e. there is a large private value for connectivity), then they may be willing to support the MNO investment under co-investment models. However, given that the requirements for connectivity might only be for particular areas or be quite niche, it may be unlikely that such arrangements (if made at all) would contribute significantly to the widespread roll-out of 5G networks, for example at a national level.

…to support service development

Where MNOs are looking to provide tailored services to a particular use-case of a vertical but consider demand is uncertain, making long term agreements could underpin the business case and limit risks (with the connectivity providers sharing benefits in terms of incremental revenues or reduced costs as a reward for a long-term commitment). However, the extent to which this will occur depends on the extent to which the vertical will need connectivity directly from the MNO to meet its requirements or the extent to which it could be served by intermediaries, as discussed above.

Will these changes be realised?

Although there is a wide range of possible changes facilitated by the emergence of 5G, the extent to which these changes will be

[99] Peter Alexiadis and Tony Shortall, "The Advent of 5G: Should Technological Evolution Lead to Regulatory Revolution?" CPI Antitrust Chronicle November, Vol 3, Autumn 2016. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2876484

realised in practice will depend on the widespread deployment and take up of 5G.

Deployment of 5G networks itself will depend on a large number of factors; not least the costs of investment, the expected demand, incremental revenue raising opportunities and any potential network cost savings (unit costs of network capacity might be lower on 5G than 4G networks). In turn, take-up will depend on the extent to which MNOs (or other connectivity providers) can successfully identify and market services to customers who might find 5G useful and the relative pricing of 5G and alternative technologies.

In the following section, we discuss why we believe that in the short term the emergence of 5G will result in a continuation of the status quo with the main driver and use case being provision of eMBB. We then discuss the extent to which, over time, the 5G business case may be supported by other use cases which will take advantage of 5G capabilities and support some of the new business models described above. As part of this assessment we consider what hurdles might need to be overcome to support the emergence of 5G.

6 Drivers and obstacles to 5G

6.1 Enhanced mobile broadband as the initial driver

One of the key expected benefits of 5G that will drive early deployment is its ability to provide eMBB to support the expected increase in mobile data.

Continued data growth is expected

Mobile data traffic continues to increase across Europe despite significant variation in data consumption patterns across networks, markets and subscriber segments. Ericsson reported that total mobile data traffic has grown by 70% year-on-year between 2012 and 2017 globally and is expected to grow with a compound annual growth rate (CAGR) of around 42 percent between 2017 and 2023[100]. This growth is not only driven by the rising number of smartphone subscriptions, but also by changes in data consumption patterns. Average data volume per subscription has increased substantially over the past years, fuelled primarily by more viewing of video content. Video streaming is expected to grow to about 75% of all mobile traffic globally by 2023 at the expense of the share of data dedicated to web browsing.[101]

Of course, exponential growth cannot continue indefinitely if the main driver continues to be from video on mobile devices. Growth forecasts must be treated with some scepticism, as ultimately growth from smartphones will have to subside. [102] However, in the long-run there may also be new sources of growth, such as machine-to-machine communications which will form an increasing share of total data traffic.

[100] Ericsson, "Ericsson Mobility Report on the pulse of the networked society", November 2017.
[101] Ericsson, "Ericsson Mobility Report on the pulse of the networked society", November 2017.
[102] For example, much growth to date has been driven by video which can already be provided in HD on many consumer devices. The user experience on these devices are unlikely to benefit from further improvements, say to 4K HDR video. Therefore, although data requirement may continue to rise, sustaining these compound growth rates is not credible as it implies unreasonable levels of data consumption.

5G can provide network capacity more cheaply and maintain or improve service quality in the face of traffic growth

Given its capabilities that allow for improvements in spectral efficiency, higher capacity and improved performance, migration to 5G will be important in meeting further traffic growth cost effectively and ensuring that service quality does not degrade leaving network operators at a disadvantage relative to their competitors.[103]

Therefore, in the short to medium term, telecom operators deploying 5G will likely focus on eMBB. Interviews conducted as part of this study suggest that eMBB is the priority in these early stages of 5G. Telecom operators responding in the Ericsson '5G Readiness Survey'[104] also suggested "*taking market share from competitors based on new features/performance*" and "*migrating current 4G subscribers to 5G with enhanced revenues*" were the preferred means of monetising 5G connectivity. Furthermore, MBB is an existing mass-market service and is not subject to significant uncertainties around the size of markets that new services face.

eMBB and network cost saving are the initial drivers of 5G deployment

The launch of eMBB over 5G can be thought of as the 'evolutionary' aspect of 5G, with 5G providing incremental improvements over 4G in meeting data traffic growth. For example, as noted in the EC 5GAP Staff Working Paper,[105] 5G will first support and then replace 4G and therefore has an important role in bringing incremental improvements to existing services: *"5G is not conceived as a technology replacing 4G, but rather enhancing it and complementing it with new services capabilities. At this time, it is considered that the usage of 4G will continue for many years, before eventually 5G takes over completely…"* and *"…this evolutionary perspective is a key aspect to support gradual investments in 5G, offering an introduction perspective designed to gradually complement the 4G offer"*.

6.1.1 Potential obstacles to deploying 5G networks for eMBB

Small sites become important for capacity and to provide indoor coverage

Whilst eMBB may be the main initial driver for 5G, deployment of infrastructure to support eMBB raises some logistical challenges and potential competition concerns arising from control of access to sites that regulators should be aware of. In particular, challenges associated with the need for a larger number of small sites and

[103] This is similar to the incentives observed for 4G deployment, where lowering the unit costs of network capacity as data usage grew was a key driver.
[104] Ericsson, "5G Readiness Survey 2017 – An assessment of operators' progress on the road to 5G".
[105] Commission Staff Working Document, 5G Global Developments Accompanying The Document, Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions, 5G For Europe: An Action Plan.

deployment of 5G indoors will become more prevalent with 5G than with previous technologies, not least due to the short-range propagation characteristics of the very high frequency spectrum (e.g. the mmWave bands). Ensuring indoor coverage will likely become an increasingly important issue over time, with problems likely to get worse rather than better due to tougher energy efficiency standards for buildings. As we discuss in the boxes below, technological changes may affect who has the upper hand in the value chain, with more control being put in the hands of the site owners. For example, there is potential for bottleneck control in some cases where it might not be feasible or cost effective for all public networks to place separate network infrastructure within that space.

There are two scenarios that might become commonplace in the roll out of 5G networks to support eMBB services:

- dense network deployment for public networks in urban environments where very high frequency mmWave bands will be needed to support capacity requirements; and
- provision of eMBB services within privately-owned but 'quasi-public' spaces (such as shopping malls, or large stadia).

We discuss these situations in the boxes below and discuss the regulatory implications in more detail in Section 7.

Example: 5G deployment for eMBB in urban environments.

Given the typically short range propagation of 5G small cells, multiple 5G small cells may need to be deployed to give contiguous coverage and configured to allow hand over between cells in order to provide consistent performance for users on the move. As demand and data consumption increases over time more small cells will need to be added.

MNOs will want to ensure that they can deploy a sufficient number of small cells in a suitable topology to ensure contiguous coverage within particular data hot spots such as city centres. However, this will typically require locating equipment on pre-existing public or private infrastructure. To negotiate access to each site would be potentially burdensome.

The proposals published in the 2016 Electronic Communications Code, imply 'competent authorities' should do as much as possible to help (or at least not unduly restrict deployment).[106] It may be that, recognising the needs of MNOs to get access to a large number of sites, local councils could offer access to public infrastructure (for example street lamps). They may do so on a tender basis, seeking to use their position as site owners to extract rent from telecoms companies looking to deploy. Given the costs of deployment and the need for power and backhaul to each cell, it might be cost efficient for only one supplier to deploy the network and then allow access to others, and this will need to be accounted for in the tender process. However, public authorities may often have strong incentives to raise revenue from commercial activities to supplement public funding, so a council might seek to maximise its returns, for example by granting one MNO exclusive access for a fee reflecting the commercial benefits to the MNO in terms of reduced cost and enhanced service quality relative to its rivals. Therefore, the site owner might use its power to distort competition in mobile sectors and look to extract a financial benefit from this.

One might hope that the site owner could specify the need for wholesale access to be granted to other MNOs as part of the tender. This would open up the possibility for the provider to be an incumbent telecoms operator or an independent 'neutral host'. However, if the incentives of the site owner are to grant exclusive access, there may be a need for regulatory intervention to ensure that other 5G providers can gain access to the site to provide services too. A general obligation to provide cost-oriented wholesale access might be difficult given that the costs may vary significantly from one site to the next. It might be possible to introduce an obligation to provide access on reasonable terms in a similar way to that previously introduced for site/mast sharing.

[106] In the current proposals for the ECC (which may, of course, be revised) Article 56 of the ECC was added to cover: "*Deployment and operation of small-area wireless access points*" and states: "*Competent authorities shall allow the deployment, connection and operation of unobtrusive small-area wireless access points under the general authorisation regime and shall not unduly restrict that deployment, connection or operation through individual town planning permits or in any other way…*" See Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the European Electronic Communications Code (Recast), Brussels, 12.10.2016 available at: http://eur-lex.europa.eu/resource.html?uri=cellar:c5ee8d55-7a56-11e6-b076-01aa75ed71a1.0001.02/DOC_3&format=PDF

Example: Provision of public 5G networks for eMBB within private spaces.

Take a simple example of a shopping mall or an events venue such as a stadium where there might be significant demand for access to mobile broadband by a large number of users simultaneously requiring high capacity networks to support the demand.

This 'in-building' coverage requirement may not be met by the initial 5G network roll-outs (given the propagation characteristics of spectrum – particularly very high frequency needed for capacity – limit the extent to which signals will penetrate building to provide indoor coverage). Therefore, to provide sufficient coverage, there will be a requirement for specific infrastructure deployed in the building (such as small-cells).

There are a number of possible ways this could be provided. For example: Telecoms providers may like to offer "boosted" coverage on the site, as part of their value proposition to consumers; a site owner may want to procure a network solution from a single party; or the site owner may wish to self provide. The self-provision would require deploying its own infrastructure and making use of shared spectrum (or even trying to get ownership of specific spectrum allocations) and then provide wholesale access to other MNOs, potentially exploiting its bottleneck control.

In the case of multiple telecoms operators wanting to deploy their own infrastructure/service, this would potentially involve the deployment of a very large number of different small cell sites by each MNO that wants to offer this service. This would not only be costly, but involve inefficient duplication of infrastructure, notwithstanding that it may also be very difficult for all parties to get permission to install such cells and meet other logistical challenges such as provision of power and connecting to backhaul.

Recognising this, and realising that it could exploit its bottleneck control and extract potentially significant rents from service providers, the site owner could tender for one party to install the necessary infrastructure and provide the services on an exclusive basis. This might certainly be an attractive proposition for some MNOs in the early days of 5G where there may be competition on coverage (for example, as we saw in the early stages of 4G deployment).

However, there may be additional complexity in this case where interoperability is important (e.g. all customers attending their event/site should have improved access regardless of provider). Similar issues to those described in the box above will apply:

- How might the site owner exploit its position?
- How can it ensure wholesale access will be provided without distorting incentives?
- Is there a role for regulators in enforcing/controlling the need for wholesale access?
- How should access be mandated or controlled?

MIMO can be used to upgrade existing sites and put off acquiring sites for small cells

In an interview with one telecoms operator, it was recognised that network densification will be required to provide high speed, high capacity services in future, but mentioned that in the first instance it will want to make as much use as possible of existing sites and assets. Therefore, use of MIMO technologies at existing sites may be preferable in the short term. Small cells may be an option for further network roll-out but this might only come later given the issues associated with gaining access to sites and having to deploy fibre backhaul and provide power. Given these hurdles, it is important that issues such as planning are dealt with effectively so as not to hinder the roll-out of networks necessary to ensure suitable coverage in dense areas and indoors.

We note that for such sites access to fibre backhaul may also be required[107] (which depends on the availability of fibre networks) and therefore access to fixed infrastructure (such as ducts and poles) may assist small-cell deployments. Where such arrangements are not already in place, NRAs may need to consider the terms on which access should be made available.

Fixed networks may have additional options for small cell deployment

There may be other roll-out options for operators with both fixed and mobile assets. For example, in Spain, Telefónica is considering rolling out a new generation of routers for its Movistar-branded residential fibre-optic service that will incorporate a mobile antenna to support 5G roll-out. Although the routers are currently at the prototype stage, if this could be achieved this might provide an alternative option for some telecom operators looking to reduce the cost of installation of small cells on private sites.[108] Note that this might suggest there could be some deployment advantages to those telecoms operators with both a fixed and mobile service offering who can take advantage of supply-side complementarities.

6.1.2 Will eMBB lead to sufficient incremental revenue to support the business case?

There is limited additional revenue from eMBB

Although eMBB may be the initial driver of 5G deployment, it is unclear if consumers will be willing to pay significant more for the enhanced broadband, especially if there are initially limited applications/services that can truly take advantage of it.

Initially, 5G is likely to lead to higher data rates and better consumer experiences for existing services. However, history suggests that there will not be a significant willingness to pay a premium for higher data rate services over mobile broadband. For example, not even 4G deployments have been able to turn around the declining ARPUs for mobile operators in Europe[109].

[107] However, non-fibre alternative technologies may also be implemented to address the challenges for the backhaul of 5G networks. For example, in February 2018, Vodafone and Huawei have announced the completion of lab tests which indicate that traditional IP microwave links will be considered a viable technology for 5G backhaul: http://www.vodafone.com/content/index/what/technology-blog/vodafone-and-huawei-test-applicability-of-ip-microwave-backhaul-for-5g.html

[108] Telecom Paper, "Telefonica testing new home fibre router with 5G antenna-report", 23 January 2018. Available at: https://www.telecompaper.com/news/telefonica-testing-new-home-fibre-router-with-5g-antenna-report--1228679

[109] Analysys Mason, Report for Qualcomm, "Study on regulatory options to promote investment in 5G and IoT infrastructure in Europe", 15 December 2016.

Consumers get more over time for a broadly similar cost for mobile data subscriptions in real terms

Although consumers are getting more for their money when it comes to mobile broadband packages (i.e. a greater data allowance within the bundle), the overall spend remains relatively unchanged, suggesting that willingness to pay for the entire service is a limiting factor.

The essential limitation on incremental revenues from eMBB is what people are willing to pay for their mobile service as a whole and history suggests that the period over which a premium can be charged for new technology (e.g. premium over existing 4G services[110]) may be relatively short-lived before it is competed away and prices drop back to the previous level.[111] With limited sustained revenue impact, eMBB services provided over 5G will have to pay for itself through other means.

Indeed, a key driver of 5G deployment for eMBB will be cost savings, primarily driven by a reduction in unit network costs of provision of data services as a result of being able to support increased capacity and spectral efficiency.

As we have seen with 4G, the initial driver was for improved mobile broadband (primarily the support of video streaming over the mobile network in the case of 4G). Whilst there was a short period where a premium could be achieved, the main driver was the reduction in the unit cost of capacity to support improved mobile services. This seems to have been the trend in recent years, with the benefits of improved mobile broadband networks arising from cost reductions and efficiencies rather than from improved revenues. For example, although customers are spending a similar amount for a mobile package, they typically get more for it i.e. the unit cost is falling. This is demonstrated by recent findings by the Office for National Statistics in the UK that although prices for telecoms services in the UK were relatively flat between 2010 and 2015, the way in which those prices are measured does not account for

[110] Although there are some examples of premia being charged for 4G-capable tarffis when 4G was first being deployed, it is unclear whether it would even be possible to change a premium for specifically 5G eMBB under the Net Neutral Regulation (EC2015/2120).

[111] For example, a 2014 4G LTE Pricing Strategies report reviewing pricing in EU, non-EU, Asia Pacific & Middle East regions shows that, *"Although 4G services were launched as a price premium by most MNOs, by 2014 the majority of 4G LTE plans are now integrated within a broader mobile data tariff structure with pricing based mainly on monthly data allowance, but with some MNOs offering higher access speeds if the user opts for a larger data allowance. Rather than use 4G LTE services as a premium service most MNOs are now offering 4G LTE for free to maintain an existing mobile data price point. Price stability is now the objective rather than premium pricing"*. See: http://www.telecomspricing.com/news_detail.cfm?item=8594

improvements in the bundles of calls, texts and minutes meaning that unit prices are falling.[112]

Incremental revenues are likely form new services and customers over the longer run, not from eMBB

Therefore, although there will be incentives for network operators to deploy 5G to reduce network costs in meeting data growth from mobile broadband services, it is not obvious that traditional customer relationships can deliver significant and sustained incremental revenue growth as a result of eMBB alone. Rather, incremental sources of revenue are likely to be from new customers; in the longer run, new uses - other than mobile broadband services - may be important to delivering sufficient return on investment in from 5G investments.

6.2 Identifying new revenue sources from additional capabilities of 5G

With little sustained incremental revenues from traditional customers from 5G eMBB, MNOs (and other 5G providers) might seek to find new incremental revenue sources by supporting developments in other industries.

5G allows differentiated services that might expand demand by attracting new customers with new uses

5G has particular characteristics that could allow it to support multiple different uses over a single network. For example, SDN/NFV gives network operators agility to create new services without the need for changing the underlying physical infrastructure. This will provide a more cost-efficient approach to adapting networks to meet evolving demands for connectivity and also allow for a much greater degree of differentiation of services. For example, a common infrastructure can use network slices to support multiple services that each have a different priority, such as bandwidth, reliability, terminal density or low power usage.

However, the extent to which 5G use cases beyond eMBB will be realised within the timeframe of this study will depend on the demand side, and the willingness to pay for 5G services, which will in part be influenced by availability and price of alternative solutions.

As shown earlier with our discussions in a number of sectors, it is very difficult to say whether any one sector/vertical will or will not need 5G going forward. Many use-cases may be possible with alternative technologies or simply evolve towards reliance on 5G when it becomes available.

[112] For example, see Financial Times, "ONS's crossed telecom wires raise questions over inflation figures", 18 Jan 2018. Available at: https://www.ft.com/content/abc14c66-fb78-11e7-a492-2c9be7f3120a

New users arising from 5G are likely to be fragmented in niches across many sectors

Therefore, rather than thinking about a small number of specific use cases (for which the likely scale of any particular one alone might be insufficient to drive 5G deployment) a better way of looking at this would be to think of particular niches that are relevant for 5G (e.g. need for dense sensor networks) with a large number of use-cases and beneficiaries fragmented over a wide number of sectors.

For example, consider key 5G characteristics that certain niche use cases will require (potentially in a large number of industries):

- **Low latency** will be crucial for real-time control and safety critical applications (and in many of these cases mobile edge computing will be important);
- **Security/reliability/dedicated capacity** may also be important for some particular niches requiring service level guarantees (SLGs) that may be met by "ultra-reliable" 5G (although 5G may be one of multiple technologies sourced for redundancy purposes)
- **Connection density and network energy efficiency (supporting low power devices)** will be important for IoT and mMTC across a wide range of sectors;
- **Peak bandwidth requirements** where existing wireless networks may struggle (especially as competing demands for bandwidth emerge).

In the table below, we give some possible examples for each of these referring to those use cases touched upon in Section 4.

Table 9: Examples from case studies

	Automo-tive	Media and enterta-inment	Manu-facturing	Logistics	Agricul-ture	Energy and utilities	Health-care	Other verticals
Low latency	Safety applications	AR/VR Off-site media production	AR/VR Critical M2M communication/safety	Drones	Drones		Wireless Telesurgery	Real time control applications
SLGs / reserved capacity	Safety applications	Content distribution	Critical M2M communication/safety	Drones	Drones	Smart grids	Wireless Telesurgery	Safety applications Public safety
Device Density		Stadium/ events	Sensor networks/ M2M		Sensor networks/ M2M		Asset tracking	Dense sensor networks for M2M or IoT
Low power use			Sensor networks/ M2M	IoT tracking	Sensor networks		Smart wearables	Dense sensor networks for M2M or IoT
Peak bandwidth	Live video for 'see through the front' vehicle	Immersive media such as AR/VR 360 video	AR/VR				Wireless telesurgery	

Source: DotEcon and Axon

Incremental revenues from 5G are hard to forecast

Together a potentially large number beneficiaries over a wide number of sectors could be sufficient to support a significant market for 5G. However, the specific niches and fragmentation across industries mean it will be difficult for any investor to estimate the exact demand for 5G services. This uncertainty makes the business case for 5G investments challenging. The difficulty lies in being able to identify the demand and market services to these users.

6.2.1 Potential obstacles to generating incremental revenues from new sources

A new service might be dependent on 5G

In some cases, the demand for 5G services will be influenced purely by technical requirements that can only be met with 5G (i.e. a revolutionary new service that cannot be done with other wireless technologies). Whilst, there may be some use cases that genuinely require 5G that could not be supported with other technologies, we have not come across any compelling evidence to convince us that such 'revolutionary' services relying solely on 5G will be available within the shorter timeframe of this study and so affect near term 5G roll-out decisions. If a service is to rely solely on 5G then the emergence of such services will likely be delayed until 5G deployments are much more developed and widespread.

It is more likely that services, applications and products will be built for a mixed connectivity environment

There is clearly a high level of risk for developers working on developing applications or services that might benefit from 5G, as it cannot be assumed that 5G will be ubiquitously available for some time. Rather for some considerable time there will be a mixed connectivity environment (with 5G running in parallel with 4G and RLAN often providing indoor connectivity). Therefore, commercial services and products using mobile connectivity will typically need to be developed with fall-back options rather relying entirely on 5G.

If fall back connectivity options are needed, they also act as alternatives that limit willingness to pay for 5G

Therefore, given that we expect most services that will emerge in the short to medium term will be designed to operate over a range of technologies (of which 5G may be one), 5G will need to be attractive relative to other technological solutions. Whilst 5G has potential to provide enhancements, the amount users will be prepared to pay additionally for 5G functionality will depend on the price and availability of alternative technologies. For many, the decision to use 5G will depend on the relative pricing and the incremental benefits relative to existing solutions that could meet their requirements i.e. the use of 5G will be **a cost efficiency decision** (so the charging model will have an important role in expanding the market).

Take up of 5G based on cost efficiency considerations

One example of the need for 5G to compete with existing technologies, and an issue likely to be common across a large number of sectors, is the expected increase in IoT and mMTC applications. The large number of potential use-cases for IoT and mMTC suggests that there will be a significant new market to be served with great potential for MNOs to generate incremental revenue. Given the expected size of the market for these applications in future, this could provide a significant further means of monetizing 5G deployment. For example, Alexiadis and Shortall (2016) suggested that: "*No longer will voice communications become the primary revenue source for operators, nor will they account for the bulk of communications. Instead, machines communicating with machines (e.g. self-driving cars) will provide the momentum for the business case in the sector*".[113]

However, MNOs (or other providers) wishing to market their 5G offering to support increasing demand for embedded connectivity in devices and sensor networks will have to compete with alternative technologies. Many of these use cases may be supported

[113] Peter Alexiadis and Tony Shortall, "The Advent of 5G: Should Technological Evolution Lead to Regulatory Revolution?" CPI Antitrust Chronicle November, Vol 3, Autumn 2016. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2876484

by other technologies that are fairly mature. Therefore, the extent to which these use cases take up 5G will **depend on charging structure** for 5G services.

Some charging structures might be inefficient as they create poor incentives for potential users

In the box below, we consider some of the specific issues with a simple example linked to the case of deploying a dense sensor network. Whilst we consider this in the context of agriculture, one can imagine that many of the key issues will translate across to a large number of IoT or M2M use-cases reliant on a large number of sensors communicating with each other.

Example: Crop monitoring service for agriculture with dense sensor networks

Take an example of a provider (referred to as the 'service provider') offering a service to the agricultural sector which allows them to gather and interpret data from a large number of sensors around the farm which allow them to make more efficient decisions around where to use fertiliser, irrigate and so on.

This service provider might offer an integrated solution, which includes the sensors and analytics software together with a 'connected' solution to allow everything to communicate with each other. For the service provider (and the farmer) the primarily value of the service might lie in the analytics, but for this to work well the sensor deployment needs to be integrated into the service offering.

Given that the bandwidth demands of each sensor are quite low, such a service could be provided using existing technologies. For example, they may be able to deploy the sensor network with a "hub and spoke topology", where a number of 'slave' devices connect to a 'master' using NB-IoT communication networks , with only that master device being connected to the mobile network using a normal SIM to 4G or 3G network, which then sends the data to servers to be analysed and interpreted.

However, existing solutions can, in some cases, have some disadvantages that could be addressed by 5G. For example, using a spoke-hub or master-slave configuration can take time to market and require professional design/configuration of the topology. Furthermore, as the number of devices increases there may be some problems regarding devices density, since increasing the number of devices hinder the topology design, organisation of communication of all devices, etc.

Developments in 4G and ultimately 5G may be able to help with this. e.g. in the case of agriculture: if sensors would be independently connected (with low power consumption) to operator's network, it would be as easy as sell them to the field owner who can him/herself deploy the nodes where they want, with no configuration at all (plug&play)[114] with 5G also having advantages in terms of being able to handle an increased density of devices and support low power devices.

The question is whether a cost effective solution can be sought for these "independently connected" sensors, especially where there is a very large number? Therefore, the pricing and charging structure of the 5G 'solution' will be an important factor in generating demand for using 5G networks for such purposes, especially where the incremental benefit of 5G may be limited (i.e. not essential for the provision of the service).

The traditional model of requiring a separate subscription per device and charging for data use on a per device basis would be unlikely to be attractive/cost effective and therefore without changes to the charging structure the market expanding possibilities of 5G may be limited. For example, if there are a considerable number of devices, but each uses relatively little data there may be little willingness-to-pay a relatively high marginal price to have a 'mobile subscription' for each device e.g. a farmer installing hundreds/thousands or sensors could not be willing to pay a per-device cost unless the marginal price is very low (e.g. some commercially available solutions offered by MNOs such as small

[114] Based on our discussion with Codesian: https://codesian.com/

tracking devices are listed as costing £3 or £4 per month which would rapidly add up if large numbers of devices were requires[115] - albeit these are currently aimed at the consumer market).

However, if the marginal price per device can be low, then there is a potentially large market available to the telecoms operator i.e. even if willingness to pay is only marginal, this may be summed over many uses in many industries to create a substantial market for embedded connectivity.

Supposing that the MNO can establish a charging structure that would allow the agriculture service provider to offer a service based on independently connected devices on a cost-effective basis (which will make its proposition much more flexible and reduce deployment topology complexity etc.), how will the service provider secure connectivity?

- will it do so on a per-site basis (i.e. having to negotiate a new deal for each and every site depending on location and scale)?
- will it have to commit to a single MNO provider?
- will choice of provider depend on coverage (regionally and internationally)?

As discussed in section 5, cases like this raise the possibilities for new entrants or further changes to business models. For example, given some of the issues involved with bi-lateral or multi-site negotiations, there is potential scope for intermediaries to come into the market to facilitate deals with telecoms companies across regions and boarders and provide a single solution to the end-user (i.e. the service provider), operating a bit like an MVNO. Alternatively, if the potential market is large enough the telecoms operator (which might even be a virtual operator using network slicing) may seek to **vertically integrate** with the service provider, or there may be a need for specialist intermediaries who can help better understand the market and provide tailored services.

Similar issues around pricing may also be relevant for other cases. For example, the emergence of such use cases relying on low latency and high bandwidth will depend to some degree on the balance between of the cost of local computing against the costs of connectivity. In some cases, it may be more cost efficient to have more complex devices that do the necessary computation themselves on the device. For example, control applications relying on very low-latency could presumably use largely local compute resources rather than relying on 5G. However, depending on the pricing, devices might be 'dumb' and make use of 5G connectivity to send the data to a centralised resource for computation and then receive the outputs. So again, the charging model adopted by telecoms operators will be key to the incentives of the user. For example, charges do not necessarily have to be priced on a per bit or capacity basis and instead, charges could be tailored, for example for services that may emphasise quality of services metrics charges could be differentiated by latency targets.

Self-provision of 5G connectivity

We have mainly focussed on the business case from the perspective of an MNO on the basis that they will be looking to support new use cases, seeking incremental revenues to support the 5G business

[115] V by Vodafone. For examples, see: http://www.vodafone.co.uk/v-by-vodafone/

case. However, it may also be that for some particular use cases, private networks would be a preferred solution.

Small cells can support private 5G networks

For example, consider a case where there are requirements for 'connectivity' within a single, well-defined environment to support IoT or mMTC (for example, within a factory). This 'in building' coverage requirement may not be met by the initial 5G network roll-outs (as the propagation characteristics of spectrum – particularly very high frequency needed for capacity – limit the extent to which signals will penetrate building to provide indoor coverage). Therefore, to ensure sufficient coverage, there will be a requirement for specific infrastructure deployed in the building (such as small cells).

This might be provided in a number of ways:

- MNOs offering to provide specific infrastructure and a tailored 5G solution, seeing this as an opportunity to diversify their standard service and expand demand by providing a solution that the enterprise could 'buy'; or
- depending on the specific requirements the enterprise may instead consider deploying its own private network solution.

In this case, the enterprise faces a decision of whether to "build or buy" 5G connectivity.

Example: private network to support IoT M2M on site (e.g. a factory)

A factory owner may be able to (or currently does) provide an in-house private network using shared spectrum and existing technologies (such as Wi-Fi solutions), to allow devices and sensors to communicate within the factory. This may be particularly relevant as Wi-Fi networks continue to evolve and become more capable. We understand that the IEEE is continuing to work with the 3GPP on ways to meet IMT-2020 requirements and further Wi-Fi developments can be expected.

However, if the number of connected devices increases and the demands of those devices increase (with respect to data throughput or low latency requirements for example), to a point that Wi-Fi based solutions will have limitations in terms of ability to handle a large number of devices, support high throughput, and provide sufficient coverage in a cost efficient way, the factory owner may seek to gain connectivity through use of other wireless technologies that can handle their demands, such as 5G.

One option would be to source connectivity from MNOs. For example, the enterprise would be able to procure connectivity from an MNO (or other 'non-traditional' connectivity provider with access to 5G spectrum). The site owner could tender for one party to install the necessary infrastructure and provide the services on an exclusive basis (similar to that discussed in the stadia/shopping mall case).

However, in some cases there may be reasons why an enterprise may prefer to 'build' rather than 'buy'. For example, depending on the extent to which there are connectivity requirements for other parts of the factory (such as machine-to-machine communication, remote monitoring devices, or services relying on mission-critical communications, for example), the manufacturer may demand some control over the network rather than relying solely on an external provider or MNO. We understand that there will be some clear cases where enterprises will have a strict preference for building their own private 5G network so as to remain in full control of the network and may therefore seek to self-supply by installing specific infrastructure and acquire access to spectrum.[116]

When deploying private networks verticals may have some difficulties, given they are not communications experts,[117] and given the need to access suitable spectrum.[118] On the other hand, some verticals may have already acquired good knowledge and experience by developing and operating their own networks using existing technologies.

Private 5G networks should not crowd incentives to roll out public 5G

We consider that the deployment of private networks should not be discouraged, as there may be some benefits associated with such small-scale deployments. For example, in cases such as those described above, the deployment of a private network would not necessarily undermine the MNO business case for deployment of 5G public networks, given that supply would in any case require specific network investment beyond that required for the public network. In other words, the private network would not be crowding out investment in the public network.

[116] This could be access to shared or secondary use spectrum. We discuss spectrum issues in more detail in Section 7.
[117] In an interview with one telecoms operator, it pointed out that verticals are not communications experts and may build a network to meet their needs now, but end up in a technology 'cul-de-sac' down the line, as they do not have the expertise to be able to adapt their network to meet their changing needs.
[118] We discuss the spectrum issues in section 7

7 Regulatory options

In many ways 5G is evolutionary, rather than revolutionary. Nevertheless, it may lead to significant changes, including:

- increased use of **small cells** to achieve higher data rates;
- possible entry of non-traditional network operators focussing on **cell densification**;
- **differentiation of service characteristics** through network slicing to meet the diverse needs of various 'vertical' industries and other user groups;
- possibilities for creating **private networks** (for example, in industrial spaces, especially indoors);
- new opportunities for **intermediation** of various forms to integrate different networks and provide connectivity tailored to particular users' needs; and
- low-latency **edge computing** being provided by network operators.

In parallel with these developments, 4G coverage will continue to increase, with 4G adding various capabilities in terms of speed and its ability to serve IoT and M2M applications needing low power terminals. Therefore, mobile networks will develop as a **patchwork**, with a mix of 4G (LTE-A) and 5G coverage, plus integration of other network infrastructure, such as use of fixed network infrastructure to deploy small cells and wholesale services from neutral hosts (who might be other MNOs).

In this section, we discuss what issues these changes might create for national regulators. We are not seeking to make specific recommendations, but rather to identify where attention is likely to be needed from regulators given the likely trends.

7.1 Challenges arising from small cells

Small cells will be needed

Higher data rates necessarily require smaller cells. Future use of mmWave bands for 5G will require very small cells, including within buildings and amongst street furniture. Suitable sites for small cells are not easy to find. Lack of alternatives may give site owners significant bargaining power relative to network operators.

This trend is largely inevitable as a result of the physical characteristics of radio spectrum and growing demand for bandwidth. It raises a number of challenges for regulators (and governments more generally):

- the possibility of **site owners making exclusive or restrictive arrangements** with network operators;

- **planning and other practical constraints** on the supply of locations for small cells; and
- the role of the **public sector itself as a site owner** within urban environments.

Exclusive site access arrangements

A site owner wishing to maximise revenue might *in some cases* seek to make an exclusive arrangement with a single network operator or to exclude one or more operators. Regulators need to consider how they might identify any competitive concerns and respond proportionately. Providing a prior indication of the likely response to such situations may help to discourage any anticompetitive behaviour in the first place.

Exclusive or discriminatory access to small cells is not a general problem …

We would emphasise that exclusive or discriminatory site access is not a general problem, but rather one that may arise in particular cases. Site owners will typically have incentives to make sites accessible to all networks in order to maximise their revenues.

Nevertheless, in certain cases, it is possible that a site owner might obtain greater revenue by limiting the number of network operators at its site rather than accepting all interested parties. In the most extreme case, this might be an exclusive access arrangement, but there are other possibilities. For example, there might be 4 competing MNOs, but the site owner might make only 3 (or fewer) access arrangements available; there would then be competition amongst the MNOs to avoid being the one MNO excluded from the site.

… but related to site owners having sufficient power to affect competition

Clearly if the site owner takes this approach it must earn sufficient additional revenue from each MNO it deals with to compensate for not dealing with all of MNOs. This could occur if either:

- there is enough impact on downstream competition in mobile markets due to only some MNOs having access to a 'pivotal' site; the site owner would then be extracting revenue related to a restriction of downstream competition; or
- the site owner is uncertain about the willingness of network operators to pay for access to the site, and rather than either negotiating individually with operators or posting a standard price for access, seeks to create competition for site access amongst network operators by excluding one or more from the site.

Any impact on downstream competition is unlikely to come from small sites, as only a small proportion of consumers will be affected by the availability of services at that location. Network operators may decide not to be present at that location if site access costs are too high and their lack of access does not lead to a significant competitive disadvantage in retail competition. Equally, small site owners are unlikely to adopt the strategy of committing to exclude one or more networks to increase their bargaining power relative to network operators, as the commitment is unlikely to be credible (i.e. the site owner might let excluded networks in later to get additional revenue later).

Concerns are largely limited to pivotal sites and large collection of sites under common control

Therefore, regulators need to be primarily concerned about large **'pivotal' sites** or collections of sites under common control where access affects the perceived quality of mobile services for consumers. For example, access to groups of small sites across a city (e.g. street lamps) or at major transport hubs may be important as a competitive differentiator for MNOs; this might meet the conditions necessary for the site owner to have an incentive to deal with a subset of network operators (and possibly just one). Another example might be a sufficiently large collection of sites, such as a chain of major shopping malls.

Neutral hosts and wholesale access obligations

If a competition problem arises how might this be remedied? Should obligations fall on network operators or site owners? There are a number of possibilities:

- if one network operator is present, then it might be required to offer access at a wholesale level to other network operators over shared infrastructure;
- a variation would be a 'neutral host' who could install the infrastructure and make wholesale access available on a non-discriminatory basis to all network operators (though the neutral host could be one particular MNO);
- an obligation could be imposed on the site owner to make physical access available to all network operators on a non-discriminatory basis.

Some NRA's are already considering different approaches to this issue. For example (as described in Section 2.4 above):

- Ofcom (UK) sought views on the potential for wholesale access models.[119]
- RTR has indicated that it plans to allow infrastructure sharing to facilitate densification of small cell deployment for 5G roll-out.[120]

Difficulties in constraining pivotal site owners who might have market power

Even if a neutral host provides non-discriminatory access to all networks, this may be insufficient to constrain the exercise of market power by the site owner, if network operators have no alternative but to use that site. In some cases, especially with small cells at millimetre wavelengths, network operators may not have effective alternatives; this can be contrasted with the use of large

[119] Ofcom, "Call for inputs on 5G spectrum access at 26 GHz and update on bands above 30 GHz", 28 July 2017.
[120] RTR, "Consultation on the 3.4-3.8 GHz award procedure", 28 July 2017

cells for coverage at frequencies below 1 GHz, where there will be greater choice in where to locate cell sites as signals will penetrate buildings to some degree. This is a potentially difficult problem, which regulators will need to keep under review as networks start to rely on small cells at higher frequencies. There is no simple regulatory solution, though competition law may constrain the pricing of site access in such cases (either through *ex post* complaints, or *ex ante* by providing incentives not to abuse market power).

Obligations (for example, such as cost orientation) on pivotal site owners are likely to be difficult to implement for a number of reasons. First, the site owner might not be a telecoms operator and so might not fall under *ex ante* regulatory obligations. Competition law would nevertheless apply, but any intervention would need first to demonstrate that the site owner had a dominant position in a defined relevant market (i.e. the supply of physical access to network operators at that location) and that this was being abused.

Second, it may be difficult to determine what a reasonable charge for site access might be, as costs may be difficult to measure. Site owners are likely to be building and maintaining infrastructure whose primary purpose is not to host telecoms equipment. Therefore, revenues from site rental are typically a contribution to the site owner's common and fixed costs. Site owners typically negotiate with network operators and so charges are primarily a reflection of network operators' willingness to pay for access.

Third, the nature of small cells means that due to lack of space it might not be physically possible to co-locate equipment for multiple networks. Therefore, sharing of at least the RAN would be needed in any case if multiple networks were to make use of the site. This situation is likely to be common in practice, especially for small cells within indoor, publicly-accessible spaces.

Site availability: planning and public sites

As discussed above, the move towards small cells (and towards higher frequencies) may give site owners greater power within the overall value chain. Measures aimed at ensuring that all networks can gain access, possibly through neutral hosts, will minimise the creation of any competitive asymmetries in downstream mobile service markets. However, pivotal site owners may still remain in a strong position. This might be detrimental if high site access costs impede roll-out.

Increasing the supply of sites

Rather than trying to control any market power that pivotal site owners might have through competition law – which will be complex given that each case will be different both in terms of the extent of any market power and the specific costs to the site owner – it may be easier to increase the supply of sites. There are a number of policy measures that could be taken, though these are questions for broader government, rather than telecoms regulators:

- Planning rules need to reflect the changing nature of infrastructure, with miniaturisation making it possible to deploy small cells with limited visual impact;
- The public sector may control many suitable locations for small cells within dense urban environments, such as street furniture or roofs of social housing. Where public bodies have objectives that include earning commercial revenue and control pivotal cell site locations, there is a danger that site access pricing could be excessive (just as if the site owner were a private entity).

There is a real risk of public bodies seeking exclusive access deals to maximise commercial revenue

Because of pressure on public finances, it is increasingly common for public bodies to have strong incentives to find commercial revenue streams. It is a real possibility that this might create incentives to conclude exclusive site access arrangements.

By way of analogy, London Underground signed an exclusive contract with Virgin Media to launch a Wi-Fi service at selected tube stations on the London Underground network. After launch (June 2012) customers of all mobile networks were able to use Wi-Fi for free during the Summer Olympics. After this period ended, only Virgin Media customers were able to use the Wi-Fi as part of their subscriptions. Customers of other networks using the Wi-Fi were able to access travel information for free or purchase packages or pay-as-you-go usage from Virgin Media. Since 2014 connecting to the Wi-Fi has been free for EE, Vodafone, O2 and Three customers after these operators signed wholesale agreements with Virgin Media, with customers of other networks still able to purchase access from Virgin Media.

7.2 Access to spectrum

Availability of spectrum for public networks

Spectrum at 3.6 GHz and 26 GHz will be made available for 5G

The recent “Second Opinion on 5G networks” from the RSPG[121] has set out a roadmap for spectrum availability for 5G in which:

- The 3.4 – 3.8 GHz band is identified as the primary 5G band for initial deployments;
- The 26 GHz band (24.25 GHz to 27.5 GHz) is identified as a ‘pioneer band’, primarily for individual licences rather than

[121] “Strategic spectrum roadmap towards 5G for Europe, RSPG Second Opinion on 5G networks”, RSPG18-005, 30 January 2018.

sharing, with a target for Member States to make a sufficiently large portion of the band (e.g. 1 GHz) available by 2020; and
- The 700 MHz band is designated to provide wide area coverage.

At the time of writing, some auctions of 3.6 GHz band spectrum have already been conducted; others are about to be run or are at an advanced stage of planning. As a result of public sector spectrum release programmes, much larger amounts of spectrum have been made available in the 3.6 GHz band than in previous awards of spectrum harmonised for mobile services. For example, 350 MHz of spectrum was sold in the Irish award[122] in 2017.

The 26 GHz band is at present commonly used for fixed links. However, the frequencies identified by the RSPG (24.25 GHz to 27.5 GHz) are much wider than the typical fixed link allocations and in many Member States parts of this band are not currently in use. Therefore, notwithstanding any need to migrate fixed links in the long run, the target set for release of this band in the RSPG's second opinion should be readily achievable. Even where migration of fixed links might be needed, there are many possible bands already in use for fixed links, so this should not be a major obstacle.

Spectrum for private 5G networks

Spectrum needs for private 5G networks

Therefore, at present there are clear and credible plans for spectrum to be made available in a timely manner for 5G on an individually licensed basis. However, it is somewhat unclear what spectrum might be appropriate to use for 5G within private spaces for private networks, for example to support automation and control applications within a large factory.

Coordination in choice of bands for private networks

One company we spoke to told us about an example with an automated car parking solution, essentially using automated trolleys requiring a private wireless network to control them. However, they found that the way in which spectrum can be accessed and used differs across member states making it difficult to design a solution that is compatible across Europe. We were told that Arcep decided that the 2.5 GHz band could be used to provide a private network for such purpose. However, in other countries there may not be such a framework for a private network and the solution would require support from a network provider (e.g. under the mobile operator licenced network). In Germany it was

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[122] ComReg, "Results of 3.6 GHz Band Spectrum Award", 22 May 2017. Available at: https://www.comreg.ie/publication/results-3-6-ghz-band-spectrum-award/

determined the 3.6 GHz band should be used for such private networks.

Clearly there may be a range of alternatives available for applications requiring private networks. RLANs may be suitable for some applications, especially given recent standards to support faster speeds (WiGig) and power saving for IoT-type applications. Narrowband telemetry and control applications might also be able to use unlicensed spectrum (e.g. 433 MHz and 868 MHz). However, all of these possibilities involve the use of shared spectrum on an unprotected basis. We have heard concerns from potential users about the reliability of using such sharing spectrum for mission-critical applications given the possibility of interference considering the large number of devices already in use on these unlicensed bands. Therefore, there appears to be a requirement for private 5G networks that are distinct from existing services and technologies using shared spectrum.

Private networks as secondary users

It would be helpful to clarify the licensing model for private 5G networks and to identify which bands this might fall into. Shared use does not appear to meet the requirements of potential users. Equally, it might be a waste to reserve spectrum exclusively for private users given that most uses of private networks would occur indoors, using small cells at low power levels, thereby limiting interference to other users outside. Therefore, there appears to be scope to licence private networks as secondary users, sharing spectrum on a non-interfering basis with public network operators as primary users. For mmWave bands, the propagation characteristics of the signals themselves greatly constrain the potential for interference. Beamforming and massive MIMO can also reduce interference by making signals more directional.

This secondary user model is different from unlicensed spectrum. Any secondary user would require a licence to operate (as opposed to unlicensed spectrum where interference is managed entirely through restrictions of permitted equipment). The primary user would be protected from interference from the secondary user. The secondary user would need to operate within this constraint, but would have some measure of protection, unlike shared spectrum. This model would seem able to address the concerns that use of shared spectrum is too risky for mission-critical applications. At the same time, it avoids the need to commit large sections of bands for providing highly localised, site-specific exclusive use licenses given that the extent of demand for private 5G networks is uncertain. It would highly inefficient if large ranges of frequencies were reserved on a national basis to provide for a small number of private networks covering a tiny geographical area.

Coordination of approaches across Member States

Clarity over the spectrum access model for private 5G networks is needed at the EU level. However, this is not to say that detailed harmonisation measures are needed. It would be sufficient simply to clarify whether spectrum would be available for private networks – we suggest licensed on a secondary basis – and, if so, which bands this would be available in. Such guidance would remove a potential barrier to innovation in services due to cross-country differences. This might be a matter on which BEREC could take a role in ensuring reasonable consistency of licensing arrangements for private 5G networks.

Taking a secondary licencing approach within spectrum bands used for public 5G networks might also be preferable to making spectrum available in distinct bands purely for 5G private networks or to support innovative new use cases. Using the same spectrum for public and private networks through sharing arrangements removes a potential inhibitor to development if equipment manufacturers cannot benefit from the scale economies they would enjoy when supporting mass market services.

Accommodating non-traditional operators

New entry possibilities

There is the possibility that 5G might encourage entry of new network infrastructure providers. In particular, there may be opportunity for specialist providers of cell densification offering wholesale access to other network operators. Indeed, the 2017 Irish 3.6 GHz auction resulted in spectrum being awarded to Airspan, who appear to have such a business model.[123]

We cannot judge at this point whether there will be sustainable business models for cell densification by independent operators or whether they might eventually consolidate into existing mobile network operators. Nevertheless, it is possible that the need to obtain suitable sites, conclude deals with site operators and then interconnect and backhaul a large number of small cells within a limited physical area could create opportunities for specialist providers of wholesale services (acting as a neutral host).

Flexible spectrum packaging can meet the needs of non-traditional entrants

Given this, spectrum award processes should be sufficiently flexible to allow such entry by what we might call 'non-traditional' operators. In particular, approaches in which spectrum is auctioned or awarded in pre-determined packages designed to meet the needs of incumbent MNOs are inappropriate as they might inhibit such entry. Recent spectrum auctions – regardless of the specific auction format used – have tended to offer spectrum in small blocks (typically 5 MHz), allowing competition over the amount of spectrum acquired by bidders (subject to any spectrum caps). This approach is sufficiently flexible to accommodate non-traditional entrants, whose spectrum requirements may be difficult to anticipate. With larger amounts of spectrum available (such as in typically 3.6 GHz awards) it is possible that incumbent MNOs will

[123] See Airspan Website: http://www.airspan.com

not necessarily win all the available spectrum and entrants may be successful, as in the Irish 3.6 GHz auction.

Licence conditions should not exclude cell densification business cases

It is also important that licence conditions are not set in a manner that excludes non-traditional operators. For example, coverage obligations that might be easily met by an MNO with an existing national network could be very onerous for an operator wanting to offer wholesale services at certain key locations where it might not be feasible for multiple networks to run dense deployments of small cells. Put simply, cell densification by non-traditional operators offering wholesale services may mean that coverage is 'spotty'.

7.3 Coverage issues

General coverage is important for innovation incentives

The **5G Action Plan**[124] sets targets for 5G availability in one major city in each Member State by 2020. This will provide opportunities to test 5G new applications and services. Whilst developers of new services, applications and products using 5G will no doubt benefit from this initiative in the short run, in the longer run their incentives to innovate are much more related to how **widespread 5G services** will be in general, which is not tied to any deployment plan for a prioritised city.

Applications and services will use a mix of different forms of connectivity

No rational developer will want to take the risk of tying their product or services entirely to 5G if coverage cannot be relied on. Rather, as we have heard in our interviews, products and services will need to be able to fall back gracefully on less capable forms of connectivity. There are various alternatives that can be used depending on the application. For example, connected vehicles are likely to use a variety of modes of connectivity, including 5G, 4G and peer-to-peer connections. There are various alternatives available for IoT applications under 4G, such as NB-IoT and LTE-M. Because of indoor coverage issues, RLANs will need to work together with public mobile networks. In summary, we are very likely to see a **mixed connectivity environment**, with various forms of connectivity being integrated and 4G and 5G coexisting.

Difficulties of defining 5G coverage

Furthermore, the 5G standards do not define a single service with fixed characteristics, but rather an envelope of performance characteristics, where there are trade-offs between different features. Therefore, **5G coverage** is not simply a matter of peak data rates. For example, 5G could be rolled out in rural areas for mMTC applications for agriculture, yet have relatively low data rates compared with mobile broadband (even under 4G). A further example is edge computing. This might be available in certain

[124] European Commission, "5G for Europe Action Plan". Available at: https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan

locations, but probably not everywhere with a 5G radio layer. Not all of the IMT-2020 targeted capabilities may be available in a given location.

Therefore, it makes little sense to draw a binary distinction between 5G coverage being present or absent at a particular location. Rather there is a set of capabilities, some of which, but not all of which, might be available. This means that coverage obligations cannot simply be specified in terms of '5G' presence, but rather need to be defined in terms of the availability of certain technical capabilities.

Service obligations might be met with a mix of 4G and 5G

Typical coverage obligations associated with spectrum have somewhat changed over the last decade or so; from a general obligation to cover a certain proportion of population to increasingly specific interventions to provide defined services in certain locations (e.g. a target data speed in certain 'not-spots'). However, if the required capability is data speed, then it is likely that for at least the medium term that requirement could be met most cost effectively with a mix of 4G and 5G deployment. Again, this highlights new difficulties with a '5G' specific coverage obligation and the danger of an excessive focus on achieving 5G roll-out.

Importance of fall back connectivity options for incentive to develop new applications and services

Given the potential for mMTC applications in rural areas (e.g. precision agriculture), it is important that there are stop-gap measures to allow such applications to develop independently of 5G coverage. Applications and services are unlikely to be successful in the marketplace if many potential customers are without the minimum levels of connectivity on public networks needed to support those applications and services. Whilst one regulatory response might be to try to provide a roadmap for 5G roll-out (and use regulatory measures to enforce this), this would still leave developers of such applications and services in a risky situation if coverage did not develop as expected. Therefore, we consider it is likely that developers may address these risks themselves by using **alternative forms of connectivity** (e.g. 4G or hub and spoke arrangements for sensor networks); this provides a fall back so that new applications and services can be marketed to a wide base of potential customers. Satellite connectivity may be important in the short term in providing a basic level of connectivity as a backstop to allow IoT applications with moderate data rate requirements to operate in remote areas.

Linkage between rural backhaul and fibre broadband interventions

In rural areas, availability of **high-quality backhaul** – particularly fibre – is often mentioned as a constraint on 5G deployment. However, this is not a '5G' specific problem, as it might also be relevant for some 4G sites as data traffic grows.

The question of backhaul for rural cell sites (regardless of technology) is likely to be closely connected with roll-out of high-speed fixed broadband to rural areas. Where Member States have intervention plans to develop deployment of fibre networks to rural areas, it is likely that these can also provide backhaul connectivity for cell sites.

7.4 Competitive issues

Private networks and non-traditional entry

Benefits of private networks and non-traditional entry

We have discussed above the possibility of self-supplied private 5G networks within indoor spaces such as factories. Also, it is possible that new parties might enter and deploy dense small cells in certain locations to provide wholesale services to other network operators.

These developments are pro-competitive. The possibility of self-supply for certain vertical industries is a direct alternative to using a traditional MNO and so may enhance price competition. Entry of wholesale cell densification services does not increase the intensity of (retail) price competition, but nevertheless it puts competitive pressure on MNOs to rollout 5G networks. There may be physical constraints on the number of separate small-cell networks that can be built at certain sites (in some cases possibly only one operator could be present) creating incentives to be the first there; competition may be enhanced by the possibility of a whole cell densifier securing such a site first.

We have discussed above that the **spectrum licensing environment should be friendly to both private networks and non-traditional entrants** because of these competitive benefits.

Supply-side complementarity between fixed and mobile

Fixed networks have a role in providing in-building coverage

Fixed network infrastructure may become important in delivering 5G services within buildings. Achieving indoor coverage may become increasingly challenging due to tighter building standards aimed to reduce energy consumption. It may be unrealistic to expect public mobile networks to penetrate highly insulated buildings; using metal foils to reflect heat will also greatly attenuate radio signals. Therefore, it may be necessary to rely on small cells within buildings, repeaters or **integration with RLANs** to deliver a seamless service.

It will be possible for a mobile-only operator to make use of available RLANs within a building and integrate them into its service. 5G will help in delivering a coherent user experience. Nevertheless, mobile operators with fixed assets may have certain advantages. For example, it may be possible to use routers supplied for fixed broadband services to act as 5G femtocells.

Fixed and mobile may be supply-side complements as well as demand-side substitutes

The increased importance of small cells and the problems of in-building coverage are likely to create a degree of complementarity between fixed and mobile services on the supply-side (in the sense that there may advantages in supplying both). At the same time, on the demand side substitution of fixed and mobile services is likely to increase; falling costs of mobile network capacity (both due to further 4G deployment and then 5G) allow larger data bundles to be offered. Therefore, there is some degree of tension: whilst consumers might increasingly want to go mobile-only, there may also be greater need for fixed services to provide in-building coverage at high data rates, even though the same terminal device might be used both in the home and outside.

Increasing competition and possible consolidation between FWA and mobile can be expected

The use of 5G technology to deliver FWA services will create a measure of convergence. MNOs may offer FWA-type services using mobile network given falling unit capacity costs and the availability of 700 MHz spectrum to provide a coverage layer. Indeed, this trend is already happening with 4G as network costs fall and there is surplus capacity at lightly loaded rural cells. Given the potential for scale economies between FWA and 5G mobile, it is possible that there might be some pressure for consolidation (at least at the network level).

Infrastructure sharing and upstream concentration

Infrastructure sharing may be essential

Infrastructure sharing avoids cost duplication, but may in some cases raise concerns that it could be used as a device to coordinate retail pricing and inhibit retail competition. For example, a common network might raise particular concerns about the usage-based wholesale charges having the effect of coordinating retail pricing amongst network sharers. Where obligations to supply MVNOs have been imposed as merger undertakings (e.g. in the Irish O2/H3G merger) **capacity-based wholesale pricing** has been required for just this reason. However, infrastructure sharing is likely to be both necessary and commonplace for 5G deployment through small cells. In many cases, it may simply be physically infeasible to deploy multiple RANs at certain locations.

Certain forms of sharing arrangements could affect retail competition

Therefore, infrastructure sharing is likely to extend beyond collocation of equipment and tower sharing, with a shared RAN or with wholesale services being provided by neutral hosts (who might be MNOs or other parties). Such arrangement should be beneficial to 5G roll-out. The likely scenario is that there will be different sharing arrangements at different locations depending on exactly which operators are present. However, regulators also need to be alert to the possibility that if small cells grow in importance and account for a large share of network traffic, there is the possibility of concentration upstream onto a single common infrastructure. If this occurs, certain forms of wholesale arrangements (based on charging traffic rather than allocated capacity) could then be used to soften competition in retail markets.

Competition assessments may need to focus more on physical networks rather than virtual ones

Given the agility of 5G networks to reconfigure network slices and adjust the amount of capacity allocated to a wholesale user rapidly, this distinction between usage-based wholesale charges (which might have retail competitive effects) and capacity-based charges (which can essentially be treated as fixed costs for the purposes of retail prices) may become blurred. This may make it more important to consider the number of competing **physical networks** when conducting competition assessments, rather than assuming that virtual network operators make a similar contribution to competition as actual networks. This observation is reinforced by the observation that MVNOs may be able to offer services that are differentiated in quality relative to the host network through network slicing.

7.5 Backhaul for 5G cell sites

We have seen that many potential use cases for 5G depend not just on urban coverage, but more on expectations about rural coverage, or at least coverage in corridors such as major roads. At present, backhaul in rural areas at sufficient bandwidth may be limited or expensive.

Rural backhaul may be helped by national broadband interventions

However, what matters is not so much the current situation, but that appropriate backhaul is available on a timescale to fit with likely rural deployment plans. We note that a number of Member States are actively intervening in the provision of high-speed broadband in rural areas through state aid. Given that these interventions typically promote fibre deployment, there would seem to be a natural **synergy between these interventions** and making fibre available for rural cell sites.

Physical infrastructure access might help, but less so in rural areas

Physical infrastructure access (to ducts and poles) is likely to assist in deployment of fibre backhaul. However, the impact of physical infrastructure access is likely to be primarily felt in urban areas where ducts are already available. Some rural deployments may not have existing infrastructure at all to be shared to provide fibre backhaul. Therefore, it is important to recognise that physical infrastructure access is unlikely to be a particularly effective instrument for achieving rural fibre deployment.

7.6 Edge computing

We have not found any live use case that is particularly likely to make use of edge computing. Nevertheless, in the longer term it is possible to imagine certain scenarios in which edge computing could become important.

In particular, augmented reality applications on smartphones could prove important as a means to overlay information from databases on the immediate world around us. This could have industrial or commercial applications (for example, allowing a service engineer to identify a part by pointing a camera at it).

Many of these applications will probably be able to cope with latency and use cloud computing resources available on the general internet. However, in some cases the interactivity associated with AR might require lower latency. There might also be a need to off-load extensive computation from handsets with limited computing power and battery life to servers. Therefore, it is possible that edge computing could be important for certain niche applications.

Open standards for edge computing are likely to be important to protect competition

Suppliers of edge computing are limited to the available network operators at a given location. Therefore, from the perspective of a customer, edge computing will come bundled with network connectivity. **Open standards for edge computing** may be important to ensure that customers (especially commercial customers) do not become locked in to a particular provider.

7.7 Net neutrality

The rules regarding treatment of traffic in the EU is contained within EU Regulation 2015/2120[125] (commonly referred to as the 'Net Neutrality' rules) and the BEREC Guidelines[126]. The rules are directly applicable across all 28 Member States. Article 3 of the regulations is intended for 'Safeguarding of open internet access':

- Article 3(1) sets out the rights of end-users of internet access services (IAS)[127] in terms of accessing and distributing information and content;
- Article 3(2) prohibits contractual conditions which limit the exercise of the end-user rights set out in Article 3(1);
- Article 3(3) regulates ISPs' traffic management practices, setting a requirement that ISPs should treat all data traffic equally (outlining some exceptions);

[125] REGULATION (EU) 2015/2120 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 November 2015 laying down measures concerning open internet access and amending Directive 2002/22/EC on universal service and users' rights relating to electronic communications networks and services and Regulation (EU) No 531/2012 on roaming on public mobile communications networks within the Union

[126] BEREC Guidelines on the Implementation by National Regulators of European Net Neutrality Rules, BoR(16) 127, August 2016

[127] An 'Internet Access Service' is "*a publicly available electronic communications service that provides access to the internet, and thereby connectivity to virtually all end points of the internet, irrespective of the network technology and terminal equipment used.*" Article 2(2)

- Article 3(4) sets out the conditions under which traffic management measures may entail processing of personal data; and
- Article 3(5) sets out that providers of electronic communications (including providers of Internet Access Service and providers of content, applications or services (CAPs)) could provide services other than IAS which may be designed to meet requirements for a specific level of quality.

Article 3(3) considering traffic management practices gives relevant rules for prioritising categories of traffic within the IAS. This is relevant for certain prospective 5G services. Article 3(5) can also be considered of particular importance to the 5G debate given that the delivery of these 'specialised services'[128] may be over network slices which might allow operators to serve particular needs (e.g. low latency) to some users separately from the general IAS offering. The BEREC Guidelines state that, "network-slicing in 5G networks may be used to deliver specialised services".[129]

Under the Net Neutrality rules, specialised services may be offered where the optimisation is objectively necessary to meet the requirements of the services. In addition, as specified in Article 3(5) and Recital 17, such specialised services must satisfy three conditions:

- *"the network capacity is sufficient to provide the specialised service in addition to any IAS provided;*
- *specialised services are not usable or offered as a replacement for IAS;*
- *specialised services are not to the detriment of the availability or general quality of the IAS for end-users."*

It will be down to regulators to determine whether the requirements of a particular case objectively require a specialised service and whether any of the above conditions are met. The BEREC Guidelines recommend the information and methods that NRAs can use to assess traffic management practices and specialised services when ISPs ask them to provide regulatory clarity on specific questions concerning implementing new technologies and services.

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[128] Specialised services are defined in the first subparagraph of Article 3 (5) as: "*services other than IAS services; they are optimized for specific content, applications or services, or a combination thereof; the optimization is objectively necessary in order to meet requirements for a specific level of quality.*"
[129]Footnote26 of BEREC Guidelines on the Implementation by National Regulators of European Net Neutrality Rules, BoR(16) 127, August 2016.

7.8 Sectoral regulation and quality of service

Telecoms NRA could have a role in assessing network reliability claims that affect sectoral regulation

In a number of cases, we noted the sectoral regulation (for example, aviation regulations for drones) with a predominant factor in determining when, and if, a particular use case might take off. Sectoral regulations are often related to reliability issues. For example, a safety assessment on a 5G-controlled drone needs to consider underlying network reliability. Similar issues may arise in medical applications and where 5G is used for monitoring and control in utility networks.

Sectoral regulators are less well placed to make assessments of network reliability than specialist telecoms regulators. There is also a need to ensure that assessments of reliability and security are broadly consistent across different applications of 5G to different sectors. Whilst 5G has the capability to increase network reliability, it is important that the claims are carefully understood and assessed. For example, even if terminal devices can be simultaneously connected to multiple cell sites, the reliability improvement depends on whether there are correlated risks of failure at those sites.

8 Conclusions

What is 5G?

- Whilst 5G may eventually be transformative for some sectors, in the short to medium term these developments are more likely to be evolutionary than revolutionary.
- 5G brings enhancements over 4G, including high speeds, low latencies, enhanced reliability, lower power consumption and greater terminal device densities. There is an envelope of network characteristics set out in the IMT-2020 standard within which trade-offs can be struck.
- Network slicing can be used to create virtual networks with particular performance characteristics by prioritising certain features. This will allow differentiated services targeting different types of users.

What will drive deployment?

- In the near term, eMBB is likely to be the main driver of 5G deployment. 5G will help network operators control the costs of growing data traffic due to MBB and to maintain service quality at competitive levels.
- In the longer run, there may be incremental revenues from new services enabled by 5G. However, there is no killer application. Rather, we expect there to be a wide variety of different niche applications. This situation arises because most commercial uses will be designed for a mixed connectivity environment of 4G, 5G and other networks and with no certainty about the dynamics for 5G coverage.
- Industries using 5G as inputs – so-called 'verticals' – are likely to have specialist requirements. This may create opportunities for intermediaries who know those industries well to assemble connectivity services targeted to their needs. Connectivity services might involve orchestrating various networks and virtual networks.
- Another role for intermediaries may result from the need for trans-national connectivity services to support products and services across the EU. We already see this in connectivity for cars for infotainment services.
- There is a danger that pricing structures might impede take-up if they excessively focus on per-connection or per-device charging models. This could cause some users to inefficiently substitute to alternative technologies.

Private networking

- There is a role for private deployments of 5G within spaces such as factories or warehouses. Private networks should be pro-competitive and help to drive coverage of public 5G networks.
- More clarity about which bands to use for private networks would be helpful to avoid uncoordinated approaches across Member States.
- A secondary spectrum licensing model might be appropriate for private networks. Unlicensed spectrum with licence licensing might run too greater a risk of reliability problems for typical use cases (e.g. industrial control).

Consequences of small cells

- Small cells are needed to achieve the high data rates needed for 5G and to exploit mmWave bands.
- Small cells put power into the hands of site owners. Pivotal site owners may be able to extract rents.
- Restrictive or exclusive access arrangements might in some cases increase pivotal site owners' revenue. Obligations on network operators to make corresponding wholesale access services available to others can remove any competitive distortion that might result downstream in retail markets, in effect imposing a neutral host. However, this does not entirely remove the ability of a pivotal site owner to extract rents.
- In response to this problem, Governments should seek to increase the supply of sites. Planning rules should not be excessively tight.
- Where public bodies control pivotal sites (possibly in urban areas), there is a danger that they exploit their power to maximise commercial returns. This needs to be avoided.
- Fixed operators might have certain advantages in deploying small cells, for example bundled in consumer routers to support FTTP services.

Backhaul availability

- In rural areas, backhaul is needed for 5G cell sites.
- However, state aid schemes for national high-speed broadband may already address this issue by encouraging fibre deployment that could be used for dual purpose.

Infrastructure sharing

- 5G is likely to lead to much more infrastructure sharing, due to the use of small cells. Sometimes there may be physical limits on how many distinct networks can be accommodated at a site.
- Charging models for shared infrastructure should ideally be capacity-based to ensure that there are no retail competitive effects. However, there is a question mark over how effective this can be in protecting competition when the agility of 5G networks might allow rapid reallocation of capacity between sharers.
- Regulators need to be alert to excessive concentration due to infrastructure sharing.

Edge computing

- Edge computing might prove useful for augmented reality or other applications, but it is too early to tell.
- Open standards for edge computing are important so that consumers do not become locked in to a particular network.

Annex A Glossary

3GPP	3rd Generation Partnership Project
4K	4000 pixels resolution
5G-IA	5G Infrastructure Association
5G-PPP	5G Infrastructure Public Private Partnership
5GAP	5G Action Plan
5GAA	5G Automobile Association
8K	8000 pixels resolution
AR	Augmented Reality
ARPU	Average revenue per user
B2B	Business to business
B2C	Business to consumer
BEREC	Body of European Regulators for Electronic Communications
BNetzA	German telecoms regulation
C-V2X	Cellular vehicular-to-everything communication
CAGR	Compound annual growth rate
CEPT	European Conference of Postal and Telecommunications Administrations
CFI	Call for input
CPS	Cyber physical systems
DSCR	Dedicated short-range communications
EC	European Commission
ECC	Electronic Communications Code
eMBB	Enhance mobile broadband
EU	European Union
FWA	Fixed Wireless Access
HD	High definition
HGV	Heavy goods vehicle
I4MS	Innovation for Manufacturing SMEs
IAS	Internet access services
ICT	Information and communications technology
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile telecommunications

IoT	Internet of Things
IP	Internet Protocol
IPTV	Internet Protocol television
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union Radiocommunication Sector
LTE	Long Term Evolution, a 4G mobile communications standard
LTE-A	LTE Advanced Major enhancement of the LTE standard
LTE-M	Long Term Evolution for Machines
M2M	Machine to machine type communications
MIMO	Multiple-input and multiple-output
mMTC	Massive machine type communications
mmWAVE	Millimetre wave spectrum in bands above 30 GHz
MNO	Mobile network operators
MVNO	Mobile virtual network operators
NB-IoT	Narrowband Internet of Things
NFV	Network function virtualisation
NGMN	Next Generation Mobile Network
NR	New radio air interface developed for 5G
NSA	Non-Standalone
NRA	National Regulatory Authority
OEM	Original equipment manufacturer
OTT	Over The Top, communication services delivered over IP
PPDR	Public Protection and Disaster Relief
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access network
RLAN	Radio Local Access Network (also known as wireless LAN)
RoI	Return on Investment
RSPG	Radio Spectrum Policy Group
RTR	Austrian Telecoms Regulator
SCM	Supply chain management
SDN	Software-defined networking, a
SME	Small to medium enterprises
UAV	Unmanned aerial vehicle

UHDTV	Ultra High Definition TV
URLLC	Ultra reliable low latency communication
V2I	Vehicle to infrastructure
V2N	Vehicle to network
V2P	Vehicle to pedestrian
V2V	Vehicle to vehicle
V2X	Vehicle to everything
VPN	Virtual private network
VR	Virtual reality
WLAN	Wireless Local Access Network
WRC	World Radiocommunication Conference

Annex B Automotive case study

Within the timeframe of this study, we might expect to see 5G being used to support two main elements of the "connected cars" proposition:

- improvements to the provision of infotainment services to the vehicle, ranging from provision of 'in-car Wi-Fi' for video and audio streaming, to real-time traffic updates, e-call services etc., and also to provide remote monitoring data back to the manufacturer regarding performance of the car and other telematics data;
- vehicle-to-everything communication for remote sensing, safety and control of cars (e.g. assisted driving and collision avoidance) laying the foundations for realising a longer-term vision of fully autonomous vehicles.

Basic requirements

For infotainment services, cars need to be connected to the 'internet', which will require a cellular modem that allows data to be sent and received over a public mobile network.

For collision avoidance type services for assisted driving today (with a view to fully autonomous vehicles in future) at the most basic level, vehicles need to be able to communicate with each other (vehicle-to-vehicle communication) sharing information such as position, speed, etc. and need to communicate this to other cars in real time. Vehicles may also need to communicate with infrastructure (vehicle-to-infrastructure communication), enabling vehicles to receive and send information to e.g. traffic lights, roadside signs or traffic control centres; and with other road users such as pedestrians or cyclists etc. Depending on the type of data being transmitted and the need for processing information may also need to be exchanged with a backend server (e.g. from a vehicle manufacturer or other mobility service providers) or with the Internet (V2N), which might rely on cellular data connections. The term Vehicle-to-Everything (V2X) is typically used to refer to all these types of vehicular communication.[130]

Can these requirements be met by existing technologies?

Basic infotainment requirements can already be met using 4G LTE services with some manufacturers already providing such functionality in their cars.[131] However, as the data requirements of services provided over these networks increase and the number of connected cars on the roads increase, 4G would likely not be able to provide a sufficient quality of service.

As described in the sector overview, V2V communication between vehicles is possible and can already be achieved using alternative technologies based on short-range communication. However, to the extent that vehicle-to-everything communications rely on vehicle-to-network

[130] As noted by 5G-PPP: "*All these V2X use cases rely on the principle that connected vehicles periodically provide either status information (e.g., position, speed, acceleration, etc.etc.) or event information (e.g., traffic jam, icy road, fog, etc.etc.). This information is usually packed into stateless, individual messages or probes which are either locally disseminated to neighboring vehicles, or sent to a central point (base station, backend) where it can be aggregated and then again disseminated to other vehicles to make use of it*." 5G-PPP White Paper on Automotive Vehicle Sectors

[131] http://www.wired.co.uk/article/ford-in-car-wi-fi-modem-vodafone-europe

communications, this will take place via mobile networks and part of the Cellular-V2X solution.[132]

The global cellular standard is now LTE-4G and the current C-V2X is based on 3GPP release 14 specifications, however there are already plans underway to accelerate support from 5G in the development of the "R16 5G V2X" standard based on 3GPP Release 16 5G standards, and 5G is expected to bring improvements.

What enhanced capabilities does 5G offer?

For infotainment services, 5G will provide improved data rates and improved mobility for vehicles travelling at speed, thus widening the scope for more data rich services to be provided.

For assisted driving, the 5GAA consider that *"…that 5G will be the ultimate platform to enable C-ITS and the provision of V2X. 5G will be able to better carry mission-critical communications for safer driving and further support enhanced V2X communications and connected mobility solutions."*[133] Furthermore, "*The C-V2X technology is already available but to support the autonomous vehicles of tomorrow, the technology must evolve to meet more demanding safety requirements. 5G will facilitate this evolution. Its extreme throughput, low latency, and enhanced reliability will allow vehicles to share rich, real-time data, supporting fully autonomous driving experiences.*"[134]

5G offers a further (and improved) option for C-V2X communication, and will be more 'future proof' in the shift towards fully autonomous driving in future. For example, *"[a]n application such as controlled fleet driving will require an ultra-low end-to-end latency for some warning signals, and higher data rates to share video information between cars and infrastructure. 5G should provide the high reliability, low latency, and high scalability required in this space"*.[135]

In this way, 5G will most likely be an evolution of already available communication technologies like LTE V2X and IEEE 802.11p but be capable of providing improvements to capabilities and be capable of delivering further capabilities that will to enable the future V2X use cases[136]

What are the technical requirements for these enhanced capabilities?

The expected technical capabilities that this use case is expected to require are summarised in the table below.

Data Rate	Latency	Reliability	Mobility	Device Density	Position Accuracy	Network Slicing
> 10 Mbps	< 5 ms	99.999 %	> 200 km/h	10000 /km^2	30 cm	Preferable

Source: DotEcon and Axon based on information from 3GPP

What are the spectrum requirements for provision of these services?

For infotainment services, it is likely that these will rely on the evolution of public cellular

[132] The 5G-AA defines C-V2X as: "…*a technology developed by the Third Generation Partnership Project (3GPP) to deliver V2X services, using two modes of communication: a direct vehicle-to-vehicle mode (called 'PC5' in 3GPP specifications) and a network communications interface (called 'Uu' in 3GPP specifications) for vehicle-to-network (V2N) communication via existing mobile networks."*
[133] http://5gaa.org/about-5gaa/vision-mission/
[134] http://5gaa.org/5g-technology/paving-the-way/
[135] NGMN, NGMN 5G White Paper, 17th February 2015
[136] 5G-PPP White Paper on Automotive Vehicle Sectors

networks as they shift from 4G to 5G. The expectations imply that MNOs would hold the spectrum rights (in line with the typical model used for 3G and 4G deployment) operated through exclusive licenses.

By design the specification for C-V2X means that safety critical features associated with device-to-device or V2V communications will not be reliant on cellular network coverage (as the risk of drop-outs, no coverage or poor network performance cannot be afforded).

The V2V communication currently requires regionally harmonised ITS spectrum. ITS applications are intended to be operated in the 5.9 GHz band[137], which is allocated for safety and traffic efficiency. Qualcomm suggests that at least 70 MHz of spectrum is recommended to support technology and use case evolution of V2X with 30 MHz dedicated spectrum to accommodate existing/emerging use cases, 20 MHz primary spectrum for future intelligent transportation use cases or technology migration, and 20 MHz of shared spectrum to be shared with unlicensed spectrum access technologies[138].

For C-V2X, the V2N communications will rely on cellular networks, given the large area over which 5G would have to be available suggesting that this would rely on public 5G networks (with good coverage and very high SLGs) rather than a private network. Therefore this would typically require the involvement of a Mobile Network Operator (MNO).[139]

Further business model considerations

Once cars are "connected" there will be scope for a large amount of data to be collected on the car's movements, locations and possible sensor data (such as acceleration and braking). This could allow the development of some business models already emerging in the insurance industry. For example, vehicle insurance premiums are traditionally calculated through risk algorithms for specific groups of drivers. However, this is not necessarily anything new or specific to 5G as the industry has already undertaken telematics trials of usage-based insurance to observer how customers drive and more accurately assess the actual risk posed by drivers (through pay-as-you-drive or pay-how-you-drive), and some companies are already offering such deals through simple smartphone apps. Telematics could also detect fraudulent claims made by customers and, through systems such as eCall, notify insurers of accidents.

Furthermore, once cars are connected: *"Automotive manufacturers will be able to use 5G networks as a platform to open up new revenue streams and business models such as charging for real-time in-car entertainment, basing rental charges on driving behaviour and route selection, or sale of road mapping data to third-party organisations. Automotive manufacturers have no experience of building nationwide communications infrastructure. They can avoid the need to build their own networks, or to acquire complex skills, by buying managed 5G network services from operators."*[140]

[137] RSPG, Opinion on Spectrum Aspects of Intelligent Transport Systems, https://circabc.europa.eu/sd/a/b30590d7-5190-480b-b1d1-def24719e061/RSPG17-008-Final_opinion_ITS.pdf
[138] Qualcomm, Leading the World to 5G: Cellular Vehicle-to-Everything (C-V2X) technologies, June 2016
[139] http://5gaa.org/5g-technology/c-v2x/
[140] Huawei, "5G Opening up New Business Opportunities. Available at: http://www.huawei.com/minisite/hwmbbf16/insights/5g_opening_up_new_business_opportunities_en.pdf

Annex C Media and entertainment case studies

Enhanced mobile broadband for live events case study

This use case is concerned with being able to support the increased data requirements that result from expanding data usage at large events. For example, the demand for connectivity may increase due to services being offered to provide an improved experience for consumers using real-time virtual/augmented reality. These could integrate physical and virtual information such as scores and information on athletes or musicians. Real-time services could include replay, choosing a specific camera or language during the event, watching high definition (HD) playback video, sharing live video, or posting HD photos to social networks. Visitors could bet, buy merchandise and order refreshments.[141][142][143][144] These services might be made available to consumers through their own mobile devices (i.e. via an app) or might be provided over devices specific to the event (e.g. a virtual reality headset).

Basic requirements

On-site live event experiences will involve significant demand for downlink and uplink, and a very high density of devices, with several thousands connected simultaneously in a single stadium or small area. Next Generation Mobile Networks *NGMN) estimate that a data volume density of up to at least 0.75 Tbps will be required for a standard stadium in the 2020s[145]. In order for consumers to be able to make the most of the services listed above, and to be able to satisfy their demand for data intensive activities at events where there are a significant number of devices (so that cumulative data requirements may be very large), the basic requirement is for increased capacity of mobile networks, in a particular location and improved mobile data services.

Can these requirements be met by existing technologies?

LTE-advanced allows for MIMO techniques and channel carrier-aggregation that can boost speed and capacity of networks. Increasing the number of cell-sites and deploying small cells to increase network density is also possible using 4G technologies, and to ‘offload’ traffic from cellular infrastructure to ‘Wi-Fi' services running off fixed infrastructure. Such technologies are currently used to temporarily boost coverage and capacity at festivals and other large events, being deployed in areas where there is a very high likelihood of significant demand for mobile data at a particular time. However, these solutions may not be sufficient (and/or cost effective) to meet the increased demand for data at events if this continues to grow.

[141] NGMN, NGMN 5G White Paper, 17th February 2015
[142] Ericsson, Opportunities in 5G: The View from Eight Industries
[143] 5G PPP, 5G and Media & Entertainment, 19th January 2016
[144] Nokia, Translating 5G use cases into viable business cases, White Paper: Financial analysis of six 5G business cases to support communication service provider investment decisions, April 2017
[145] NGMN, NGMN 5G White Paper, 17th February 2015

For example, based on the NGMN estimates above, the 5G-PPP notes that "*this very challenging target, which is not reachable with 4G and its evolutions, will require a seamless integration of various innovative technologies including broadcast and millimetre waves.*"[146]

What enhanced capabilities does 5G offer?

5G promises to provide a significant improvement in cell capacity and boost data rates, which will be ideal to accommodate the increasing traffic demands and device density at large events. This is expected to allow for improved performance and potentially, more cost efficiently than could be done with existing technologies. For example, Nokia assessed the relative costs of deploying connectivity to support many people in a stadium streaming HD video (as part of an immersive experience) and reported the following key findings:

*"**Capacity**: 5G provides up to 40 times more capacity in the stadium than 4.5G*

***Overall cost:** The cost of providing the video services is up to 20 times lower with 5G*

***Penetration:** When delivering high definition video, 4.5G achieves a take-rate (the percentage of the total audience available to the operator based on its market share) of just 2 percent, compared to almost 30 percent for 5G multi-camera video steaming."*[147]

It concludes: "*5G is the only feasible solution for this scenario due to the high capacity density required. Other technologies would require more small cells than is possible when taking interference restrictions into account. The better performance with 5G is achieved by being able to use more spectrum, the much higher spectral efficiency achieved by massive MIMO and advanced techniques in interference mitigation and receiver technology. The findings show that an operator wanting to provide good video quality would not realistically be able to use LTE as this would reach too few subscribers and would incur too high a cost. In contrast, 5G can deliver high definition video simultaneously to a large number of subscribers within the stadium.*"[148]

What are the technical/network requirements for these enhanced capabilities?

As previously stated, this use case requires a very high data peak rate with on-site live event experience being the most important driver for uplink and downlink throughput. Live events also imply a very high device density, with several thousands of devices connected concurrently in a stadium or venue. This leads to high traffic density, which may not be properly attained by the current 4G networks and requires uniform integration of different innovative technologies such as the use of mmWave spectrum bands, massive MIMO and densification through the deployment of micro-cells. The use of these techniques will reach their maximum potential with the deployment of 5G networks.

The expected technical capability requirements for this use case are summarised in the table below.

Data Rate	Latency	Reliability	Device Density	Traffic Density	Service Deployment	Network Slicing

[146] 5G-PPP White Paper on Media Entertainment Vertical Sector.
[147] Nokia white paper, "The 5G advantage in real network scenarios Techno-economic simulation results for solid 5G business and technology planning"
[148] Nokia white paper, "The 5G advantage in real network scenarios Techno-economic simulation results for solid 5G business and technology planning"

					Time	
15-30 Mbps	10 ms	99%	150000 /km²	3.75 Tbps/km²	90 minutes	Effective

What are the spectrum requirements for provision of these services?

This use case is expected to require a mixture of frequency spectrum of low frequency bands for coverage and data traffic, and high frequency bands (e.g. mmWave spectrum bands) with large contiguous bandwidth to cope with the increasing traffic demand, including wireless backhaul solutions. In Europe, 3.4-3.8 GHz and 26 GHz layers are proposed for stadium and large events[149], with 5G trials at the 2020 Euro Championships representing a practical realisation of the use case.

Who provides the 'connection' will depend on the opportunities afforded by spectrum authorisations, who holds spectrum rights and vice versa. For example, if spectrum is allocated on a fixed term, exclusive use basis (e.g. as has typically been the case with bands designated for mobile broadband use in recent years), then the main connectivity solution will be traditional MNOs deploying 5G networks on these sites.

However, if spectrum is available on an area defined exclusive use licence, then a new third-party network provider selling wholesale access or even the stadium/event owner could provide the cellular network solution. Given high throughput and capacity requirements in localised hot-spot and congested areas, we understand that some stakeholders have stated a preference for individual exclusive licenses[150].

As discussed in Section 7 of this report, there are a number of options that regulators can choose from to make spectrum available in order to meet such specific needs.

What are the network requirements for provision of these services?

As discussed in the main report, given the need for indoor or localised coverage and the very high capacity requirements such a use case will need to be supported with deployment of multiple 5G small cells with seamless hand-over between cells, which might typically have very short range due to the propagation characteristics of the mmWave spectrum.

As explored in more detail in Section 6 and Section 7 of this report, there may be a number of considerations that regulators should be aware of when it comes to site access and the deployment of small cells.

The future of broadcasting case study

[149] ITU and Nokia: 5G for people and things- 700Mhz band as key to success for wide-area 5G services. Available at: https://www.itu.int/en/ITU-D/Regional-Presence/Europe/Documents/Events/2017/Spectrum%20Management/Ulrich__Nokia__5G_in%20700w.pdf

[150] European Commission: Study of spectrum assignment in the European Union, October 2017.

The broadcasting sector will face a number of challenges as the demand for (and creation of) 'immersive media' increases. This includes the increase in demand for 4k/8k/ultra-high definition television with high dynamic range and high frame rates, but also 'object-based content' which includes things such as virtual reality, augmented reality and 360 degree media.

Furthermore, there will continue to be a shift in demand for the seamless integration of different broadcasting technologies so that consumers can move from viewing content on one to the next without disruption. Whilst at present, distribution networks might largely be considered separate and independent (for example, distribution over cellular, satellite, broadcast airwaves, digital terrestrial television etc.), 5G may facilitate the development and provision of a single solution that can *"exploit delivery modes for unicast, multicast, broadcast as well as local caching."*[151]

One particular project currently on-going seeks to *"devise, assess and demonstrate a conceptually novel and forward-looking 5G network architecture for large scale immersive media delivery".*[152] This project is known as 5G-Xcast.

The main objectives of the project are to investigate whether 5G technology could be used to support a number of different use cases, by considering how one might:

- *"design a dynamically adaptable 5G network architecture enabling seamlessly switching between unicast, multicast and broadcast and exploiting built-in caching capabilities"*
- *"develop 5G broadcast and multicast point-to-multipoint capabilities for Media and Entertainment"* (but also with a view to supporting some Automotive, Internet of Things (IoT) and Public Warning Systems (PWS) applications)

Work Package 3 of the 5G-Xcast project focuses on the Radio Access network for future broadcast/multicast 5G transmissions and work is currently on going as part of the technical research project.

However, a key part of the project is also based on designing a content distribution framework. This Framework would be network/technology agnostic in order to optimise the use of a range of networks (e.g. 4G, 5G, home broadband via Wi-Fi) to deliver content to end users and provide a simple user interface for the content provider so they can code everything in the same way to deliver to people regardless of the distribution method. The content distribution framework would provide a single interface (or common set of standards) that a content provider could use to deliver the content using a single set of standards for any technology.

Whilst there may be a number of ways to meet these goals using existing technologies, there is potential for 5G to support the media and broadcasting sector, and the 5G-Xcast project is exploring these issues.

For example, as reported by the 5G-XCast project:

- *Audio-visual media services generate very large volumes of data traffic on networks which is unevenly distributed over time and geographical areas. At the same time, Quality of Experience (QoE) is strongly dependent on sustained minimum data rates and low latencies to all regardless of the total number of concurrent users. This is particularly challenging for very popular live content (e.g. sports) or unpredictable events (e.g. breaking news) that tend to cause large traffic spikes.*

[151] 5G-Xcast website. Available at: http://5g-xcast.eu/about/
[152] 5G-Xcast website. Available at: http://5g-xcast.eu/

- *The increasing bit-rate demands of 4k UHDTV and, in the future 8k UHDTV, and the emerging new interactive services (e.g. augmented reality, virtual reality and 360º visual media) will further increase the demand on network capacity and performance."*[153]
- *"None of the existing networks, whether fixed, mobile or broadcast, has the capability to support this type of future demand on their own due to limitations associated with capacity, delay and cost of deployment. Furthermore, the fragmented landscape of protocols and APIs across them severely limits their ability to cooperate in addressing this demand."*
- *"5G-Xcast will develop a solution that targets such limitations and therefore addresses future demand, based on the key capabilities of 5G that by far exceed those of the legacy systems."*

However, it must be acknowledged that 5G usage will not be ubiquitous (or at least not for a very long time), so one cannot ***rely*** on 5G for delivering all of these services and other methods for distribution may be needed. This will be particularly important for public service broadcasters (who have obligations to provide a service to all).

[153] 5G-Xcast website. Available at: http://5g-xcast.eu/

Annex D Manufacturing case study

Manufacturing case study

As noted in the main report, many of the potential manufacturing use cases generally fall under the larger umbrella of massive machine type communication or the Internet of Things. To the extent that this will require improved wireless connections within a factory there are decisions to be made about how to source this connectivity (and also the charging models). We consider some of the important concepts with the help of an example of an augmented reality service.

Augmented reality could be used to support design, maintenance, process manufacturing, training, assembly and repair by aiding the execution of procedural tasks through simulations. Augmented reality (AR) will also enable virtual collaboration amongst engineers in different locations. This will help to improve communications and effective knowledge sharing across the industry and will take advantage of the enhanced mobile broadband capabilities being offered by 5G.

For example, as identified by the 5G-PPP, *"the application of augmented reality in the plant will facilitate:*

- *Augmented-reality support in production and assembly: Precisely positioned picture-in-picture fade-ins, it shows the operator the next step and helps avoiding misplacement and unnecessary scrap,*
- *Augmented-reality support in maintenance and repair: Repair machine without training due to augmented information and operational guidance."*[154]

This may, for example, connect the engineer on site with a back-office support centre who have all of the necessary information at their fingertips, providing guidance along the way. Similarly, a connection may be made with a large database of necessary information, which can then be provided to the engineer on-site.

Basic requirements

The use of augmented reality applications in the work place and factory and an increasing number of wireless, mobile devices that are using such applications will lead to increasing demand for the transfer of large amounts of data in these environments (for example, graphical overlays and models, large data sets, etc.). Therefore, high bandwidth requirements will be particularly important. The high bandwidth requirements will be driven by both bandwidth per application/device (with video based applications likely to be a primary example: *"in the case of video-controlled maintenance, with real-time augmented content mixed into the video signal, bandwidth is important."* [155]) and a potentially large number of those devices running simultaneously.[156]

Furthermore, low-latency will be required in most of the applications falling under this use case (for example, where information must be fed in real time and overlaid on video on a

[154] 5G-PPP White Paper, "5G and the Factories of the Future".
[155] 5G-PPP White Paper, "5G and the Factories of the Future".
[156] Qualcomm, "Augmented Reality and Virtual Reality: the First Wave of 5G Killer Apps", 1 February 2017.

handheld device). High reliability/availability will also be crucial: *"high availability is key to ensure that (emergency) maintenance actions can take place immediately."*[157] Therefore, high bandwidth, high reliability and low latency are the most important factors for this use case.

Can these requirements be met by existing technologies? And what enhanced capability does 5G offer?

Although existing technologies may be sufficient for early deployments of this use case, as the number of devices using these applications and the requirements of these applications become more complex, 5G will be crucial to fulfil the full set of technical requirements needed under this use case in terms of high data rates (bandwidth requirements), coverage reliability and, in some cases, low latency.

What are the technical/network requirements for these enhanced capabilities?

A highly reliable wireless communication, will be important to integrate the applications of augmented reality into the closed loop control processes, and provide a seamless experience while using hybrid wireless and wired network technologies. Augmented reality content such as overlay on live video being displayed on a mobile device, will involve high data transmission that can be supported by 5G, for example, as noted by 5G-PPP, "*In case of video-controlled maintenance, with real-time augmented content mixed into the video signal, bandwidth is important"*[158]

Furthermore, 5G will help support the time criticality of interactive AR support in manufacturing is characterised by low communication latency[159]. For some applications latency may be required to be below 1 ms. It is also worth noting that the need for coverage is also important to ensure that such applications can be used both on-site and in the field.

The network needs to provide a highly heterogeneous multi-connectivity scenario, where everything is capable of communicating even in harsh industrial environments. It is also necessary to provide a fast and reliable configuration of QoS and traffic demands, to enable fast network adaption.

Furthermore, depending on the exact requirements and the level of dedicated capacity/control over the network, there may be a greater role for key network management functions that can be facilitated by 5G networking solutions. For example, as noted by 5G-PPP, "*Concepts such as network slicing, software-defined networking and network function virtualization are key buildings blocks within 5G, and may become cornerstones in tomorrow's communication infrastructure of manufacturers."*[160]

The expected technical capabilities that this use case is expected to require are summarised in the table below.

Data Rate	Latency	Reliability	Availability	Network Slicing
10-100 Gbps	< 7 ms	99 %	99.999 %	Preferred

What are the spectrum requirements for the provision of these services?

This use case is expected to require a mixture of frequency spectrum of low bands for both

157 5G-PPP White Paper, "5G and the Factories of the Future".
158 5G-PPP White Paper, "5G and the Factories of the Future".
159 For non-interactive content, such as streamed 360° video, this does not apply.
160 5G-PPP White Paper, "5G and the Factories of the Future".

coverage purposes and data traffic (e.g. for engineers that are using AR applications for maintenance and support on the field), and high bands (e.g. mmWave spectrum bands) for capacity purposes.

Therefore, on the one hand, this use case will require exploiting higher bands and making more flexible use of available bandwidth. Furthermore, leveraging higher spectrum bands (e.g. 28 GHz), not previously used for LTE, with simultaneous connectivity with spectrum bands below 6 GHz is expected to ensure a seamless, ubiquitous AR user experience.

The licensing scheme will depend on the particularities of the case. For example, in case of on-site operations within the walls of a single factory, the use of licensed bands would be, in principle, feasible with no limitation on technologies and application other than requirements to avoid harmful interference and reduce risk for interference, which will disrupt the manufacturing operations.

As discussed in Section 7 of this report, there are a number of options that regulators could choose from to make spectrum available in order to meet such specific needs.

Business model implications

The manufacturing industry players are expected to incur costs in procuring the devices, software, and training that would help them smoothly integrate AR into the various manufacturing processes. However, these costs may be recouped through improvements to efficiency and productivity in training and maintenance activities - for example, support can be provided more quickly, with off-site specialists communicating with local engineers in real time, using augmented reality to supervise activities such as maintenance, repairs, equipment upgrades or training. This will remove the need to wait for specialist advisors to come on-site and reduce the need for in-depth training for new recruits. In this way, the introduction of new remote services such as AR could lead to the re-structuring of teams within the manufacturing environment, with the creation of virtual back office teams of specialists. *"These remote teams may use the data coming from smart devices for preventives analytics and easy access to work instructions"* [161]

There may be scope for new intermediaries in this market to develop specific AR solutions tailored to the factories needs which may be made up of an entire solution (including the wireless network) or provide the means by which the application can be integrated with devices and the networking arrangements already in place.

One of the main issues will be around who provides the network. The main cost driver for connectivity providers will be in providing the necessary infrastructure (e.g. small cells, power, backhauling). Given the potentially significant costs involved and depending on the exact demands of the network the manufacturer that wishes to use 5G to support AR applications in the work place will face a build or buy decision.

If a solution is to be provided that is reliant on public mobile networks, then MNOs will see a change in their business model through shifting away from the traditional B2C model and towards a B2B relationship where it will need to offer a bespoke solution to the manufacturer and set prices in such a way that allows them to get a RoI.

However, depending on the extent to which there are connectivity requirements for other parts of the factory (such as machine-to-machine communication, remote monitoring devices, or services relying on mission-critical communications, for example), the manufacturer may demand some control over the network rather than relying solely on an external provider or MNO. This will require the factory owner to come up with their own

[161] 5G-PPP White Paper, "5G and the Factories of the Future".

networking solution (subject to spectrum licencing conditions).

Many of the issues regarding the sourcing of 'connectivity' are similar to the 'events' case study, however the issue of interoperability across different mobile networks is unlikely to be as relevant given that the network will be used only for private purposes. We discuss these issues in more detail in Section 6 and 7 of the main report.