Setting the scene for 5G: Opportunities & Challenges

Discussion Paper

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Work in progress, for discussion purposes
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Abbreviations and acronyms

Various abbreviations and acronyms are used through the document; they are provided here for simplicity.

Abbreviation/acronym	Description
2G, 3G, 4G, 5G[1]	Refers to different generations of mobile standards
5GIA	5G Infrastructure Association
AI	Artificial Intelligence
AV	Autonomous Vehicle
CAV	Connected Autonomous Vehicle
CCTV	Closed-Circuit TV
C-RAN	Cloud/centralized radio access network
EMBB	Enhanced Mobile Broadband
EMF	Electromagnetic Field
EC	European Commission
EU	European Union
FCC	Federal Communications Commission
FTTH	Fiber to the Home
FTTP	Fiber to the Premise
FUTEBOL	Federated Union of Telecommunications Research Facilities for an EU-–Brazil Open Laboratory
GSMA	The GSM Association
ICT	Information Communications and Technology
IMT-2020	International Mobile Telecommunication 2020 standards
IoT	Internet of Things
ITU	International Telecommunication Union
ITU-D	ITU Development Sector
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Standardization Sector
LTE-A Pro	Long-Term Evolution Advanced Pro
MCS	Mission Critical Services
MER	Main Equipment Room
MIMO	Multiple Input, Multiple Output
MIoT	Massive Internet of Things
mmWave	Millimeter Wave

[1] https://www.itu.int/en/publications/Documents/tsb/2017-IMT2020-deliverables/mobile/index.html#p=1

NFV	Network Function Virtualization
NISA	National Information Society Agency Korea (Rep. of)
NRA	National Regulatory Authority
PPP	Public–Private Partnership
Q.NBN	Qatar National Broadband Network
RAN	Radio Access Network
SDN	Software-Defined Networking
TIM	Telecom Italia Mobile
WRC-19	World Radiocommunication Conference 2019

Unless otherwise stated, policy makers refers to NRAs, local (municipal or state) or national (federal) government agencies.

Executive summary

The 5G 'nirvana' promises to deliver an improved end-user experience by offering new applications and services through gigabit speeds, and significantly improved network performance and reliability. Building on the successes of 2G, 3G and 4G mobile networks, 5G is expected to transform societies to support new services and new business models. Independent economic studies have forecast significant economic gains as a result of 5G network deployment and through the provision of 5G services.

Despite the potential benefits that are expected to be realised from 5G, there is concern that 5G is premature. In fact, operators are sceptical about the commercial case for investment given the significant amount of investment that will be required to be made by them in deploying 5G networks.[2] This paper estimates the cost to deploy a small-cell ready 5G network – assuming fiber backhaul is commercially feasible – can range from USD 6.8 million for a small city to USD 55.5 million for a large dense city.

Where a viable case for investment in 5G can be made it is likely to take place in highly densely populated urban areas which are the most commercially attractive regions to operators. It will be economically challenging to make investments in 5G networks outside of these densely populated areas – particularly in the early years of 5G deployment. As a result, rural and suburban areas are less likely to receive any investment in 5G potentially widening the digital divide.

Until such time that the investment case for 5G is proven the industry and policy makers should approach 5G investment with caution and should consider enhancing the availability and quality of existing 4G networks in the run up to 5G. The need for 5G is not immediate and policy makers and operators should only consider deploying 5G networks where there is demand or a robust commercial case to do so.

Where there is demand for mobile broadband networks but deployment costs of 5G networks are high, policy-makers can consider a range of legal and regulatory actions to facilitate and reduce the challenges to implement 5G networks. This can include supporting the use of affordable wireless coverage (e.g. through the 700 MHz band) to reduce the digital divide where it is not commercially feasible to deploy fiber backhaul networks. In addition, commercial incentives such as grants, or PPPs can be used to stimulate investment in 5G networks.

This report highlights 17 key issues for consideration by policy-makers to stimulate investment in 5G networks.

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2 https://www.techradar.com/news/eu-backed-groups-warns-about-5g-claims

Key issues for consideration

No.	Summary	Description of issues for consideration
1)	Investment case	Policy makers may consider undertaking their own independent economic assessment of 5G to evaluate the commercial viability of deploying 5G networks.
2)	4G network strategy	Until such time that the case for 5G networks can be made, policy makers may consider enhancing the availability of and boosting the quality of 4G networks.
3)	Harmonize spectrum	NRAs may consider allocating/assigning globally harmonized spectrum bands for 5G.
4)	Spectrum roadmap	NRAs may consider a spectrum roadmap with a predictable renewal process.
5)	Spectrum sharing	NRAs may consider allowing spectrum sharing to maximize efficient use of available spectrum particularly to benefit rural areas.
6)	Spectrum pricing	NRAs may consider selecting spectrum award procedures that favour investment.
7)	700Mhz spectrum	Policy makers may consider supporting the use of affordable wireless coverage (e.g. through the 700 MHz band) to reduce the risks of the digital divide.
8)	Fiber investment incentives	Where market failure has occurred, policy-makers may consider stimulating fiber investment and passive assets through PPPs, investment funds and offering grant funds, etc.
9)	Fiber tax	Policy-makers may consider removing any tax burdens associated with deploying fiber networks to reduce the associated costs.
10)	Copper migration to fiber	Policy-makers may consider policies and financial incentives to encourage the migration from copper to fiber and to stimulate the deployment of fiber services.
11)	Wireless backhaul	Operators may consider a portfolio of wireless technologies for 5G backhaul in addition to fiber including point to multi point (PMP) microwave and millimeter wave (mmWave) and satellite where possible.
12)	Access/sharing of passive infrastructure	Policy makers may consider allowing access to government-owned infrastructure such as utility poles, traffic lights and lampposts to give wireless operators the appropriate rights to deploy electronic small cell apparatus to street furniture.

No.	Summary	Description of issues for consideration
		NRAs may consider continuing to elaborate existing duct access regimes to encompass 5G networks allowing affordable fiber deployments
13)	Access costs	Policy-makers/NRAs may consider ensuring reasonable fees are charged to operators to deploy small-cell radio equipment onto street furniture.
14)	Asset database	Policy-makers may consider holding a central database identifying key contacts, showing assets such as utility ducts, fiber networks, CCTV posts, lampposts, etc. to help operators cost and plan their infrastructure deployment more accurately.
15)	Wayleave (rights of way) agreements	Policy-makers may consider agreeing upon standardized wayleave agreements to reduce the cost and time to deploy fiber and wireless networks.
16)	5G test beds	Policy makers may consider encouraging 5G pilots and test beds to test 5G technologies and use cases and to stimulate market engagement.

1 Introduction

5G networks and artificial intelligence (AI) have been highlighted by the ITU as fields of innovation necessary to enabling smarter societies. 5G is the next generation of mobile standards that promises to deliver improved end-user experience by offering new applications and services through gigabit speeds, and significantly improved performance and reliability. 5G networks are expected to be enhanced with AI to make sense of data, manage and orchestrate network resources and to provide intelligence to connected and autonomous systems.

To this end, the ITU is developing "IMT for 2020 and beyond" - IMT-2020, setting the stage for 5G research activities emerging around the world. The ITU has also established a focus group to study machine learning in 5G networks. This Focus Group is studying the use cases, services, requirements, interfaces, protocols, algorithms, ML-aware network architecture and data formats.

This paper has been prepared as part of the overall framework of AI series of reports to help governments, information communications and technology (ICT) regulators or national regulatory authorities (NRAs) prepare for AI and 5G digital transformation.

This report reviews our expectations of 5G and examines the infrastructure and investment requirements on the private and public sectors to prepare for 5G, to support emerging use cases and services, and to meet the expected performance (gigabit data rates), low latency and high reliability requirements of these services, ensuring that end users reap the economic benefit that 5G is expected to offer.

In addition, the report looks at the transition strategies used by wireless operators to upgrade 4G networks to 5G – particularly in urban areas where 5G rollouts are likely to be prioritized - and the various political, strategic and tactical challenges that can hold back the deployment of 5G networks. While significant steps are being made towards 5G in developed economies, consideration is also given to the challenges that will be faced by wireless operators in less developed economies.

Also included in this paper is a high-level cost model to estimate the potential capital investment required by a wireless operator to upgrade to a 5G network and the potential models that can be used by NRAs to incentivize investment in 5G. Finally, based on interviews with operators and supplemented by secondary research, the report draws on real examples of the role policy-makers can play as facilitator, enabler and coordinator to prepare for 5G development, to speed up deployment and reduce the cost of deploying 5G networks.

The remainder of this document is structured as follows:

- Section 2 examines 5G, its evolution and what it can deliver over and above existing wireless technologies, including economic and wider societal benefits.
- Section 3 explains 5G spectrum requirements and the technologies to support 5G networks and how operators are expected to evolve to 5G networks.
- Section 4 describes the key challenges to rolling out 5G networks from an infrastructure and spectrum policy perspective.
- Section 5 provides examples of how policy-makers are starting to work through the issues associated with deploying 5G networks.
- Section 6 explores the investment requirements of developing 5G networks and potential approaches to incentivizing investment in 5G networks.
- Section 7 recommends actions for policy-makers in NRAs and governments to implement in order to simplify and reduce the cost of deploying 5G networks.

2 5G overview

This section introduces the role of the ITU in developing 5G standards and the potential benefits that 5G can generate. However, there is a risk that 5G may not be an appropriate consideration across all regions, just yet. Further, there is concern that 5G may lead to a digital divide given its initial suitability to dense urban areas.

2.1 The role of the ITU

5G is the next generation of mobile standards being defined by the ITU. IMT-2020 (5G) is a name for the systems, system components, and related aspects that support enhanced capabilities beyond those offered by IMT-2000 (3G) and IMT-Advanced (4G) systems.

International Mobile Telecommunication 2020 standards (IMT-2020) set the stage for 5G research activities that are emerging around the world and defines the framework and overall objectives of the 5G standardization process as well as the roadmap to guide this process to its conclusion by 2020 see Figure 1.

Figure 1: Detailed timeline and process for ITU-R IMT-2020

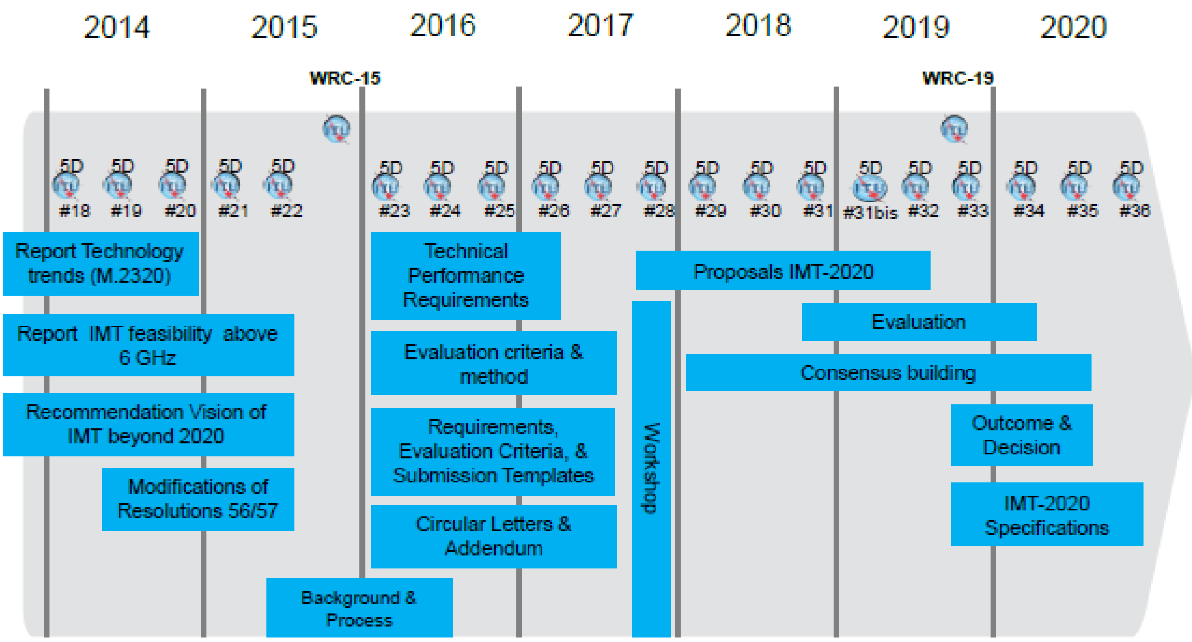

Figure 1: Detailed timeline and process for ITU-R IMT-2020. Source: ITU, 2016

Annex A provides an overview of the work the ITU has undertaken on 5G.

2.2 What is 5G?

5G promises to deliver improved end-user experience by offering new applications and services through gigabit speeds, and significantly improved performance and reliability. 5G will build on the successes of 2G, 3G and 4G mobile networks, which have transformed societies to support new services and new business models. 5G provides an opportunity for wireless operators to move beyond providing connectivity services, to developing rich solutions and services for consumers and industry across a range of sectors at an affordable cost. 5G is an opportunity to implement Wired and Wireless converged networks, in particular in terms of integrating the management systems of networks.

Most of all, 5G is an opportunity for policy-makers to empower their citizens and businesses. 5G will play a key role in supporting governments and policy-makers to transform their cities into smart cities, allowing them to realize and participate in the socioeconomic benefits that can be achieved by being a part of an advanced data intensive digital economy.

Commercial 5G networks are expected to start deployment after 2020, as shown in Figure 2, when the standards for 5G are likely to be finalized.[3] The GSM Association (GSMA) expects 5G connections to reach 1.1 billion, some 12 per cent of total mobile connections, by 2025. It also forecasts overall operator revenues to grow at a CAGR of 2.5%, to reach USD 1.3 trillion by 2025.[4]

5G is also expected to increase data rates dramatically and reduce latency compared to 3G and 4G. 5G is expected to significantly reduce latency to below 1ms, opening it up to be used for mission-critical services where data are time-sensitive. Its high-speed capability allows 5G networks to be considered for the provision of a range of high-speed broadband services and potentially as an alternative to the last mile access such as FTTH or copper connections.

Box 1: Role of IMT 2020 (5G) and beyond

The framework of the future development of IMT for 2020 and beyond, is described in detail in ITU-Recommendation M.2083-0 that states that IMT systems should continue to contribute to the following:

– Wireless infrastructure to connect the world: Broadband connectivity will acquire the same level of importance as access to electricity. IMT will continue to play an important role in this context as it will act as one of the key pillars to enable mobile service delivery and information exchanges. In the future, private and professional users will be provided with a wide variety of applications and services, ranging from infotainment services to new industrial and professional applications.

– New ICT market: The development of future IMT systems is expected to promote the emergence of an integrated ICT industry which will constitute a driver for economies around the globe. Some possible areas include: the accumulation, aggregation and analysis of big data; delivering customized networking services for enterprise and social network groups on wireless networks.

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[3] In 2012, the ITU's Radiocommunications sector (ITU-R) embarked on a programme to develop international mobile telecommunication (IMT) standards for 5G by 2020.

[4] "The 5G era: Age of boundless connectivity and intelligence automation", GSMA Intelligence, 2017

– Bridging the Digital Divide: IMT will continue to help closing the gaps caused by an increasing Digital Divide. Affordable, sustainable and easy-to-deploy mobile and wireless communication systems can support this objective while effectively saving energy and maximizing efficiency.

– New ways of communication: IMT will enable sharing of any type of contents anytime, anywhere through any device. Users will generate more content and share this content without being limited by time and location.

– New forms of education: IMT can change the method of education by providing easy access to digital textbooks or cloud-based storage of knowledge on the internet, boosting applications such as e-learning, e-health, and e-commerce.

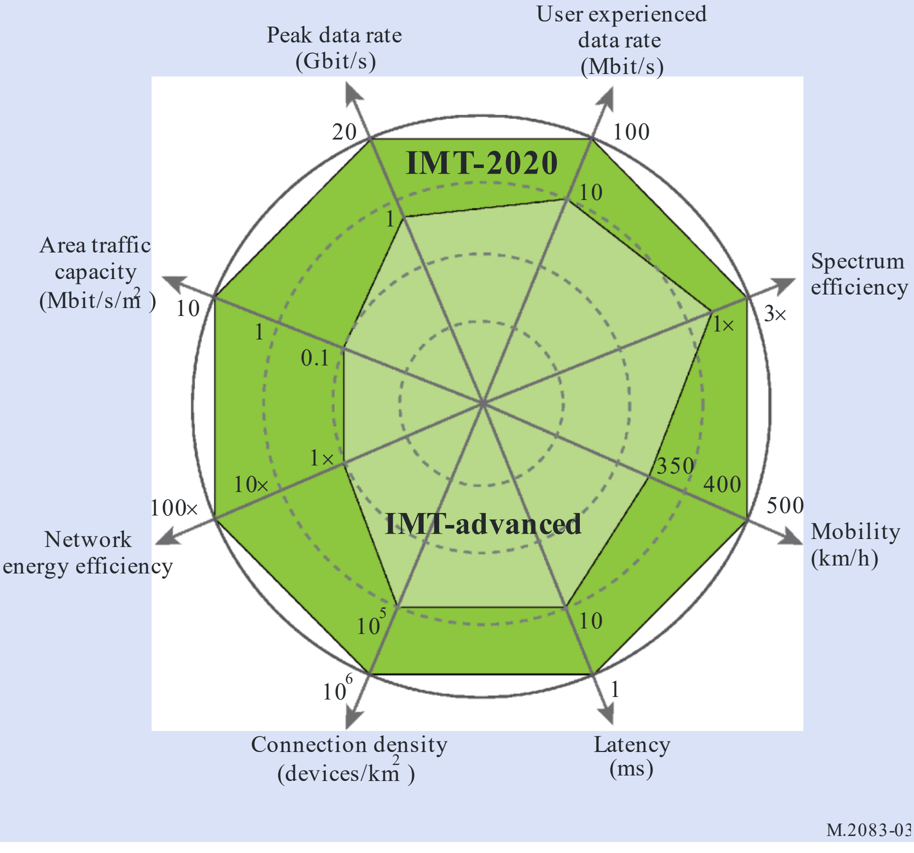
– Promote Energy Efficiency: IMT enables energy efficiency across a range of sectors of the economy by supporting machine to machine communication and solutions such as smart grid, teleconferencing, smart logistics and transportation.

– Social changes: Broadband networks make it easier to quickly form and share public opinions for a political or social issue through social network service. Opinion formation of a huge number of connected people due to their ability to exchange information anytime anywhere will become a key driver of social changes.

– New art and culture: IMT will support people to create works of art or participate in group performances or activities, such as a virtual chorus, flash mob, co-authoring or song writing. Also, people connected to a virtual world are able to form new types of communities and establish their own cultures.

The targets set for IMT-2020 are described below.

Enhancement of key capabilities from IMT-Advanced to IMT-2020



The peak data rate of IMT-2020 for enhanced Mobile Broadband is expected to reach 10 Gbit/s. However under certain conditions and scenarios IMT-2020 would support up to 20 Gbit/s peak data rate, as shown in Fig. 3. IMT-2020 would support different user experienced data rates covering a variety of environments for enhanced Mobile Broadband. For wide area coverage cases, e.g. in urban and sub-urban areas, a user experienced data rate of 100 Mbit/s is expected to be enabled. In hotspot cases, the user experienced data rate is expected to reach higher values (e.g. 1 Gbit/s indoor).

The spectrum efficiency is expected to be three times higher compared to IMT-Advanced for enhanced Mobile Broadband. The achievable increase in efficiency from IMT-Advanced will vary between scenarios and could be higher in some scenarios (for example five times subject to further research). IMT-2020 is expected to support 10 Mbit/s/m2 area traffic capacity, for example in hot spots.

The energy consumption for the radio access network of IMT-2020 should not be greater than IMT networks deployed today, while delivering the enhanced capabilities. The network energy efficiency should therefore be improved by a factor at least as great as the envisaged traffic capacity increase of IMT-2020 relative to IMT-Advanced for enhanced Mobile Broadband.

IMT-2020 would be able to provide 1 ms over-the-air latency, capable of supporting services with very low latency requirements. IMT-2020 is also expected to enable high mobility up to 500 km/h with acceptable QoS. This is envisioned in particular for high speed trains.

Finally, IMT-2020 is expected to support a connection density of up to 106/km2, for example in massive machine type communication scenarios.

Source: ITU-R Recommendation M.2083-0.

Figure 2: Evolution of mobile networks

	1G	2G	3G	4G	5G
Approximate deployment date	1980s	1990s	2000s	2010s	2020s
Theoretical download speed	2kbit/s	384kbit/s	56Mbit/s	1Gbit/s	10Gbit/s
Latency	N/A	629 ms	212 ms	60-98 ms	< 1 ms

Figure 2: Evolution of mobile networks. Source: GSMA, OpenSignal, operator press releases, ITU

2.3 5G use cases

The high speeds and low latency promised by 5G will propel societies into a new age of smart cities and the Internet of Things (IoT). Industry stakeholders have identified several potential use cases for 5G networks, and the ITU-R has defined the most important of these, which can be classified into three categories (see Figure 3):

1. **Enhanced mobile broadband (eMBB)** – enhanced indoor and outdoor broadband, enterprise collaboration, augmented and virtual reality.

2. **Massive machine type communications (mMTC)** – IoT, asset tracking, smart agriculture, smart cities, energy monitoring, smart home, remote monitoring.

3. **Ultra-reliable and low-latency communications (URLLC)** – autonomous vehicles, smart grids, remote patient monitoring and telehealth, industrial automation.

Figure 3: 5G usage scenarios

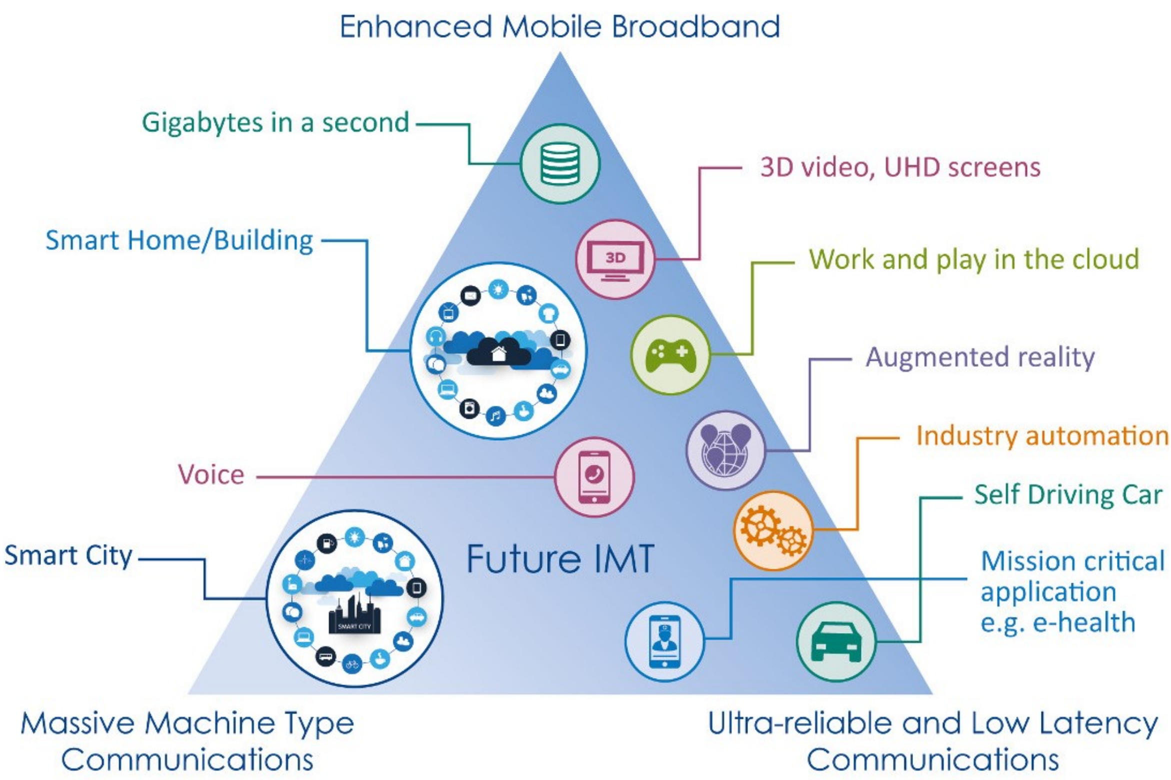


Figure 3: 5G usage scenarios. Source: IMT Vision for 2020 and beyond from Recommendation ITU-R M.2083, 2015

eMBB is expected to be the primary use case for 5G in its early deployments, according to wireless operators. eMBB will bring high-speed mobile broadband to crowded areas, enable consumers to enjoy high-speed streaming for in-home, screen and mobile devices on demand, and allow enterprise collaboration services to evolve. Some operators are also considering eMBB as the last mile solution in the areas lacking copper or fiber connections to homes.

5G is also expected to drive smart cities and IoT through the deployment of a considerable number of low-power sensor networks in cities and rural areas. The security and robustness built into 5G will make it suitable for public safety and for use in mission-critical services, such as smart grids, police and security services, energy and water utilities, and healthcare. Its low latency performance characteristics make it suitable for remote surgery, factory automation and the control of real-time processes.

As intelligent transport systems evolve, and with 5G's low latency and safety characteristics, smart vehicles will be able to communicate with each other, creating opportunities for connected autonomous cars and trucks. For example, an autonomous vehicle (AV) being operated via a cloud-based autonomous driving system must be able to stop, accelerate or turn when told to do so. Any network latency or loss in signal coverage preventing the message from being delivered could result in catastrophic consequences. However, wireless operators believe that AVs are quite a while away from implementation, despite ongoing pilots and trials.

Box 2: 5G and fixed mobile convergence (FMC)

FMC is a networking solution in a given network configuration, enabling the provision of services and application to the end user regardless of the fixed or mobile access technologies being used and independent of the user's location. The concept of FMC has been implemented since 2005. With the move towards 5G, the FMC solution gets additional flavour.

According to Recommendation ITU-T Y.3101, the IMT-2020 network is envisioned to have an access network-agnostic architecture whose core network will be a common unified core network for new radio access technologies for IMT-2020, as well as existing fixed and wireless networks (e.g., wireless local area network (WLAN)). The access technology-agnostic unified core network is expected to be accompanied by common control mechanisms which are decoupled from access technologies.

Emerging information and communications technologies (e.g., virtualization, cloud, software-defined networking (SDN), network function virtualization (NFV)) are transforming telecommunication operators' networks including fixed and mobile networks to achieve high resource utilization and network flexibility, which can contribute to network functions' convergence in an IMT-2020 network.

To this end, ITU-T SG13 approved the Recommendation ITU-T Y.3130 (01/2018) that specifies service related requirements such as unified user identity, unified charging, service continuity and guaranteed quality of service support, and network capability requirements such as control plane convergence, user data management, capability exposure and cloud-based infrastructure, to support fixed mobile convergence in IMT-2020 networks.

Currently, ITU-T SG13 continues to investigate different facets of FMC approach, for instance, the FMC service scheduling - a network capability to collect information from application layer, network layer and user layer to generate service scheduling policies (i.e. traffic scheduling, access selection, etc.) in FMC network which supports multiple RAT accesses.

In the context of IMT-2020, FMC represents the capabilities that provide services and applications to end users regardless of the fixed or mobile access technologies being used and independently of the users' location.

2.4 Socio economic implications of 5G

Third party studies undertaken on the economic impact of investments being made in 5G are few and far between; nonetheless, it is possible to draw upon some third-party forecasts to estimate the impact that 5G could have on economic output.

The ITU would suggest that policy makers undertake an independent economic benefits assessment since third party estimates are not endorsed by the ITU.

One report estimates that 5G will enable USD 12.3 trillion of global economic output by 2035, with the greatest growth in sales activity coming from manufacturing due to the anticipated increase in spending on 5G equipment. This is followed by sales growth in the ICT sector because of higher expenditure on communications services. Investment in the value chain is expected to generate a further USD 3.5 trillion in output and support 22 million jobs by 2035.[5]

The European Commission (EC) estimates that the total cost of 5G deployment across the EU28 Member States will be EUR 56 billion, resulting in benefits of EUR 113.1 billion per annum arising from the introduction of 5G capabilities, and creating 2.3 million jobs. It is also estimated that benefits are largely driven by productivity in the automotive sector and in the workplace. Most of the benefits are expected to be generated in urban areas as only 8% of benefits (EUR 10 billion per annum) will be realized in rural areas.[6]

Other reports have also indicated significant economic benefits resulting from investment in 5G networks and the productivity enhancements expected to be generated as a result.[7]

These estimates merely attempt to provide some quantification of the benefits of 5G assuming ideal investment conditions. The actual economic benefit to each country will vary depending upon market structure, the advancement of existing digital infrastructure and the availability of supporting economic infrastructure.

Key findings: policy makers may consider undertaking their own economic assessment of the commercial viability and economic impact of 5G networks.

Despite the potential economic benefits that can be realised from 5G, the industry is sceptical about the commercial case for investment in 5G. Given the significant amount of investment that will be required to be made by operators in deploying 5G networks there is scepticism among some European operators over the hype that 5G has caused and over how they are supposed to make money from it. These concerns have been supported by the 5G Infrastructure Association (5GIA), a European Union (EU)-backed body, and by senior telecoms executives which have cautioned the market against premature 5G launch announcements.[8]

Many 5G announcements – some of which are highlighted in the remainder of this paper – are simply regional 5G pilots and trials rather than full scale commercial deployments. Although pilots and trials are necessary in verifying the technology in a range of environments, there is some way to go before the investment case for operators can be made robustly and before any large scale commercial deployment can commence.

Key findings: Until such time that the investment case for 5G is demonstrable the industry and policy makers may consider approaching 5G investment with caution and should continue to enhance the availability and quality of existing 4G networks.

2.5 Digital divide

There is general industry consensus that the initial deployment of 5G networks will commence in dense urban areas comprising of services such as enhanced mobile broadband (EMB). Consequently, rural areas are likely to be left behind potentially leading to a digital divide. This is

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5 "The 5G Economy", IHS economics and IHS technology, January 2017

6 "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe", European Commission, 2016

7 "5G mobile – enabling businesses and economic growth", Deloitte, 2017; "Tech-onomy: Measuring the impact of 5G on the nation's economic growth", O2 Telefonica (UK), 2017

8 https://www.techradar.com/news/eu-backed-groups-warns-about-5g-claims

because, it can be commercially challenging to deploy 5G networks in rural areas, due to poor network economics, and where demand tends to be lower.

To counteract this, coverage in rural areas may be supported through the availability of 700MHz frequency spectrum. Using 700MHz will allow mobile operators to cover a wider area and for less cost than higher frequency spectrum. Data speeds and network capacity at 700MHz will not be as high as the speeds of higher frequency spectrum, however. 700MHz spectrum has the benefit of being suitable for 5G and for enhancing the coverage of rural 4G networks.

Key findings: Local authorities and regulators should recognise these risks of 5G to the digital divide and support commercial and legislative incentives to stimulate investment for the provision of affordable wireless coverage (e.g. through the 700 MHz band).

3 5G technology and spectrum requirements

Radio spectrum, backhaul, softwarization of core networks and radio access networks will be vital components in the deployment of early 5G networks particularly to allow 5G services such as enhanced mobile broadband to be provided.

3.1 Radio access networks

Most outdoor 4G mobile network deployments around the world are currently based on macro-cells.[9] Macro-cells that cover large geographical areas will struggle to deliver the dense coverage, low latency and high bandwidth required by some 5G applications as shown in Figure 4.

Figure 4: Bandwidth and latency requirements for 5G applications

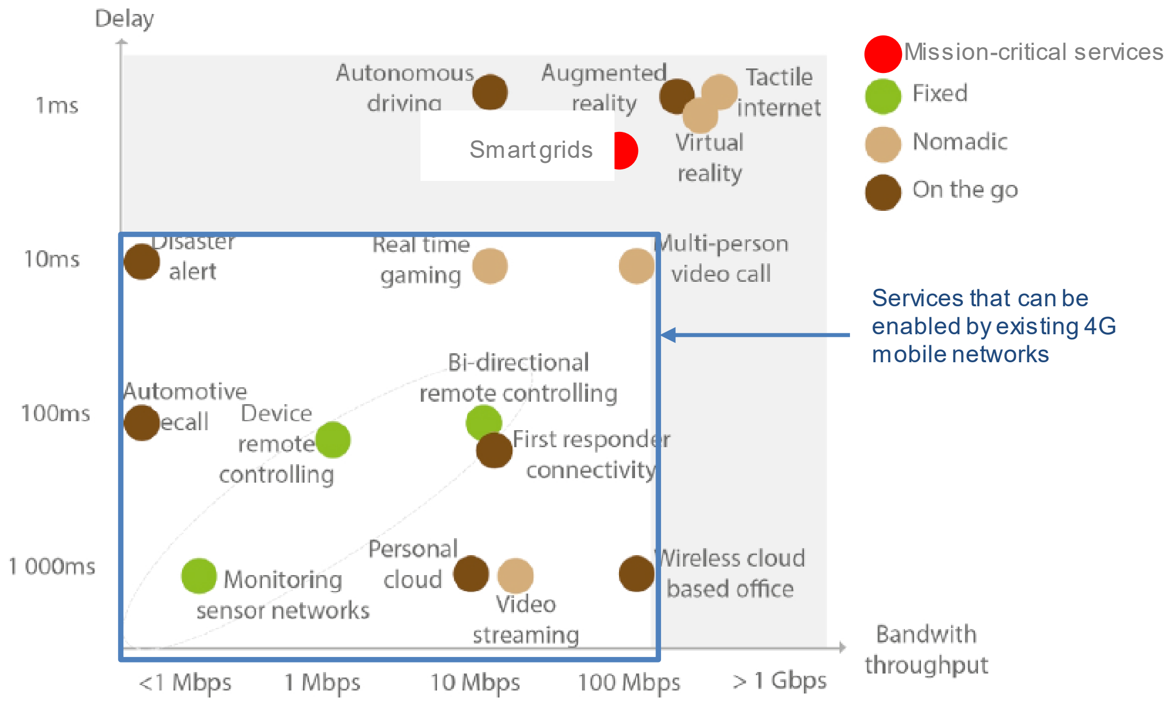

Figure 4: Bandwidth and latency requirements for 5G applications. Source: GSMA Intelligence and Intelligens, 2018

To deliver the dense coverage and high capacity network required by 5G, wireless operators are now starting to invest in the densification of their 4G radio access network (RAN) – particularly in densely populated urban areas by deploying small cells. Small cells serve a much smaller geographical area than a macro cell therefore increasing network coverage, capacity and quality of service, see Figure 5.

[9] https://www.mobileworldlive.com/blog/blog-global-base-station-count-7m-or-4-times-higher/

Figure 5: Macro versus small-cell networks

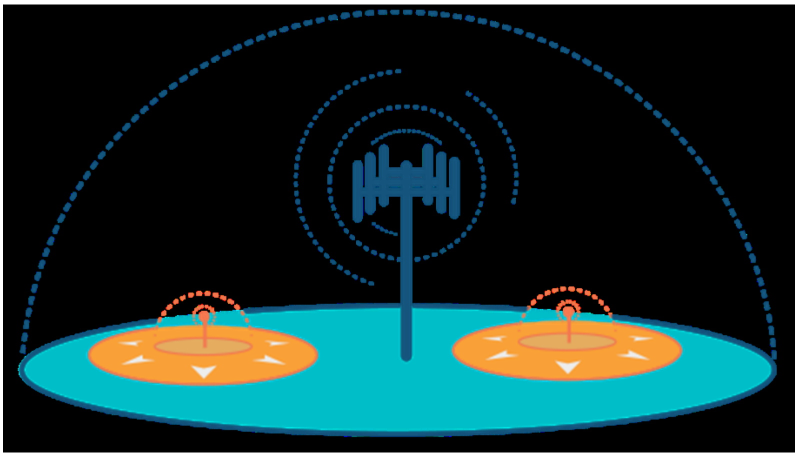

Figure 5: Macro versus small-cell networks. Source: Wireless Infrastructure Group, 2018

Network densification in urban areas through the deployment of small cells is one way in which to boost the capacity and quality of existing 4G networks while laying the foundation for commercial 5G networks and early EMB services. Small cells are already being used by some wireless operators to boost the capacity and coverage of their existing 4G networks particularly in a dense urban setting, see Box as an example.

Box 3 – Aberdeen

In September 2017, independent tower specialist Wireless Infrastructure Group, in collaboration with Telefónica, launched Europe's first small-cell network supporting cloud RAN (C-RAN) for faster and higher capacity mobile services in the city centre of Aberdeen.

Source : http://www.wirelessinfrastructure.co.uk/city-of-aberdeen-paves-the-way-for-5g/

Small cells are also attractive to operators with a low spectrum holding or where spectrum is scarce because they boost network capacity without the need for additional spectrum. Further, there is general industry consensus that the deployment of small cells in dense urban to boost existing 4G network quality is likely to support the anticipated high capacity requirements of 5G networks and early EMB services.[10]

Due to the dense coverage that small cells need to provide, small-cell antennas need to be installed onto street furniture such as bus shelters, lampposts, traffic lights, etc. This is often accompanied by a street cabinet to accommodate the operator radio equipment, power and site connectivity. Figure 6 shows an example of an antenna system mounted onto a lamppost and a street cabinet.

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10 TechUK, https://goo.gl/Q58ZA8
FCC: https://www.fcc.gov/5G
ITU: https://www.itu.int/ITU-T/workprog/wp_item.aspx?isn=14456

Figure 6: An example of a small-cell antenna system and a street cabinet

Figure 6: An example of a small cell antenna system and a street cabinet. Source: Wireless Infrastructure Group, 2018

Massive MIMO (multiple input, multiple output) scales up to hundreds or even thousands of antennas, increasing data rates and supporting beamforming, essential for efficient power transmission. Massive MIMO increases spectral efficiency and in conjunction with dense small cell deployment will help operators to meet the challenging capacity requirement of 5G.[11]

3.2 Core networks

End-to-end flexibility will be one of the defining features of 5G networks[12]. This flexibility will result in large part from the introduction of network softwarization where the core network hardware and the software functions are separate. Network softwarization through network functional virtualization (NFV), software defined networking (SDN), network slicing and Cloud-RAN (C-RAN) aims to increase the pace of innovation and the pace at which mobile networks can be transformed.

- **NFV** – replaces network functions on dedicated appliances – such as routers, load balancers, and firewalls – with virtualized instances running on commercial off-the-shelf hardware, reducing the cost of network changes and upgrades.
- **SDN** – allows the dynamic reconfiguration of network elements in real-time, enabling 5G networks to be controlled by software rather than hardware, improving network resilience, performance and quality of service.
- **Network slicing** – permits a physical network to be separated into multiple virtual networks (logical segments) that can support different RANs or several types of services for certain customer segments, greatly reducing network construction costs by using communication channels more efficiently.
- **C-RAN.** C-RAN is presented as a key disruptive technology, vital to the realization of 5G networks. It is a cloud-based radio network architecture that uses virtualization techniques combined with centralized processing units, replacing the distributed signal processing units at mobile base stations and reducing the cost of deploying dense mobile networks based on small cells.

For the last few years, Telefónica has been focusing its efforts on virtualizing its core network based on SDN/NFV in preparation for 5G in Argentina, Mexico and Peru, see Box 4.

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[11] IEEE: https://ieeexplore.ieee.org/document/7881053/

[12] ITU: http://news.itu.int/5g-update-new-itu-standards-network-softwarization-fixed-mobile-convergence/

Box 4 – Telefonica investing in SDN and NFV

Operators such as Telefónica are already investing in SDN and NFV as part of their gradual transition to 5G, which is likely to reduce core networks costs in the long term. Telefónica has an ambitious plan to virtualize its network end-to-end, across access, aggregation and backbone domains under its UNICA programme.

Source: https://www.telefonica.com/documents/737979/140082548/Telefonica_Virtualisation_gCTO_FINAL.PDF/426a4b9d-6357-741f-9678-0f16dccf0e16?version=1.0

Other technology enhancements being considered for 5G include signal coding techniques to provide improved spectral efficiency and the high-speed performance required by 5G. In addition, edge computing is increasingly important for real-time and very latency-sensitive application. Edge computing brings data closer to end-user devices, providing computing power with very low latency for demanding applications. This speeds up the delivery of actionable data and cuts down on transport costs, optimizes traffic routes.

3.3 Backhaul

Backhaul networks connect the radio network (RAN) to the core network. The ultra-high capacity, fast speeds and low latency requirements of 5G require a backhaul network capable of meeting these high demands. Fiber is often considered the most suitable type of backhaul by mobile operators due to its longevity, high capacity, high reliability and ability to support very high capacity traffic.

However, fiber network coverage is not ubiquitous in all cities where 5G is expected to launch initially and even less so in suburban and rural areas. Building new fiber networks in these areas - can often be cost prohibitive to the investment case for operators. In this case, a portfolio of wireless backhaul technologies should be considered in addition to fiber including point to multi point (PtmP) microwave and millimeter wave (mmWave). PtmP is capable of downstream throughput of 1Gbit/s and latency of less than 1ms per hop over a 2-4km distance. mmWave has significant less latency and is capable of higher throughout speeds.

While most focus is being given to terrestrial technology, there is also a potential role for satellite technology in 5G. Satellites today can deliver very high data rates (> 100 Mbit/s – 1 Gbit/s) to complement fixed or terrestrial wireless networks outside major urban / suburban areas and to deliver video transmission to fixed locations. Satellites will integrate with other networks rather than be a standalone network to provide 5G capability and it is this integration that forms the core of the vision for satellites in 5G. Satellite will augment the 5G service capability and address some of the major challenges in relation to the support of multimedia traffic growth, ubiquitous coverage, machine to machine communications and critical telecom missions.[13]

Key findings: A portfolio of wireless technologies may be considered in addition to fiber including point to multi point (PtmP) microwave, millimeter wave (mmWave) and satellite.

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[13] EMEA Satellite Operators Association: https://gscoalition.org/cms-data/position-papers/5G%20White%20Paper.pdf

In summary, a realistic 5G backhaul strategy is likely to comprise of a portfolio of technologies. Each approach should be considered on its own merits in light of the performance needs, available infrastructure and the likely return on investment.

3.4 Fronthaul

Conventionally in 4G wireless network, the fronthaul link exists between radio frequency (RF) function and the remaining layer 1, 2 and 3 (L1/L2/L3) functions. Recommendation ITU-T Y.3100 defines fronthaul as “a network path between centralized radio controllers and remote radio units (RRU) of a base station function”. This architecture allows the centralization of all high layer processing functions at the expense of the most stringent fronthaul latency and bandwidth requirements. The increase in data rates in 5G makes it impractical to continue with the conventional Common Public Radio Interface (CPRI) fronthaul implementation. Allocating more processing function to RRU would relax the latency and bandwidth requirements, but then fewer processing functions can be centralized. It is thus critical that the new functional-split architecture take into account technical and cost-effective tradeoffs between throughput, latency, and functional centralization[14].

The following documents specify or describe technologies that can be used for fronthaul:

- Supplement 55 to G-series Recommendations “Radio-over-fiber (RoF) technologies and their applications”
- Supplement 56 to G-series Recommendations “OTN transport of CPRI signals” describes alternatives for mapping and multiplexing CPRI client signals into the OTN.
- Recommendation ITU-T G.987 series: 10-Gigabit-capable passive optical networks (XG-PON)
- Recommendation ITU-T G.9807 series: 10-Gigabit-capable symmetric passive optical network (XGS-PON)
- Recommendation ITU-T G.989 series: 40-Gigabit-capable passive optical networks 2 (NG-PON2)
- Draft Recommendation ITU-T G.RoF “Radio over Fiber systems” (under development)
- Draft Supplement to G-series Recommendations (G.sup.5GP) “5G wireless fronthaul requirements in a PON context” (under development)

3.5 Spectrum for 5G

More spectrum bandwidth than 4G will be required to deploy 5G networks to the high capacity requirements of 5G, increasing the need for spectrum. So the industry is making concerted efforts on harmonizing 5G spectrum. ITU-R is coordinating the international harmonization of additional spectrum for 5G mobile systems development (Box 5). ITU’s Standardization Sector (ITU-T) is playing a key role producing the standards for the technologies and architectures of the wireline elements of 5G systems.

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[14] G-series Technical Report on “Transport network support of IMT-2020/5G” (GSTR-TN5G) http://www.itu.int/pub/publications.aspx?lang=en&parent=T-TUT-HOME-2018

Box 5 – ITU-R technical feasibility of IMT in the frequencies above 24 and up to 86 GHz

The ITU-R investigates the technical feasibility of future 5G spectrum in the frequencies above 24 and up to 86 GHz based on recently conducted and still ongoing studies carried out by many sector members. Solutions based on MIMO and beamforming are becoming increasingly feasible with higher frequencies. Bands below and above 6 GHz could be used in a complementary manner for the year 2020 and beyond. The ITU is expected to decide on the additional spectrum for IMT in the frequency range between 24 GHz and 86 GHz at the World Radiocommunication Conference in 2019 (WRC-19).

New spectrum bands under study for WRC-19:

Existing mobile allocation	No global mobile allocation
24.25 – 27.5 GHz	31.8 – 33.4 GHz
37 – 40.5 GHz	40.5 – 42.5 GHz
42.5 – 43.5 GHz	
45.5 – 47 GHz	47 – 47.2 GHz
47.2 – 50.2 GHz	
50.4 GHz – 52.6 GHz	
66 – 76 GHz	
81 – 86 GHz	

5G use cases could potentially be met by a variety of spectrum frequencies. For example, low-latency and short-range applications (suited to dense urban areas) are likely to be suitable for mmWave frequency (above 24 GHz). Long-range, low-bandwidth applications (more suited to rural areas) are likely to be suitable for sub-1 GHz frequencies. While the lower frequencies have better propagation characteristics for better coverage, the higher frequencies support higher bandwidths due to the large spectrum availability at mmWave bands. Huawei, for example has proposed a multi-layer spectrum approach, which summarizes this approach best (see Box).

Box 6– An operator's perspective: Huawei's multi-layer spectrum approach

- **Coverage layer** – exploits spectrum below 2 GHz (e.g. 700 MHz) providing wide-area and deep indoor coverage.
- **Coverage and capacity layer** – relies on spectrum in the 2– 6 GHz range to deliver the best compromise between capacity and coverage.
- **Super data layer** – relies on spectrum above 6 GHz and mmWave to address specific use cases requiring extremely high data rates.

Source: http://www.huawei.com/en/about-huawei/public-policy/5g-spectrum

The challenge for NRAs will be to select globally harmonized spectrum bands for 5G and the best way to achieve this goal will be to take into account the WRC-19 relevant decisions for higher bands, as well as WRC-07 and WRC-15 decisions for lower bands.

While the EC has earmarked the 700 MHz spectrum as essential to achieve wide-area and indoor coverage for 5G services[15] it may be used differently in parts of Africa to enhance 4G coverage. It is expected that by 2020, only 35% of the Sub-Saharan population will be covered by 4G networks – many rural areas have little or no 4G mobile coverage – compared to a global average of 78%.[16] For this reason, policy makers in Sub-Saharan Africa might consider using 700MHz spectrum ideal for increasing rural 4G coverage rather than for 5G.

Key findings: Policy makers may consider making available low frequency spectrum (e.g. in the 700MHz) to ensure mobile broadband can be provided to rural areas.

The GSMA expects the 3.3–3.8 GHz spectrum to form the basis of many initial 5G services, particularly to offer enhanced mobile broadband. This is because the 3.4-3.6 GHz range is almost globally harmonised which can drive the economies of scale needed for low-cost devices.

Key findings: Policy makers may consider grouping together to reach agreement on harmonized spectrum bands for 5G. NRAs could therefore benefit from an exchange on best practices with regards to the market-shaping aspects of spectrum licence-granting.

15 EC: https://ec.europa.eu/commission/commissioners/2014-2019/ansip/blog/700-mhz-must-digital-single-market_en

16 GSMA: https://www.gsma.com/mobileeconomy/sub-saharan-africa-2017/

4 Key challenges in rolling out 5G

This section reviews the key challenges faced by telecom operators rolling out 5G networks. Particular focus is given to how appropriate regulation and government policy might assist wireless operators in the deployment of small cells, fiber backhaul and the use of spectrum.

4.1 Small cell deployment challenges

In some countries, regulation and local authority policy have slowed the development of small cells by imposing excessive administrative and financial obligations on operators, thus blocking investment. Constraints to deploying small cells include prolonged permitting processes, lengthy procurement exercises, excessive fees and outdated regulations that prevent access. These issues are described in Box 7 and in detail below:

- **Local permitting and planning processes**: the time taken by local authorities to approve planning applications for small-cell implementations can take 18 to 24 months (Box 7), resulting in delays.

- **Lengthy engagement and procurement exercises**: local authorities have engaged in lengthy procurement processes lasting 6 to 18 months to award wireless providers with exclusive rights to deploy small-cell equipment onto street furniture, costing time and expense.

- **High fees and charges to access street furniture**: local authorities currently charge high fees to use street furniture. According to the American Consumer Institute, one city set a USD 30 000 application fee to attach small-cell equipment onto a utility pole; another locality imposed a USD 45 000 fee.

- **Human exposure to radiofrequency electromagnetic fields (EMF):** The exposure limits differ in some countries, and in some cases are more restrictive. ITU recommend that if radio frequency electromagnetic field (RF EMF) limits do not exist, or if they do not cover the frequencies of interest, then ICNIRP limits should be used. Where new antennas are added, all the regular steps should be taken during the deployment phase to respond to any public concern. One contributing factor to public concern is the visibility of antennas, particularly on rooftops. Where possible, it is important to use multi-band antennas in order to reduce visual impact by maintaining the same number of antennas on rooftops. Without any spectrum or technology refarming strategy, the 5G network will increase the localized exposure resulting from wireless technologies, at least during the transition period. It is important to include national authorities at an early stage in establishing how 5G can be deployed and activated and the compliance with national limits assessed. This has already been difficult in countries where exposure limits are more restrictive than those recommended by WHO, based on the ICNIRP RF-EMF exposure guidelines.[17]

[17] From Supplement ITU-T K.Suppl.9 “5G technology and human exposure to RF EMF”.

Access and code powers: wireless operators[18] may not have the right to install small-cell or radio apparatus onto street furniture such as lampposts. In the UK, for example, the code has been updated to overcome these limitations, but is non-binding, meaning its impact might be debatable.

Many of these local rules and regulations are prohibiting the rapid and cost-effective roll-out of small cells in city centres where 5G is initially expected to be most in demand. Policy makers that offer streamlined and flexible regulatory processes stand to benefit the most from the innovation and economic growth that 5G will bring.

Box 7 – Industry viewpoint on barriers to deploying small cells

Telecom providers such as Crown Castle, AT&T, Sprint, T-Mobile and Verizon have all described experiencing significant regulatory barriers from local authorities including excessive fees, prohibitions on small-cell placement, unreasonable aesthetic restrictions and prolonged permitting processes. According to Crown Castle, the company's small-cell deployments usually take 18 to 24 months to complete, from start to finish, largely due to the need to obtain local permits for the installation of the devices.

Source: https://goo.gl/6UaKJ4

Small cells have also yet to be deployed on a significant scale in Asia, although wireless operators in Japan and Korea (Rep. of) have densified their networks using macro cell C-RAN. C-RAN deployments are possible in Japan and Korea (Rep. of) because of the widespread availability of fiber backhaul, which may not be the case in other markets.

4.2 Fiber backhaul

Deploying fiber backhaul networks for small cells – to support high data rates and low latency – will be one of the largest challenges faced by operators due to poor availability of fiber networks in many cities.

The UK, for example, has one of the lowest fiber penetration rates in Europe at 2% penetration compared to a European average of around 9%.[19] To incentivise investment in fiber networks, the UK Government has introduced a five-year relief from business rates on new fiber networks infrastructure.[20]

Where it is not cost effective to deploy fiber backhaul operators should consider wireless backhaul technologies. A portfolio of wireless technologies including PMP, mmWave and satellite should be considered in addition to fiber in this instance.

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[18] Code powers are statutory entitlements for specified telecoms operators to have the right to install, maintain, adjust, repair or alter their apparatus on public and private land. In order to have the benefit of these rights, telecoms provider must apply to and be recognized by OFCOM, the UK telecoms regulator.

[19] https://www.ispreview.co.uk/index.php/2017/02/uk-shunned-2017-ftth-ultrafast-broadband-country-ranking.html

[20] The UK's valuation office agency has recently undertaken a revaluation of business rates which will increase the tax likely to be paid by fiber operators. High business rates could adversely affect the commercial model to deploy fiber connectivity to support small cell deployment.

Key findings: Policy makers may consider removing tax burdens associated with fiber for the deployment of 5G networks to reduce the investment costs.

Some of the other challenges faced by operators are described in Box .

Box 8 – Barriers to deploying fiber networks

- **Refused planning permission:** lack of early engagement between operators and local authorities can result in planning permission being refused. Local authority policy on the siting and aesthetics of street cabinets can also increase costs and delays as alternative solutions are sought**.**

- **Complex wayleave processes**: wayleave agreements allow operators to install telecoms infrastructure on public or private land. Landowners using a procurement process to grant wayleaves add risk, time and expense to the process. In addition, using bespoke wayleaves are expensive. Local authorities using wayleaves to generate revenues create an additional barrier to investment.

Source: Intelligens Consulting, 2018

Key findings: Local authorities may consider agreeing upon standardized wayleave agreements to reduce the cost and time to deploy fiber networks.

4.3 Spectrum

The allocation and identification of globally harmonized spectrum across a range of frequencies requires coordination among the global community, regional telecommunication organizations and NRAs and is one of the largest challenges that confronts NRAs for the successful deployment of 5G networks. Uniform allocation has many advantages, as it minimizes radio interference along borders, facilitates international roaming and reduces the cost of equipment. This is the main objective of the ITU-R process in World Radiocommunication Conferences (WRCs).

In particular, there needs to be some consensus on large contiguous blocks of world-harmonized radio spectrum – especially above 24 GHz, where large bandwidths are available – before final decisions on identification of additional spectrum above 24 GHz for IMT-2020 (5G) are expected to be made at WRC-19. These decisions will be the result of extensive sharing and compatibility ITU-R studies between the mobile (incl. IMT-2020) and the incumbent services in these and the adjacent frequency bands, as well as agreement between countries before and at WRC-19.

A number of NRAs in developed countries consider the 700 MHz, 3.4 GHz and 24 GHz bands for initial deployment of 5G to satisfy the coverage and capacity requirements.

Consideration also needs to be given to spectrum sharing to make more efficient use of available spectrum. Traditionally, NRAs have allocated spectrum to mobile operators on an exclusive basis. However, due to the growing need, sharing can provide a means to improve efficient use of existing spectrum.

Key findings: Policy makers should consider allowing spectrum sharing to maximize efficient use of available spectrum particularly to benefit rural areas.

Further consideration also needs to be given to the licensing and usage models for 5G spectrum, particularly above 24 GHz. Traditionally, mobile spectrum divided into small bandwidths (e.g. 5 MHz, 10 MHz, 20 MHz) has been scarce, and therefore can attract a high price at auction. Spectrum above

24 GHz is more readily available, so scarcity is less of an issue. This will influence commercial models and spectrum auctions. NRAs will need to consider what licensing models they should use (see also Section 5.7). National examples of approaches to spectrum sharing have been published by the ITU, for instance in the ITU Report on WTDC-14 Resolution 9.

Key findings: Policy makers may consider a spectrum roadmap supporting exclusive, shared and unlicensed models with a predictable renewal process. Policy makers should avoid artificially high 5G spectrum prices and instead select spectrum award procedures that favour investment.

4.4 Other factors

- **Device availability** – the availability of devices compatible with 5G standards and spectrum will be vital in creating end user demand for 5G services in the initial launch. Manufacturers are currently developing technology that embeds 5G, 4G, 3G and 2G onto a single chip and is expected to become available from 2019 and after 2020 for globally harmonized standards.

- **Coordination of industry verticals** – the telecoms industry is a well-tuned and formal ecosystem comprising device and chip manufacturers, equipment vendors and retail and wholesale operators. Collaboration within this ecosystem is therefore relatively straightforward when developing new standards and services.

- **Net neutrality** – BEREC, the European telecoms regulator, has published final guidelines on how to strengthen net neutrality by requiring Internet service providers to treat all web traffic equally, without favouring some services over others. However, 17 mobile operators including Deutsche Telekom, Nokia, Orange, Vodafone and BT lobbied heavily for BEREC to adopt a more relaxed interpretation of the rules, saying that the rules "create significant uncertainties around 5G return on investment" and they would not introduce high-speed 5G networks unless BEREC took a softer approach to net neutrality.[21]

[21] "5G manifesto for timely deployment of 5G in Europe", various industry players, July 2016

5 What does 'good' look like?

This section reviews what can be learned from the way in which wireless providers, NRAs and governments across various parts of the world are starting to work through the deployment issues associated with deploying 5G networks.

5.1 Streamlining small-cell deployments

Bills have been proposed in Illinois, Washington State, Florida and California to streamline the deployment of small-cell equipment on street furniture. These bills restrict the fees that local governments may charge, and some go further to ensure no exclusive arrangements are made with wireless providers.

Key findings: Federal and state governments should work with local municipal authorities to ensure reasonable fees are charged to deploy small-cell radio equipment onto street furniture.

Box 9 – Streamlining the deployment of small cells

In September 2017, a bill was passed in California to streamline small-cell deployment by making it a permitted use and no longer subject to a local discretionary permit or with specified criteria. The new legislation treats small cells as permitted use, standardizing small-cell deployments across the state in addition to:

- granting providers non-discriminatory access to public property
- allowing local governments to charge permit fees that are fair, reasonable, non-discriminatory and cost-based
- limiting the costs charged by local governments of attaching equipment to USD 250
- prohibiting local governments from placing an unreasonable limit on the duration of the permit on the telecom facility.

A similar approach has been proposed in a bill in Florida, requiring an authority to process applications for siting small-cell equipment on utility poles on a non-discriminatory basis and approving applications within set timescales. The bill also proposes that authorities may not enter into any exclusive arrangements with providers to attach equipment to authority utility poles. Furthermore, the bill states that authorities may not charge more than USD 15 per year, per utility pole. In Washington State, a bill proposes to authorize the installation of small-cell facilities on publicly owned assets and limits charges to USD 500 per annum. In Illinois, a bill proposes that local government may not prohibit, regulate or charge operators to deploy small-cell wireless equipment.

Sources: California SB-649, 2017; Florida SB-596, 2017; Washington SB-5711, 2017; Illinois SB-1451, 2017.

Key findings: Local authorities may consider improving access to government-owned street furniture and consider streamlined engagement processes as alternatives to lengthy procurement exercises.

5.2 Policy intervention - fiber and spectrum

Leading economies like the UK have low fiber penetration, according to the FTTH Council, because of underinvestment in pure fiber networks. Box 1 describes the actions being taken by UK policy-makers to improve fiber penetration in the run up to 5G.

Box 1 – UK fiber investments

In the UK, the Government announced a GBP 740 million challenge fund in 2016 to invest in local full fiber networks to support the development of 5G. The fund is now being distributed through a competitive process to local authorities across the UK.

Sources: Federal Ministry of Transport and Digital Infrastructure, Germany, 2017; "a 5G Strategy for Germany", Federal Government of Germany, 2017; Department of Culture Media and Sport, Government of United Kingdom, 2016.

The Australian government has identified a clear 5G policy agenda to speed up the deployment of digital infrastructure and availability of 5G spectrum.

Box 2 – 5G working group, Australia

The Australian Government has undertaken an initiative to developing a 5G Directions Paper which outlines a 5G policy approach for Australia including the establishment of a 5G working group to facilitate an ongoing collaborative dialogue with industry. The paper highlights actions to make spectrum available in a timely manner and streamlining arrangements to allow wireless providers to deploy digital infrastructure more quickly and at lower cost.

Source: "5G-Enabling the Future Economy", Department of Communications and the Arts, Australia, 2017

Key Findings: Where market failure has occurred, governments may consider stimulating investment in fiber networks and passive assets through setting up PPPs, investment funds and offering grant funds, etc.

5.3 Infrastructure sharing

Where fiber is the preferred method of backhaul, it may not be commercially attractive. Modest levels of duct sharing, and reuse can generate significant savings in the development of fiber networks. Regulatory policies that promote infrastructure sharing and reuse could help significantly lower 5G deployment costs, although they can be complex to implement (see Box 3).

A study undertaken by Vodafone suggests that the duct access regime is commonly used by the NRAs in France, Spain and Portugal to ensure that the offer can be used in practice, with the minimum of bureaucracy and maximum transparency to all parties. In contrast, in countries where SMP infrastructure access has been mandated, such as in the UK and Germany, many of these detailed provisions are lacking.[22]

Box 3 – Mandated network sharing

- In November 2017, the Netherlands passed a bill on passive broadband infrastructure mandating all owners/administrators of networks and related infrastructure to comply with reasonable requests for shared access and/or coordinated network deployment, and to share information about their infrastructure, with the aim of accelerating broadband roll-outs.

- Indonesia's Ministry of Communications and Information Technology is working toward the introduction of new rules to encourage the development of passive infrastructure sharing such as ducts, poles, towers, cabinets, etc.

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[22] "Best practice for passive infrastructure access", WIK-Consult, 2017

- UK telecoms regulator Ofcom is currently running a market consultation to mandate the incumbent operator and significant market player BT to offer duct fiber access to rival operators. Previous attempts to mandate dark fiber access failed.

- In Italy, ultrafast broadband legislation has enabled TIM and UTILITALIA (the federation of electricity, gas, water and the environment companies) to sign a memorandum of understanding to facilitate the use of pre-existing infrastructures of more than 500 local utility operators to deploy fiber networks.

Sources: https://goo.gl/kqYCRM (Netherlands), https://goo.gl/vWq7aD (Indonesia), https://goo.gl/vdFxz9 (Ofcom, UK), https://goo.gl/m24g32 (Italy)

Key findings: Policy makers may consider continuing to elaborate the duct access regime to encompass 5G networks to reduce the cost of investing in 5G fiber backhaul networks.

Commercially led network-sharing agreements are preferred by most NRAs and seem to have gained significant market traction and can speed up the deployment and cost of 5G networks, see Box 4, where network sharing ranges across mobile infrastructure as well as fiber.

Box 4 – Commercially driven network sharing

- In Spain, telecoms operator MASMOVIL has passed ten million households using a fiber network that it shares with Orange Espana through a network-sharing pact.

- In Portugal, Vodafone and operator NOS have signed an agreement to deploy and share a fiber network that will be marketed to around 2.6 million homes and businesses. The two companies will provide reciprocal access to each other's networks on commercially agreed terms.

- New Zealand's wholesale network operator, Chorus, is calling on the Government to begin formulating plans for a single 5G mobile network, which can be shared by all service providers, as it would not be sustainable for the country's three mobile operators to roll out separate 5G networks due to the amount of investment needed.

- Vodafone Cameroon has recently signed a 'strategic national network sharing agreement' with CamTel, allowing Vodafone to use CamTel's existing network infrastructure in Douala and Yaounde and to expand its coverage to new locations across the country.

- Telenor Denmark and Telia Denmark have signed a managed services contract with Nokia, which will manage their shared mobile networks run by a common infrastructure company TT-Netvaerket.

- Econet Wireless (Zimbabwe), has recently revealed that it is open to infrastructure sharing as long as it is conducted under a 'one-for-one' system-sharing infrastructure on an equitable basis.

Sources: https://goo.gl/u2fojb (Spain), https://goo.gl/bT9hZ4 (Portugal), https://goo.gl/vh4LGP (New Zealand), https://goo.gl/AAbapS (Cameroon), https://goo.gl/JmuSnJ (Denmark), https://goo.gl/iSb4sq (Zimbabwe)

The use of independent wholesale infrastructure providers for the provision of small-cell networks has increased over the last few years. Wireless provider Crown Castle (USA), for example, increased its small-cell revenues by over 40% between 2015 and 2016[23] as mobile operators densify their networks ahead of 5G roll-outs. Wholesale provision of mobile infrastructure can reduce deployment costs, promote retail competition and increase service coverage.

5.4 Transition to fiber

At present, lower wholesale copper access prices can compete with fiber services adversely affecting the take-up of fiber. There is no consensus on the most appropriate approach to pricing during the transition from copper to fiber. NRAs may consider allowing incumbents to withdraw copper-based access products as soon as they offer fiber-based access services, to prevent a situation in which competition from cheap copper services undermines the business case for more expensive fiber services (Box 5).

Box 5 –Transition to fiber

- The Government of Australia has imposed a deadline of 2020 for all premises to be migrated from copper to fiber. In 2014, Telstra (Australia) began to gradually switch off services being delivered over its copper networks. The government-funded NBNCo initiative, which has driven wholesale fiber connectivity across Australia, will switch off copper networks in areas where NBNCo already provides fiber services.

- Verizon (USA) has requested regulatory permission to migrate its copper network in selected markets from 2018. Verizon delivers services via its fiber infrastructure and hopes to cease maintaining the copper facilities in Virginia, New York, New Jersey, Pennsylvania, Rhode Island, Massachusetts, Maryland and Delaware.

- ComReg, the Irish telecoms regulator, has recently launched a consultation on the potential of its incumbent operator, Eir, transitioning from its copper network in some parts of the country, particularly in areas of extensive fiber coverage.

- Singtel (Singapore) has announced plans to discontinue its copper-based ADSL network in April 2018 as it accelerates fiber-based service adoption for its business and residential customers in the city.

- Chorus (New Zealand) is set to get regulatory relief from its copper network under plans to deregulate the copper network where it competes with fiber access networks from 2020.

Sources: https://goo.gl/2YVKsd (Australia), https://goo.gl/VCyfap (USA), https://goo.gl/X3EeKa (Ireland), https://goo.gl/mRKu1C (Singapore), https://goo.gl/n6kqVb (New Zealand)

Key findings: NRAs may consider policies and financial incentives to encourage the migration from copper to fiber and to stimulate the deployment and take-up of fiber services.

[23] https://www.telegeography.com/products/commsupdate/articles/2017/02/07/tower-talk-a-guide-to-the-latest-major-cell-site-developments/index.html

5.5 Addressing local planning challenges

Operators have often cited that it would be helpful to have a central database showing all infrastructure and utility assets available, such as existing local authority or utility ducts, fiber networks, CCTV posts, lamp posts, etc. The database should also identify key contacts and the process to gain access to the assets. Such databases exist in Portugal and Spain and may exist in other countries.

Key findings: Local authorities may consider holding a central database identifying key contacts, showing assets such as utility ducts, fiber networks, CCTV posts, lampposts, etc. to help operators cost and plan their infrastructure deployment more accurately.

Standardized wayleave agreements used among local authorities can significantly reduce the cost and time to implement fiber networks such as that developed by the City of London Corporation (15).

Box 15 – City of London standardized wayleave agreements

In 2015, the City of London Corporation recognized that a key reason for the lack of fiber investment was the complex wayleave process. The corporation developed a standardized wayleave toolkit to delivery fiber infrastructure effectively and efficiently. The toolkit is now available to all local authorities in London.

Source: http://news.cityoflondon.gov.uk/standardised-toolkit-helps-london-businesses-get-faster-access-to-broadband/

Local authorities should also standardize the processes to give operators the appropriate permission to undertake relevant street works to lay fiber networks or deploy small-cell equipment onto street furniture (Box 16). It is also considered best practice to undertake consultations with the market to understand potential issues and solutions to deploying 5G networks.[24]

Key findings: Local authorities may consider undertaking market consultations or soft market testing to identify best practices for deploying 5G networks prior to committing to any formal procurement process.

Box 16 – Efficient planning processes

In 2015, the City of Centennial (Colorado, USA) permitting office was authorized to require the co-location of underground facilities upon the filing of a major right of way permit request by telecoms operators. The right of way policy allowed the city to coordinate investments, saving time and costs.

In Kentucky (USA), a guide was issued on fiber planning to communities and utilities. The guide included advice on streamlining survey requirements and permit applications and developing pole attachment agreements.

Sources: City of Centennial, Chicago, 2015; https://goo.gl/FswzSv (Kentucky)

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24 http://webarchive.nationalarchives.gov.uk/20100402171309/http://www.ogc.gov.uk/documents/Early_Market_Engagement_Guidance.pdf

5.6 Spectrum harmonisation

The focus for early 5G applications has been on the bands above 24 GHz and below 6 GHz (see Box 6). NRAs should coordinate their proposals on the millimetre bands to maximize the opportunity for global spectrum harmonisation.

In order facilitate the preparation of the European positions for WRC-19, EU ministers, for example, agreed a roadmap for the roll out of 5G technology across Europe in December 2017. The roadmap will provide consensus over the harmonisation of 5G spectrum bands and how they will be allocated to operators across Europe.

Box 6 – 5G spectrum proposals by some NRAs

- **Ofcom, UK:** working closely with European NRAs has proposed the use of spectrum in the 700 MHz, 3.4 GHz and 24 GHz bands for 5G use. Ofcom has also proposed to change the authorization regime in the 64–66 GHz band to licence-exempt and expanding the use cases for the 57–66 GHz band.
- **The FCC, USA**: has identified almost 11 GHz of spectrum for flexible use wireless broadband – 3.85 GHz of licensed spectrum in the 28 GHz, 37 GHz and 39 GHz bands.
- **MIIT, China**: plans to allocate 5G mmWave spectrum in the 24–27 GHz and 37–42 GHz bands, in addition to the 3.3–36 GHz and 4.8–5 GHz bands for 5G.
- **KCC, Korea (Rep. of)**: will start to auction off 5G spectrum in the 3.5 GHz and 28 GHz bands in 2018.
- **ACMA, Australia:** announced plans for a multi-band spectrum auction to be launched before the end of 2017, comprising lots from the 1800 MHz, 2 GHz, 2.3 GHz and 3.4 GHz bands.

It should be noted that the 28GHz band was eliminated from international harmonisation by WRC-15.

Sources: https://goo.gl/kpPnTy (UK), https://goo.gl/Mc5wZx (USA), https://goo.gl/bdusHx (China), https://goo.gl/pGz5jG (South Korea), https://goo.gl/1aK5LY (Australia)

5.7 Spectrum licensing

The design of the selection procedures and the conditions attached to 5G licences can have significant consequences on the structure of mobile markets, either by enhancing competition or by limiting it.

Traditionally, spectrum offered to mobile operators has been licensed, where NRAs have granted exclusive rights for a mobile operator to offer voice or data services. In some cases, the licence may come with population and time-based coverage obligations. The licensed spectrum allows mobile operators to plan and invest in mobile infrastructure with certainty, and should include conditions to ensure that the allocated spectrum is effectively used, particularly in rural areas.

Licensed shared access spectrum can overcome some of the limitations with licensed spectrum to improve spectrum utilization in rural areas. By granting use of the spectrum to a few secondary users to – for example in rural areas –it will not interfere with the primary licence-holder's radio signals.

Current examples of shared spectrum include aeronautical telemetry, broadcast and wireless cameras. The shared licence model may provide the 5G ecosystem with flexibility to use spectrum that is underutilized by other services to provide additional capacity at lower cost. ITU-R has been studying the matter and recently approved some regulatory tools to support enhanced shared use of the spectrum [25] as well as some spectrum management principles, challenges and issues related to dynamic access to frequency bands by means of radio systems employing cognitive capabilities [26].

Spectrum auctions have traditionally awarded exclusive spectrum rights to wireless operators paying the highest fees. Policy-makers view auctions favourably as they can generate significant incomes. However, auctions can be counterproductive to the economy as they can reduce the funds available to invest in infrastructure, diluting the economic impact.[27]. As investment in 5G infrastructure becomes critical to the digital economy, it will be important for NRAs to select spectrum award procedures that favour investment in infrastructure and maximize economic impact.

Unlicensed spectrum enables NRAs to allow access to spectrum, but without certainty in tenure of the investments due to obligations to operate on a non-interference non-protection basis. In addition, controlling interference can be challenging and difficult, if not impossible, to manage. For this reason, unlicensed spectrum is typically more appropriate in high-frequency bands – such as the mmWave band, which has poorer propagation characteristics –, with low-power equipment to meet stringent limits for the protection of primary services, and for more localized usages. In view of the above, the use of unlicensed spectrum may be considered by NRAs for instance in small-cell deployments.

The GSMA and operators such as Telefonica have proposed that licensed spectrum is essential to guarantee high-quality 5G services, while unlicensed spectrum will play a complementary role in enhancing user experiences.[28]

Key findings: Policy makers may consider the use of licensed, unlicensed and shared spectrum to create a balanced spectrum ecosystem that encourages investment, makes efficient use of spectrum and promotes competition.

5.8 5G pilots

Policy-makers in governments and NRAs are encouraging early technology pilots to promote early investment in 5G networks and infrastructure and to aid their understanding of the various 5G technologies (see Box 7).

Box 7 – Government-led 5G initiatives

- The South Korean Government, via the NISA established 5G pilot networks at the 2018 Winter Olympics, providing futuristic experiences such as augmented reality-based navigation.
- A GBP 17.6 million government grant has been awarded to a consortium led by the University of Warwick to develop a UK central test bed for connected autonomous vehicles (CAVs). As part of this test bed, small cells will be deployed along a route through Coventry and Birmingham where the CAVs will be tested.

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[25] See Report ITU-R SM.2404, https://www.itu.int/pub/R-REP-SM.2404.

[26] see Report ITU-R SM.2405, https://www.itu.int/pub/R-REP-SM.2405.

[27] Additional information on the economic aspects of spectrum management can be found in Report ITU-R SM.2012, https://www.itu.int/pub/R-REP-SM.2012.

[28] "5G Spectrum Public Policy Position", GSMA, 2016.

- The FCC (USA) has encouraged applications from the research community to apply for experimental licences for radio frequencies not currently granted to or held by an applicant, to promote innovation and research by conducting experiments in defined geographic areas.

- The EC Horizon 2020 work programme (2018–2020) is promoting innovation in 5G across the EU and with China, Taiwan and the USA to undertake end-to-end testing of cross-border connected and automated mobility and 5G trials across multiple vertical industries.

- The Federated Union of Telecommunications Research Facilities for an EU–Brazil Open Laboratory (FUTEBOL), is creating research that promotes experimental telecommunication resources in Brazil and Europe. FUTEBOL will also demonstrate use cases based on IoT, heterogeneous networks and C-RAN.

- The Russian Ministry of Communications concluded an agreement with Rostelecom and Tattelecom on the creation of an experimental 5G zone in the hi-tech city of Innopolis.

Sources: https://goo.gl/JWFBCY (Korea Rep. of), https://goo.gl/FnLZCd (UK), https://goo.gl/wNVZqs (USA), https://goo.gl/iXkYQo (Europe), https://goo.gl/VNeDwn (EU-Brazil), https://goo.gl/4DySs2 (Russia)

In addition, the telecoms sector, comprising operators, vendors and research institutes, has been participating in 5G test beds independently of NRA or government intervention (see Box 8).

Box 8 – Commercially led 5G test beds

- Telstra (Australia) is working with Ericsson on key 5G technologies including massive MIMO, beamforming and beam tracking and waveforms. Telstra and Ericsson achieved download speeds of between 18 Gbit/s and 22 Gbit/s during the first live trial of 5G in Australia. Optus also just completed a 5G trial with Huawei, reaching the fastest speeds in Australia so far of 35 Gbit/s.

- Italian mobile operator Wind Tre, Open Fiber (Italy's wholesale fiber operator) and Chinese vendor ZTE have announced a partnership to build what they say will be Europe's first 5G pre-commercial network in the 3.6– 3.8 GHz band. They will also collaborate with local universities, research centres and enterprises to test and verify 5G technical performance, network architecture, 4G/5G network integration and future 5G use cases including augmented reality or virtual reality, smart city, public safety and 5G healthcare. The pilot project will run until December 2021.

- A 5G pilot network will be deployed in and around the Kazan Arena stadium (Russia) for the World Cup 2018 football tournament in a project led by MegaFon. Rostelecom is also partnering with Nokia on a 5G pilot wireless network located at a Moscow business park to test various 5G usage scenarios.

- Verizon (USA) announced it is planning 5G tests in several US cities. The roll-outs will be based on wireless backhaul rather than fiber. AT&T also indicated that it will launch 5G fixed-wireless customer trials based on its recent trials in Austin where it achieved 1 Gbit/s speeds and sub-10 milliseconds latency. The tests will be conducted using equipment from Ericsson, Samsung, Nokia and Intel.

- Comsol plans to launch South Africa's first 5G wireless network. Comsol's trial will test the performance of 5G in real-world conditions using small cells in addition to macro solutions. It is likely that Comsol will offer fixed-wireless service to compete with fiber-to-the-home (FTTH) services.

- Huawei and NTT DOCOMO, announced that they have successfully achieved a 4.52 Gbit/s downlink speed over 1.2km. Huawei supplied one of its 5G base stations, which supports massive MIMO and beamforming technologies in addition to its 5G core network.

Sources: https://goo.gl/cWTC31 (Australia), https://goo.gl/tYspR9 (Italy), https://goo.gl/EQftwd (Russia), https://goo.gl/yxaoyy (USA), https://goo.gl/VeuiaW (South Africa), https://goo.gl/Teq6e2 (Japan)

Key findings: Policy makers may consider encouraging 5G pilots and test beds to test 5G technologies and use cases and to stimulate market engagement.

6 Example of costs and investment implications

The deployment of small cells in dense urban areas is likely to be a key focus for investment for mobile operators in the run up to 5G. This section develops an example of a high-level cost model to estimate the potential investment required by a wireless operator to deploy a 5G ready small-cell network.

6.1 Overview

In the run up to 5G, operator strategies are most likely to focus on enhancing existing 4G coverage in urban areas through the deployment of small cells. Small cells will increase the amount of network capacity available, improve street level coverage and enhance overall network quality, as would be required by 5G networks. Most of these deployments will incur in densely populated urban centres or cities.

For the purpose of this exercise we have assumed a small cell network is deployed by an independent wireless operator on a wholesale basis to mobile operators. This approach reduces the total cost of ownership (TCO) to mobile operators and increases the attractiveness of small cells to mobile operators. A typical small cell solution that is currently in deployment across parts of Europe and the USA is depicted in Figure 7. Although this approach assumes a fiber backhaul strategy, wireless backhaul can be considered in cases where it is not commercially feasible to deploy a fiber backhaul network.

Figure 7 - Typical neutral host wholesale small cell solution

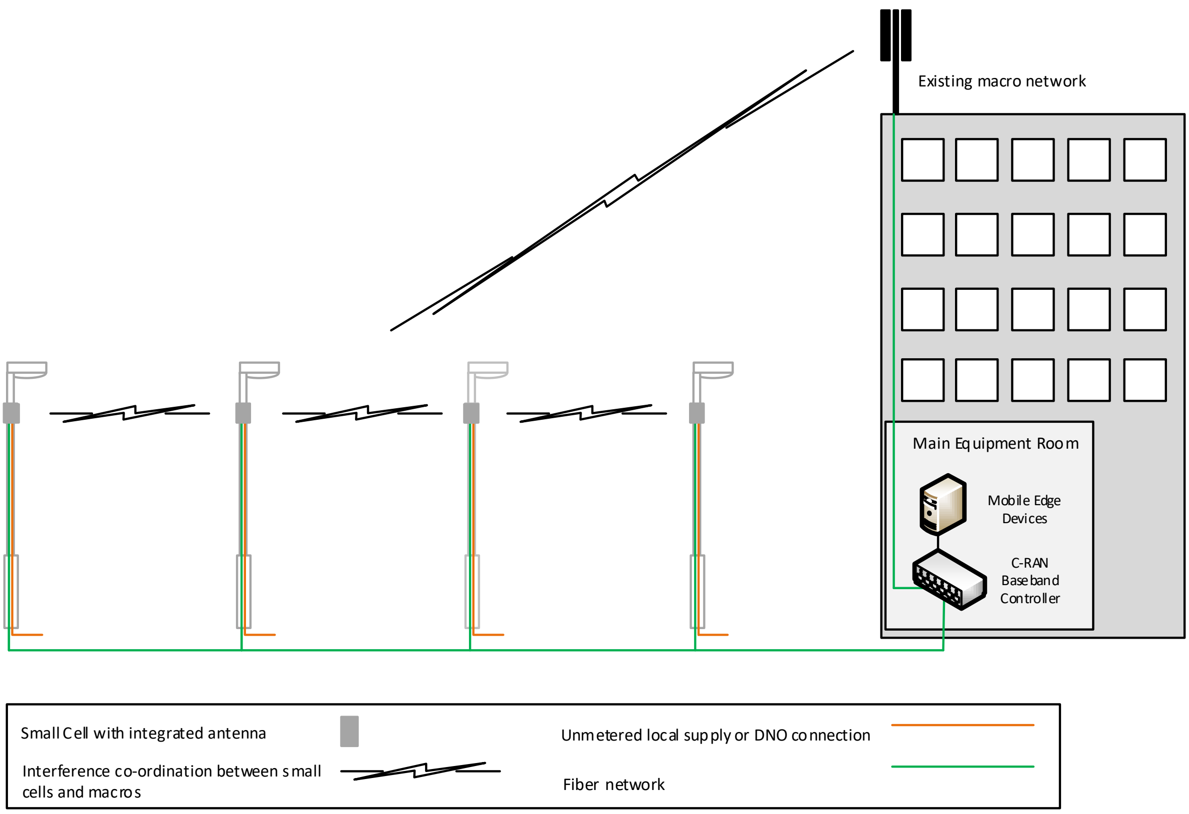

Figure 7 - Typical neutral host wholesale small cell solution, Source: Inteligens Consulting, 2018

The solution comprises the following elements:

- **Antennae** – discreet high-performance antenna system which shapes the mobile operators signal to maximise service performance for end users.

- **Street lights** – deployment of antennae on existing street lights to minimise aesthetic disruption.
- **Street cabinets** – shared accommodation hosting mobile operator radio equipment, battery backup and control equipment.
- **Fiber network** – high speed fiber that connects the radio network with the core network. Note that in some cases it may be more cost effective to use wireless backhaul.
- **Main Equipment Rooms (MER)** – A series of localised, shared main equipment room and a central point of interconnect to mobile operator backhaul networks.

6.2 Methodology

The focus of the model is to understand initial investment (capital expenditure) costs of deploying a small cell network; therefore, it only takes capital expenditure into consideration and excludes operating costs such as electricity, rent and maintenance, etc. Being a wholesale model, it does not include mobile operator radio equipment costs as these will be provided by each operator. Due to the uncertainty surrounding the cost of 5G spectrum and investment in NFV/SDN, these costs are also excluded, as are site acquisition costs, as these can vary significantly from one city to another. Figure 8 shows that there are two steps to developing the cost model, dimensioning and capex calculation.

Figure 8 - Typical neutral host wholesale small cell solution

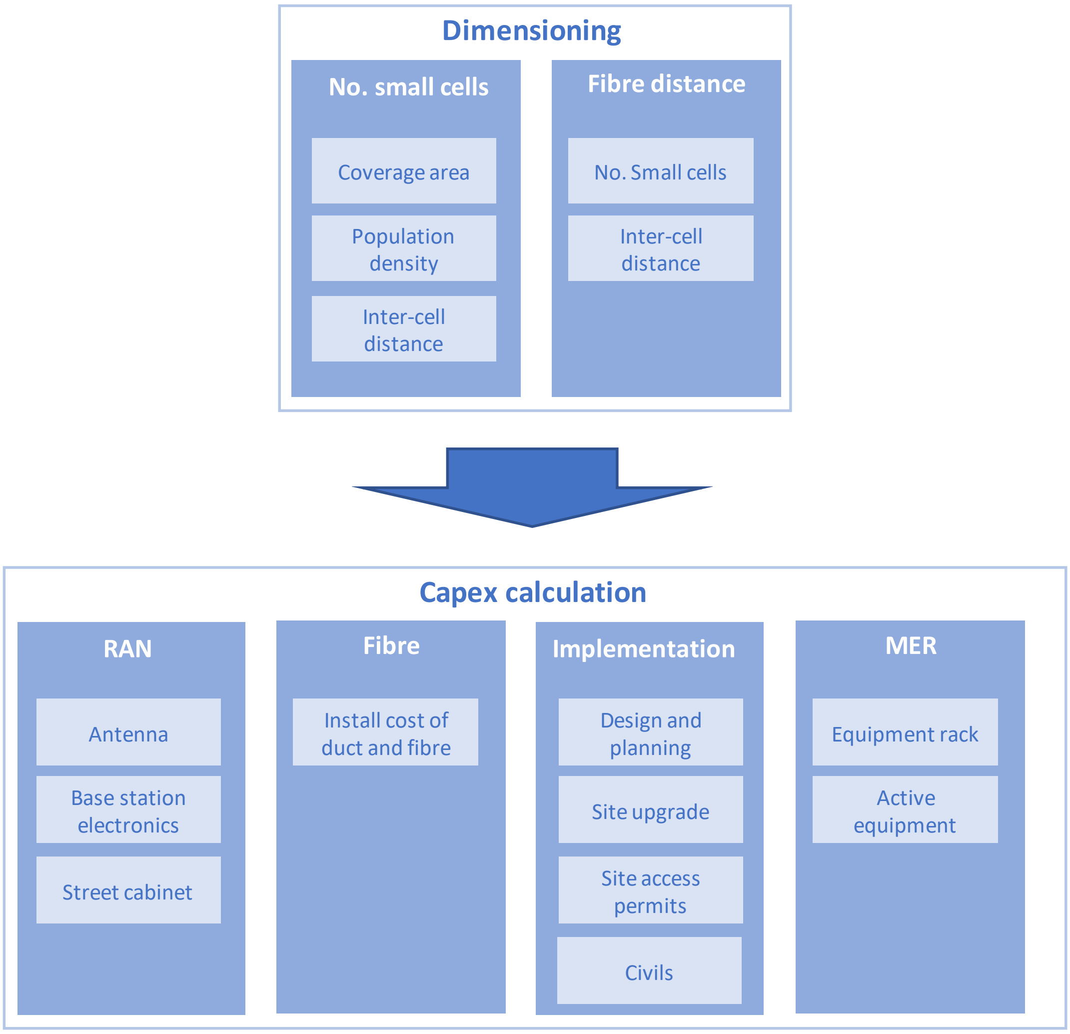

Figure 8 – Network dimensioning and Capex calculation methodology, Source: Inteligens Consulting, 2018

Network dimensioning estimates the number of small cells and amount of fiber needed and are calculated based on the required coverage area, population density and intercell cell-site distances. The outputs of the dimensioning step are used to determine the total investment capex required to implement the small cell solution for the RAN, fiber, the main equipment room, implementation and design.

The model assumes the following cost elements:

- **RAN**, which includes the cost of antenna, street cabinet and base station electronics such as battery backup and network maintenance modules.
- **Implementation costs**, which include design and planning costs, site upgrade costs, permit costs and civils costs to lay street cabinets.
- **Fiber network**, which includes the provision of 144 fiber and new ducts along the route of the activated street assets.
- **Main equipment room (MER),** comprising a single rack and termination equipment to provide an interconnection between the mobile operators and the dark fiber network in a co-location site.

Note that the actual costs may vary according to each country as labor costs, exchange rates. Equipment costs and taxes will vary in each country. The cost model assumes a Western country with a highly competitive market comprising four mobile operators and advanced levels of 4G coverage and low urban fiber density.

6.3 Scenarios

The above methodology is used to provide an estimate of the cost of deploying a fiber connected small cell solution in the central business district of a large dense city (scenario 1) and of a small less dense city (scenario 2). In both scenarios it is assumed that the city benefits from advanced levels of macro 4G coverage and the network demand characteristics are such that the investment case for 5G based small cells connected by fiber is commercially attractive.

Scenario 1 – large densely populated city

In this scenario the following assumptions are made:

- Proposed urban coverage area:15sqkm
- Population density of coverage area: 12,000 people per sqkm
- Inter-site small cell distance: 150m.

Scenario 2 – small medium density city

- Proposed urban coverage area: 3 sqkm
- Population density of coverage area: 3,298 people per sqkm
- Inter-site small cell distance: 200m.

A larger and denser city puts a higher strain on the mobile network, and therefore requires small cells to be sited closer together. For this reason, the distance between small cell sites is smaller in scenario 1 compared to scenario 2.

6.4 Results

Figure 9 and Figure 10 show that the capex required to deploy a fiber-connected small-cell network can range from USD 6.8 million for a small city to USD 55.5 million for a large dense city. The cost of deploying a small cell network in a dense city is greater per square kilometer because of the greater density of small cells deployed, owing to the shorter distance between small cell sites.

Figure 9: Capex for scenario 1 – large dense city

Item	Value
Total capex (USD millions)	**55.5**
Number of small-cell sites	1,027
Cost per square km (USD millions)	3.7
Capex per site (USD thousands)	54.1

Figure 9: Capex for scenario 1 – large dense city. Source: Intelligens, 2017

Figure 10: Capex for scenario 2 – small less dense city

Item	Value
Total capex (USD millions)	**6.8**
Number of small-cell sites	116
Cost per square km (USD millions)	2.3
Capex per site (USD thousands)	58.6

Figure 10: Capex for scenario 2 – small less dense city. Source: Intelligens, 2017

The total capex incurred by each operator will vary according to the population, population density, current 4G coverage and the proposed coverage area. Furthermore, the cost of fiber deployment will be lower in cities where there is a high availability of, and easy access to, dense fiber networks or ducts. Where wireless backhaul is more cost effective than fiber, the backhaul costs will be significantly reduced. In cities where the existing macro network density is high (e.g. in Madrid where site access is less restrictive than in other cities), there will be less need for small cells. Likewise, mobile operators with large spectrum assignments will not be required to densify their networks as much with small cells.

Figure 11 provides a breakdown of the cost components for scenario 1 and scenario 2 and shows that the implementation costs are the most significant cost element. In regions where labor costs are low, then the deployment costs will be less than those estimated in this report.

Figure 11: Contribution to capex

Small cell distance	Scenario 1	Scenario 2
RAN equipment (antenna, street cabinet, base station electronics, battery backup and network maintenance modules)	25%	24%
Implementation costs (design and planning costs, site upgrade costs, permit costs and civils costs to lay street cabinets)	50%	46%
Fiber (provision of 144 fiber along the route of activated street assets)	25%	30%
MER (single rack and termination equipment)	<0.1%	<0.1%

Figure 11: Contribution to capex. Source: Inteligens Consulting, 2018

6.5 Independent cost estimates

The above costs – in particular capex per site – are in line with industry estimates. AT&T estimate that the deployment costs can range from USD 20,000 to USD 50,000 per site assuming fiber backhaul for sites, something AT&T has in abundance.[29,30] According to Nokia site capex is estimated to be between USD 40,000 to USD 50,000 for a site that requires trenching and power.

Work undertaken by independent analysts estimates a total cost of ownership of GBP 71 billion to build a ubiquitous 5G network in the UK delivering 50 Mbit/s, which is built in 2020 and operated until 2030. This reduces to GBP 38 billion when infrastructure sharing is encouraged.[31]

Other reports estimate the cost of deploying 5G across the USA would be USD 300 billion. In Europe the investment costs are expected to range between EUR 300 billion to EUR 600 billion according to one mobile operator.[32]

Although these reports do not state the frequency spectrum used to derive the analysis, it is assumed that much of the cost is as a result of network densification. Network densification – through the deployment of small cells - is necessary for the smaller cell sizes required due to the use of higher mMWave frequency spectrum that will be used by 5G, e.g. above 28GHz, as mentioned in Section 3.5.

6.6 Investment models

Given the considerable capex investment required in deploying 5G may pose major challenges for operators and they may struggle to make the investment case for 5G. Policy-makers will need to give consideration to alternative investment models such as PPPs, loans, challenge funds and investment vehicles to ensure the high upfront capex costs are not a barrier for wireless providers to deploy 5G networks.

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29 https://www.rcrwireless.com/20170814/carriers/att-small-cell-cactus-antenna-concealment-tag17
30 http://www.telecompetitor.com/cfo-extensive-fiber-assets-firstnet-give-att-an-advantage-on-5g-backhaul/
31 https://www.itrc.org.uk/wp-content/PDFs/Exploring-costs-of-5G.pdf
32 http://www.lightreading.com/mobile/5g/how-much-will-5g-cost-no-one-has-a-clue/a/d-id/733753

Some examples of government interventions have already been described in Section 5, which include a range of PPP programmes aimed at promoting the development of fiber networks. These programmes can either be: i) publicly led, where the government builds and owns the fiber networks as in Qatar; or ii) privately led, where the government partly funds the development of fiber networks in partnership with the market, as in Germany.

Other approaches include offering local authorities grants – as in the UK – or funds to construct and upgrade passive assets (such as ducts, fiber networks, data centres, street furniture, etc) that are required by wireless operators to deploy 5G networks. Governments can also offer low-cost loans to operators to help finance the construction of 5G networks in return for a guaranteed investment from the operators, as in Malaysia.

Where operators prefer to access capital from private markets, governments can set up investment funds in collaboration with established private sector fund managers to provide operators with equity. The equity would be used to support operator network expansion programmes.

Many other PPP models for incentivizing investment in telecom networks do exist and have been written about extensively.[33]

It is important to add, however, that not all 5G deployments will require government intervention. Some small-cell and pre-5G deployments to date have been privately financed, as demonstrated in the previous sections.

[33] "Investment strategies for broadband deployment and access to the digital economy", ITU, 2016

7 Conclusion

Until such time that the investment case for 5G is demonstrable the industry and policy makers should approach 5G investment with caution while enhancing the availability and quality of existing 4G networks.

5G is expected to play a key role in digital economies, improving economic growth, enhancing citizens' life experiences and creating new business opportunities.

Despite the potential economic benefits that might be realised from 5G, care must be taken in establishing that there is indeed a commercial case for 5G and whether 5G is in fact a priority for the economy. A 5G investment decision must be backed by a sound investment case.

Further, operators are sceptical about the return on investment due to the significant sums of investment required by operators to deploy 5G networks. In fact, operators are currently investing in 5G test beds and pilot networks in large dense cities with advanced 4G deployments and with readily available supporting economic and digital infrastructure which more suited to network economics.

This 'city led' operator strategy is likely to have an adverse impact on the digital divide as the case for 5G in rural areas is more challenging to make. Local authorities and regulators should recognise these risks to the digital divide and support commercial and legislative incentives to stimulate investment for the provision of fiber networks and affordable wireless coverage (e.g. through the 700 MHz band) to reduce digital divide.

An overhaul of the regulatory, government and local authority approach to digital policy will be necessary to facilitate, rather than hinder, the roll-out of 5G networks. This includes allowing affordable access to public assets enabling wireless operators to make a robust commercial case to invest in small cell infrastructure and in 5G spectrum as it becomes available.

Annex A

ITU-R carries out sharing and compatibility studies in preparation for WRC-19 in the frequency bands agreed at WRC-15 that could potentially be identified for implementation of IMT-2020 (5G).

ITU-R Study Group 5 (Terrestrial systems), among other relevant topics such as intelligent transport systems, is responsible for the overall radio system aspects of IMT systems and for the studies related to the land mobile service, including wireless access in the fixed service.

Recommendations and Reports developed by ITU-R include:

ITU-R M.1457 "Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000)". Specifications for IMT-2000.

ITU-R M.2012 "Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced)". Specifications for IMT-Advanced.

ITU-R M.2083 "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond", includes a broad variety of capabilities associated with envisaged usage scenarios. Furthermore, it addresses the objectives of the future development of IMT-2020, which includes further enhancement of existing IMT and the development of IMT-2020.

ITU-R M.2370 "IMT Traffic estimates for the years 2020 to 2030", as traffic demand for mobile broadband communications represented by IMT is increasing, the transport network in the mobile infrastructure is becoming an important application that requires special consideration.

ITU-R M.2375 "Architecture and topology of IMT networks", offers an overview of the architecture and topology of IMT networks and a perspective on the dimensioning of the respective transport requirements in these topologies, in order to assist relevant studies on the transport network in the mobile infrastructure.

ITU-R M.2376 "Technical feasibility of IMT in bands above 6 GHz", expects that usage of higher frequencies will be one of the key enabling components of future IMT.

ITU-R M.2410 "Minimum requirements related to technical performance for IMT-2020 radio interface(s)", describes the key requirements related to the minimum technical performance of IMT-2020 candidate radio interface technologies.

ITU-R M.2411 "Requirements, evaluation criteria and submission templates for the development of IMT-2020", describes the requirements and the submission process of the technologies.

ITU-R M.2412 "Guidelines for evaluation of radio interface technologies for IMT-2020", provides guidelines for the evaluation of the radio interface.

Additional documentation can be found *at https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/Pages/default.aspx*.

The standardization activities within ITU also cover the needs for backhauling in support of 5G development. This aspect includes the studies of several radiocommunication solutions, such as satellite communications or the use of high speed radio relays or high-altitude platforms stations (HAPS).

ITU-T Study Group 13 (Future networks), ITU's lead group for 5G wireline studies, continues to support the shift to software-driven network management and orchestration. The group is progressing draft 5G standards addressing subjects including network architectures, network capability exposure, network slicing, network orchestration, network management-control, and frameworks to ensure high quality of service.

5G wireline standards developed by ITU-T Study Group 13 and approved in 2017 -2018 include:

Recommendation ITU-TY.3071 "Data Aware Networking (Information Centric Networking) – Requirements and Capabilities" will support ultra-low latency 5G communications by enabling proactive in-network data caching and limiting redundant traffic in core networks.

Recommendation ITU-T Y.3100 "Terms and definitions for IMT-2020 network" provides a foundational set of terminology to be applied universally across 5G-related standardization work.

Recommendation ITU-T Y.3101 "Requirements of the IMT-2020 network" provides general principles of the IMT-2020 network, then specifies requirements for overall non-radio aspects of the IMT-2020 network from both the service and network operation points of view.

Recommendation ITU-T Y.3102 "Framework of IMT-2020 network" specifies the framework for overall non-radio aspects of the IMT-2020 network: the key features of the IMT-2020 network and architectural design considerations.

Recommendation ITU-T Y.3111 "IMT-2020 network management and orchestration framework" establishes a framework and related principles for the design of 5G networks.

Recommendation ITU-T Y.3112 "Framework for the support of Multiple Network Slicing" describes the concept of network slicing and the high-level requirements and high-level architecture for multiple network slicing in IMT-2020 network, illustrated by the use cases.

Recommendation ITU-T Y.3110 "IMT-2020 network management and orchestration requirements" describes the capabilities required to support emerging 5G services and applications.

Recommendation ITU-T Y.3150 "High level technical characteristics of network softwarization for IMT-2020". Taking from global recognition of the usefulness of network slicing technology, as the most typical substantiation of the network softwarization approach, this Recommendation describes how network softwarization and network slicing contribute to IMT-2020 systems, explores network slicing from two viewpoints: vertical and horizontal aspects, details network slicing for mobile fronthaul/backhaul, introduces the advanced data-plane programmability, and capability exposure.

Recommendation ITU-T Y.3130 "Requirements of IMT-2020 fixed mobile convergence" specifies service related requirements such as unified user identity, unified charging, service continuity and guaranteed quality of service support, and network capability requirements such as control plane convergence, user data management, capability exposure and cloud-based infrastructure, to support fixed mobile convergence in IMT-2020 networks.

ITU-T Supplement 35 to Y.3033-series "Data-aware networking - scenarios and use cases" lists a set of service scenarios and use cases supported by data aware networking (DAN) including: 1) content dissemination; 2) sensor networking; 3) vehicular networking; 4) automated driving; 5) networking in a disaster area; 6) advanced metering infrastructure in a smart grid; 7) proactive video caching; 8) in-network data processing; 9) multihoming; and 10) traffic engineering. It provides informative illustrations and descriptions of how DAN can be designed, deployed and operated to support DAN services. In addition, the benefits of data aware networks to the scenarios and use cases, as well as several migration paths from current networks to data aware networks, are elaborated.

Supplement 44 to ITU-T Y.3100 series "Standardization and open source activities related to network softwarization of IMT-2020" summarizes open-source and standardization initiatives relevant to ITU's development of standards for network softwarization.

Supplement 47 to the ITU-T Y.3070-series Recommendations "Information-Centric Networking - Overview, Standardization Gaps and Proof-of-Concept" provides the overview of information-centric networking and describes the fifteen standardization gaps and five proof-of-concept based on the ICN related contents investigated by ITU-T Focus Group on IMT-2020 (FG IMT-2020) during 2015-2016.

In addition, ITU standardization work on the wireline elements of 5G systems continues to accelerate. ITU-T Study Group 15 (SG15 - Transport, access and home) develops standards for providing transport support for 5G systems.

SG15 work related to 5G includes:

G-series Technical Report (GSTR-TN5G) "Transport network support of IMT-2020/5G".

Supplement 55 to G-series Recommendations "Radio-over-fiber (RoF) technologies and their applications" provides general information on radio over fiber (RoF) technologies and their applications in optical access networks. This technology is used in the radio shadow.

Supplement 56 to G-series Recommendations "OTN transport of CPRI signals" describes alternatives for mapping and multiplexing CPRI client signals into the OTN. This Supplement relates to Recommendations ITU-T G.872, ITU-T G.709/Y.1331, ITU-T G.798 and ITU-T G.959.1.

Recommendation ITU-T G.987 series: 10-Gigabit-capable passive optical networks (XG-PON)

Recommendation ITU-T G.9807 series: 10-Gigabit-capable symmetric passive optical network (XGS-PON)

Recommendation ITU-T G.989 series: 40-Gigabit-capable passive optical networks 2 (NG-PON2)

Recommendation ITU-T G.RoF "Radio over Fiber systems" (under development)

New Supplement to G-series Recommendations (G.sup.5GP) "5G wireless fronthaul requirements in a PON context" (under development)

Recommendation ITU-T G.9700 series: Fast access to subscriber terminals (G.fast)

Recommendation ITU-T G.709 series: Optical Transport Network (OTN)

In addition, SG15 develops standards on network synchronization for supporting 5G networks (Recommendation ITU-T G.8200 series).

ITU-T Study Group 11 (Protocols and test specifications) is studying the 5G control plane, relevant protocols and related testing methodologies.

Supplement 67 to Q-series Recommendations "Framework of signalling for software-defined networking" enables the development of a signalling protocol(s) capable of supporting traffic flows in SDN environment.

Recommendations ITU-T Q.3710-Q.3899 series on Signalling requirements and protocols for SDN.

Recommendation ITU-T Q.3315 "Signalling requirements for flexible network service combination on broadband network gateway". As the key position to offer broadband network services, the broadband network gateway (BNG) should be able to support flexible service combination, new services introduction and provisioning. Q.3315 describes the signalling requirements, based on the service platform broadband network gateway (BNG) architecture, needed to achieve outstanding benefits like easy deployment of network services, fine grained network services, etc.

ITU-T Study Group 5 (Environment, climate change and circular economy) has assigned priority to its emerging study of the environmental requirements of 5G systems. ITU-T SG5 is developing a series of international standards (ITU-T Recommendations), Supplements and Technical Reports that will study the environmental aspects related to: electromagnetic compatibility (EMC), electromagnetic fields (EMF); energy feeding and efficiency, and resistibility. The ITU-T Recommendations and Supplements developed by ITU-T SG5 include:

Supplement ITU-T K.Suppl.8 “Resistibility analysis of 5G systems” analyses 5G system resistibility requirements for lightning and power fault events.

Supplement ITU-T K.Suppl.9 “5G technology and human exposure to RF EMF” contains an analysis of the impact of the implementation of 5G mobile systems with respect to the exposure level of electromagnetic fields (EMF) around radiocommunication infrastructure.

Supplement ITU-T K.Suppl.10 “Analysis of electromagnetic compatibility aspects and definition of requirements for 5G mobile systems” provides guidance on the EMC compliance assessment considerations for 5G systems. It focuses on possible emission and immunity requirements for 5G systems.

Supplement ITU-T K.Suppl.14 “The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment” provides an overview of some of the challenges faced by countries, regions and cities which are about to deploy 4G or 5G infrastructures. It also provides information on a simulation on the impact of RF-EMF limits that was carried out in Poland as an example of a wider phenomenon, which is applicable to several other countries, which have set limits that are stricter than those contained in the ICNIRP or IEEE guidelines.

Recommendation ITU-T L.1220 Innovative energy storage technology for stationary use - Part 1: Overview of energy storage introduces an open series of documents for different families of technologies (battery systems, super-capacitor systems, etc.) that will be enriched progressively as new technologies emerge that may have a possible significant impact in the field of energy storage.

ITU-T L.Suppl.36 to ITU-T L.1310 “Study on methods and metrics to evaluate energy efficiency for future 5G systems” analyses the energy efficiency issues for future 5G systems.

Earlier the ITU-T Focus Group IMT-2020 produced a set of technical reports elaborating the different facets of the 5G wireline aspects “ITU-T Focus Group IMT-2020 deliverables flipbook, 2017”:

https://www.itu.int/en/publications/Documents/tsb/2017-IMT2020-deliverables/mobile/index.html#p=4.

The preparatory work of ITU-T for the introduction on IMT-2020 is depicted in the “5G Basics flipbook,2017”,https://www.itu.int/en/publications/Documents/tsb/2017-IMT2020-deliverables/mobile/index.html#p=1

See ITU-T webpages at: https://www.itu.int/en/ITU-T/Pages/default.aspx.