

Setting the Scene for 5G: Opportunities & Challenges



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2018

Acknowledgments

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I am pleased to present this report on Setting the Scene for 5G: Opportunities & Challenges, prepared in collaboration with the ITU's Standardization and Radiocommunication Bureaux. The report sets out the landscape for ICT policy-makers, national regulatory authorities (NRAs) and operators as 5G technologies move ever closer. 5G has the potential to be transformative for citizens, businesses, governments and economies. Investment is key but there are many factors to take into account before investments can be committed.

This report helps navigate through the issues related to 5G and provides a measured, practical approach to policy-makers looking to make important investment decisions in the months and years ahead. The sixteen key issues presented are essential reading and constitute a powerful embarkation point as we set out to grapple with 5G opportunities and challenges.

This report further helps demystify the hype surrounding 5G, recognizes the great potential of 5G and makes a host of recommendations designed to help policy-makers, regulators and operators work together effectively, both to meet the challenges and to benefit from the many opportunities that this new technology represents. It also recommends that policy-makers improve availability and quality of 4G networks until the case for 5G networks becomes clearer and more compelling.

I thank my colleagues Mr Chaesub Lee, Director of ITU Telecommunication Standardization Bureau, and Mr François Rancy, Director of ITU Radiocommunication Bureau, for their invaluable contribution in making this report a useful ITU tool to provide guidance as policy-makers and NRAs seek to harness the benefits of the digital economy.



Brahima Sanou

Director, Telecommunication Development Bureau, ITU

Table of Contents

Foreword	iii
Abbreviations and acronyms	ix
Executive Summary	xii
1 Introduction	1
2 5G overview	3
2.1 The role of the ITU	3
2.2 What is 5G?	3
2.3 5G use cases	6
2.4 Socio economic implications of 5G	8
2.5 Digital divide	9
3 5G technology and spectrum requirements	10
3.1 Radio access networks	10
3.2 Core networks	12
3.3 Backhaul	12
3.4 Fronthaul	13
3.5 Spectrum for 5G	14
4 Key challenges in rolling out 5G	16
4.1 Small cell deployment challenges	16
4.2 Fibre backhaul	17
4.3 Spectrum	17
4.4 Other factors	18
5 What does 'good' look like?	20
5.1 Streamlining small cell deployments	20
5.2 Policy intervention- fibre and spectrum	20
5.3 Infrastructure sharing	21
5.4 Transition to fibre	23
5.5 Addressing local planning challenges	23
5.6 Spectrum harmonization	24
5.7 Spectrum licensing	25
5.8 5G pilots	26
6 Example of costs and investment implications	28
6.1 Overview	28
6.2 Methodology	29
6.3 Scenarios	30
Scenario 1 – large densely populated city	30
Scenario 2 – small medium density city	30
6.4 Results	30
6.5 Independent cost estimates	31
6.6 Investment models	32

7	Conclusion	33
	Annex A	34

List of Tables, Figures and Boxes

Figures

Figure 1: Detailed timeline and process for ITU-R IMT-2020 Enhancement of key capabilities from IMT-Advanced to IMT-2020	3
Figure 2: Evolution of mobile networks	6
Figure 3: 5G usage scenarios	7
Figure 4: Bandwidth and latency requirements for 5G applications	10
Figure 5: Macro versus small cell networks	11
Figure 6: An example of a small cell antenna system and a street cabinet	11
Figure 7: Typical neutral host wholesale small cell solution	28
Figure 8: Typical neutral host wholesale small cell solution	29
Figure 9: CAPEX for scenario 1 – large dense city	31
Figure 10: CAPEX for scenario 2 – small less dense city	31
Figure 11: Contribution to CAPEX	31

Boxes

Box 1: Role of IMT 2020 (5G) and beyond	4
Box 2: 5G and fixed mobile convergence (FMC)	8
Box 3: Aberdeen	11
Box 4: Telefonica investing in SDN and NFV	12
Box 5: ITU-R technical feasibility of IMT in the frequencies above 24 and up to 86 GHz	14
Box 6: An operator's perspective – Huawei's multi-layer spectrum approach	15
Box 7: Industry viewpoint on barriers to deploying small cells	17
Box 8: Barriers to deploying fibre networks	18
Box 9: Streamlining the deployment of small cells	20
Box 10: UK fibre investments	21
Box 11: 5G working group, Australia	21
Box 12: Mandated network sharing	22
Box 13: Commercially driven network sharing	22
Box 14: Transition to fibre	23
Box 15: City of London standardized wayleave agreements	24
Box 16: Efficient planning processes	24
Box 17: 5G spectrum proposals by some NRAs	25
Box 18: Government-led 5G initiatives	26
Box 19: Commercially led 5G test beds	27

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*	Refers to different generations of mobile standards
5GIA	5G Infrastructure Association
AI	Artificial Intelligence
AV	Autonomous Vehicle
BEREC	Body of European Regulators for Electronic Communications
BNG	Broadband Network Gateway
CAGR	Compound Annual Growth Rate
CAV	Connected Autonomous Vehicle
CCTV	Closed-Circuit TV
CPRI	Common Public Radio Interface
C-RAN	Cloud/centralized Radio Access Network
DAN	Data Aware Networking
EC	European Commission
EMBB	Enhanced Mobile Broadband
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
EU	European Union
FCC	Federal Communications Commission
FG ML5G	Focus Group on Machine Learning for Future Networks, including 5G
FMC	Fixed Mobile Convergence
FTTH	Fibre to the Home
FTTP	Fibre to the Premise
FUTEBOL	Federated Union of Telecommunications Research Facilities for an EU-Brazil Open Laboratory
GSMA	The GSM Association
HAPS	High Altitude Platform Systems
ICNIRP	International Commission on Non-Ionizing Radiation Protection

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

Abbreviation/acronym	Description
ICT	Information and Communications Technology
IMT-2020	International Mobile Telecommunication 2020 standards
IoT	Internet of Things
ITU	International Telecommunication Union
ITU-BDT	ITU Telecommunication Development Bureau
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
MIoTT	Massive Internet of Things
mmWave	Millimeter Wave
MMTC	Massive Machine-type Communications
NFV	Network Function Virtualization
NISA	National Information Society Agency (Korea Rep. of)
NRA	National Regulatory Authority
OTN	Optical Transport Network
PMP	Point-to-Multipoint
PPP	Public–Private Partnership
Q.NBN	Qatar National Broadband Network
RAN	Radio Access Network
RF EMF	Radio Frequency Electromagnetic Field
ROF	Radio-over-Fibre
RRU	Remote Radio Unit
SDN	Software-Defined Networking
SMP	Significant Market Power
TCO	Total Cost of Ownership
TIM	Telecom Italia Mobile

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

Abbreviation/acronym	Description
URLLC	Ultra-Reliable and Low-Latency Communication
WHO	World Health Organization
WLAN	Wireless Local Area Network
WRC-19	World Radiocommunication Conference 2019
WTDC	World Telecommunication Development Conference

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

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

Executive Summary

Expectations of 5G are high, with many assuming it will deliver a transformative promised land – an improved end-user experience, new applications, new business models and new services riding swiftly on the back of gigabit speeds, improved network performance and reliability. 5G networks and services, standing as they do on the shoulders of successful 2G, 3G and 4G mobile networks, are forecast by independent economic studies to deliver very significant economic gains.

Caution: high levels of investment needed

However, despite the potential benefits, there is concern that 5G is premature and notes of caution are being sounded. Operators are sceptical about the commercial case given the high-levels of investment needed to deploy 5G networks.¹ The report estimates the cost to deploy a small cell-ready 5G network – assuming fibre 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.

Danger of increasing digital divide

A viable case for investment in 5G can be made for densely populated urban areas – always the most commercially attractive regions for operators. More challenging will be a commercial argument for investing in 5G networks outside such areas, especially in the early years of 5G deployment. As a result, rural and suburban areas are less likely to enjoy 5G investment, and this will potentially widen the digital divide.

Balanced view is needed

As long as the investment case for 5G remains uncertain, industry and policy-makers should remain cautious 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. Policy-makers and operators should only consider deploying 5G networks where there is demand or a robust commercial case in favour of doing so.

Policy-makers' actions will make a difference

Where demand exists alongside high 5G deployment costs, policy-makers can use a range of legal and regulatory actions to facilitate 5G network deployment. These include:

- Supporting the use of affordable wireless coverage (e.g. through sub-1 GHz bands) to reduce the digital divide;
- Commercial incentives such as grants, or PPPs to stimulate investment in 5G networks.

5G: 16 key issues for policy-makers to consider

This report highlights 16 key issues – and responses – for policy-makers to consider as they formulate strategies to stimulate investment in 5G networks. Together they represent powerful means of calibrating an overall approach across major aspects of migration and, where appropriate, embarking on a judiciously facilitated, accelerated transition to 5G.

¹ <https://www.techradar.com/news/eu-backed-groups-warns-about-5g-claims>

Key issues for consideration

No.	Summary	For consideration...
1)	Investment case	Policy-makers may consider undertaking their own independent economic assessment of the commercial viability of deploying 5G networks
2)	4G network strategy	Until the case for 5G networks can be clearly 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 5G spectrum bands
4)	Spectrum roadmap	NRAs may consider adopting a spectrum roadmap and a predictable renewal process
5)	Spectrum sharing	NRAs may consider allowing 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 risk of digital divide
8)	Fibre investment incentives	Policy-makers, where the market has failed, may consider stimulating fibre investment and passive assets through PPPs, investment funds and the offering of grant funding, etc.
9)	Fibre tax	Policy-makers may consider removing any tax burdens associated with deploying fibre networks to reduce the associated costs
10)	Copper migration to fibre	Policy-makers may consider adopting policies/financial incentives to encourage migration from copper to fibre and stimulate deployment of fibre
11)	Wireless backhaul	Operators may consider a portfolio of wireless technologies for 5G backhaul in addition to fibre, including point-to-multipoint (PMP), microwave and millimeter wave (mmWave) radio relays, high altitude platform systems (HAPS) and satellites
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 NRAs may consider continuing to elaborate existing duct access regimes to encompass 5G networks allowing affordable fibre 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, fibre networks, CCTV posts, lampposts, etc. This will help operators cost and plan their infrastructure deployment more accurately
15)	Wayleave (rights of way) agreements	Policy-makers may agree upon standardized wayleave agreements to reduce cost and time to deploy fibre 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

The ITU has highlighted 5G networks and artificial intelligence (AI) as fields of innovation necessary for enabling smarter societies. 5G is the next generation of mobile standards and 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”, setting the stage for 5G research activities emerging around the world. The ITU has also established the Focus Group on Machine Learning for Future Networks, including 5G (FG ML5G).¹ This Focus Group is studying the use cases, services, requirements, interfaces, protocols, algorithms, ML-aware network architecture and data formats.

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

This report reviews expectations of 5G and examines the infrastructure and investment requirements on the private and public sectors as they prepare for 5G. It is designed to support emerging use cases and services, and to help all sectors meet the expected performance (gigabit data rates), low latency and high reliability requirements of these services, ensuring that end users reap in full 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 deployment of 5G networks. While significant steps are being taken 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 report 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 in preparing for 5G development, to speed up deployment and reduce the cost of deployment.

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 of 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 them.

¹ <https://www.itu.int/en/ITU-T/focusgroups/ml5g/Pages/default.aspx>

- Section 7 recommends actions for policy-makers in NRAs and governments, helping them simplify and reduce costs as they move towards implementation.

2 5G overview

This section introduces the role of the ITU in developing 5G standards as well as the potential benefits that 5G can generate. While the ecosystem is not fully developed, 5G may not yet be an appropriate consideration across all regions. In addition, there is some concern that the initial deployment of 5G in dense urban areas may increase the digital divide.

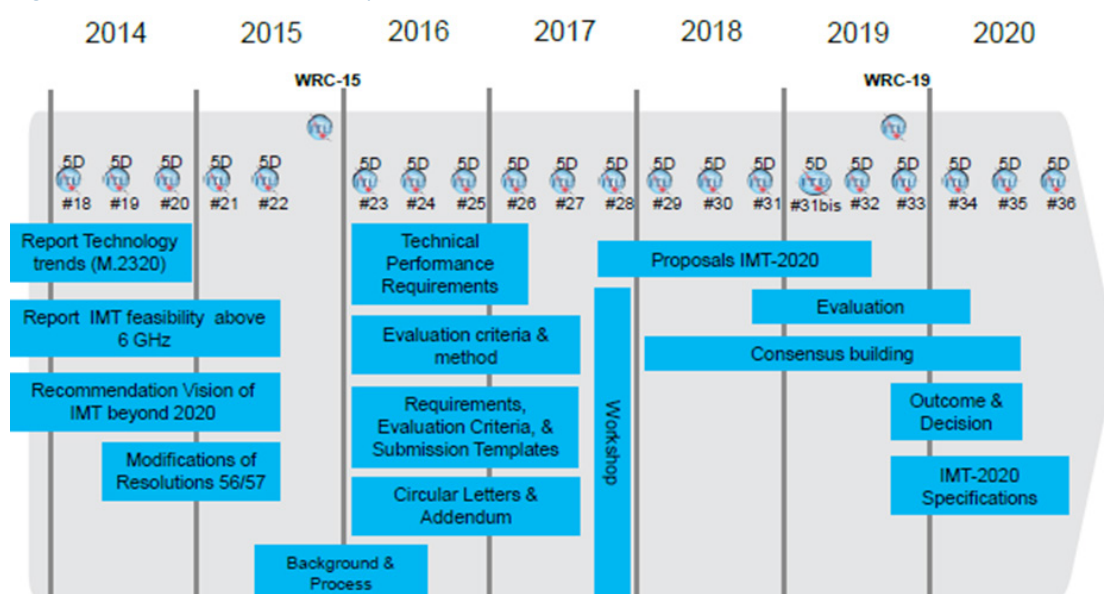
2.1 The role of the ITU

5G is the next generation of mobile standards being defined by the ITU. IMT-2020 (5G) is a name for the systems, components, and related elements 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
- Define the framework and overall objectives of the 5G standardization process
- Set out 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



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

2.2 What is 5G?

At the highest level, 5G is an opportunity for policy-makers to empower citizens and businesses. 5G will play a key role in supporting governments and policy-makers in transforming their cities into smart cities, allowing citizens and communities to realize and participate in the socio-economic benefits delivered by an advanced, data-intensive, digital economy.

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, supporting 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 – and at affordable cost. 5G is an opportunity to implement wired and wireless converged networks, and offers in particular opportunities in integrating network management systems.

Commercial 5G networks are expected to start deployment after 2020, as shown in Figure 2, as 5G standards are finalized.¹ By 2025, the GSM Association (GSMA) expects 5G connections to reach 1.1 billion, some 12 per cent of total mobile connections. It also forecasts overall operator revenues to grow at a CAGR of 2.5 per cent, to reach USD 1.3 trillion by 2025.²

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, suited to mission-critical services where data are time-sensitive. Its high-speed capability means 5G networks can provide a range of high-speed broadband services and offer an alternative to 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. This 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 a key pillar in enabling mobile service delivery and information exchange. 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 in turn drives economies around the globe. Some possible areas include: the accumulation, aggregation and analysis of big data; the delivery of customized networking services for enterprise and social network groups on wireless networks.
- **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 content anytime, anywhere and 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 methods 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.

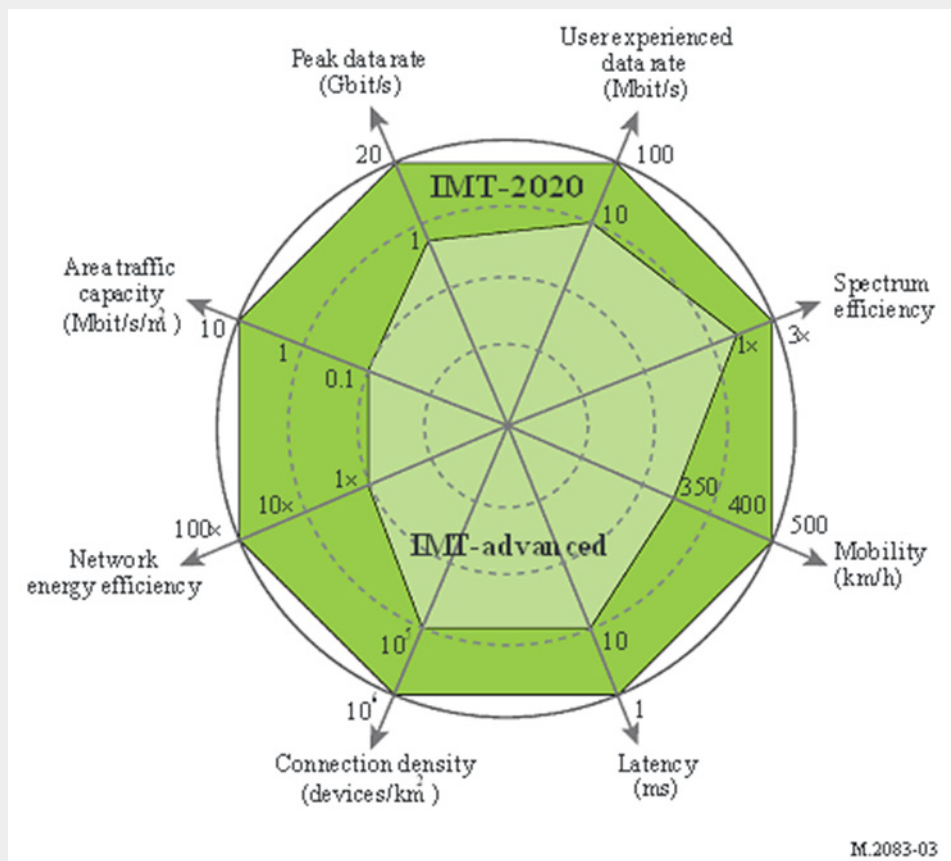
¹ In 2012, the ITU's Radiocommunications sector (ITU-R) embarked on a programme to develop international mobile telecommunication (IMT) standards for 5G by 2020.

² "The 5G era: Age of boundless connectivity and intelligence automation", GSMA Intelligence, 2017: <https://www.gsmainelligence.com/research/2017/02/the-5g-era-age-of-boundless-connectivity-and-intelligent-automation/614/>

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

- Social changes: Broadband networks make it easier to quickly shape and share public opinions for a political or social issue through social network service. Opinions formed by a huge number of connected people due to their ability to exchange information anytime anywhere will become a key driver of social change.
- New art and culture: IMT will support artists and performers in creating works of art or in participating in group performances or activities, such as a virtual chorus, flash mob, co-authoring and 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 Figure 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).

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

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 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 higher than IMT networks deployed today, even as it delivers 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

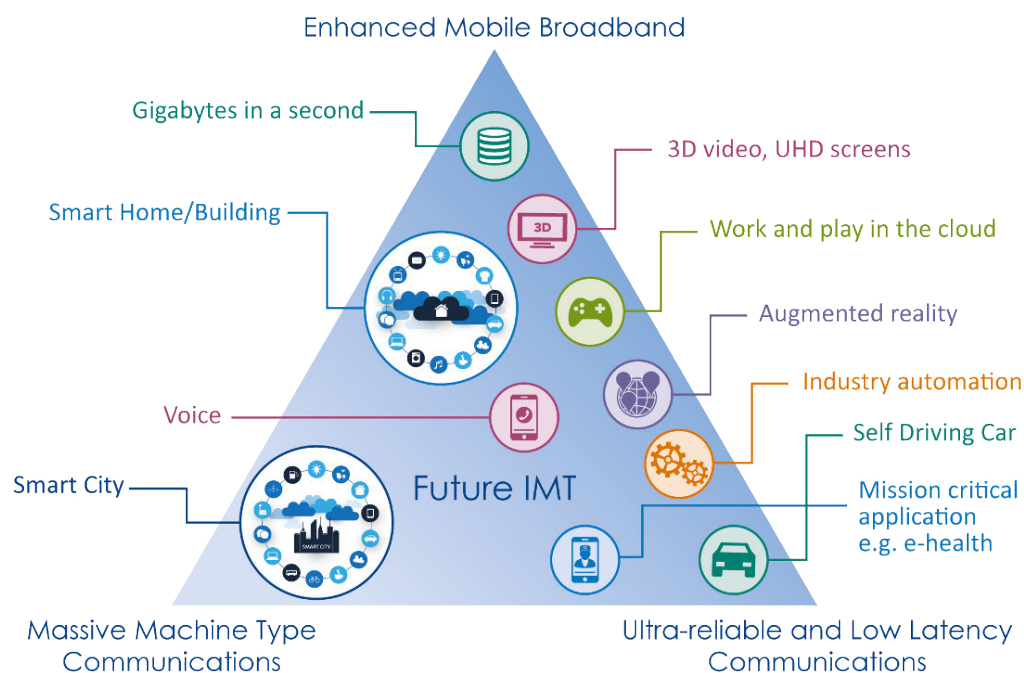
	1G	2G	3G	4G	5G
Approximate deployment date	1980s	1990s	2000s	2010s	2020s
Theoretical download speed	2kbit/s	384kbit/s	56Mbit/s	1Gbit/s	10Gbit/s
Latency	N/A	629 ms	212 ms	60-98 ms	< 1 ms

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 three important categories of these (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



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 will allow enterprise collaboration services to evolve. Some operators are also considering eMBB as the last-mile solution in those areas lacking copper or fibre connections to homes.

5G is also expected to drive the evolution of 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 as well as 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.

5G's low latency and safety characteristics will play well in the evolution of intelligent transport systems, enabling smart vehicles to communicate with each other, and creating opportunities for connected, autonomous cars and trucks. For example, an autonomous vehicle (AV) 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 have a significant way to go before they come into service, despite ongoing pilots and trials.

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

FMC is a networking solution in any given configuration, providing services and applications to the end user regardless of fixed or mobile access technologies and independent of the user's location. The concept of FMC has been implemented since 2005. With the move towards 5G, the FMC solution acquires additional flavour.

Recommendation ITU-T Y.3101, the IMT-2020 network envisages an access network-agnostic architecture, the core of which 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, decoupled from access technologies.

Emerging information and communications technologies (for example virtualization, cloud, software-defined networking (SDN), network function virtualization (NFV)) are transforming telecommunication operators' fixed and mobile networks to achieve high resource utilization and network flexibility, which in turn 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 – as well as 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 the FMC approach. This includes 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 the FMC network which supports multiple RAT accesses.

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

2.4 Socio economic implications of 5G

There are few third party studies that have looked at the economic impact of investments in 5G. Nevertheless, it is possible to draw upon some third-party forecasts to estimate the impact that 5G could have on economic output.

The ITU suggests 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 underwrite USD 12.3 trillion of global economic output by 2035, with the greatest growth in sales activity coming from manufacturing because of an anticipated increase in spending on 5G equipment. This is followed by sales growth in the ICT sector driven by higher expenditure on communications services. Investment in the value chain is expected to generate a further USD 3.5 trillion in output and provide support for 22 million jobs by 2035.³

³ "The 5G Economy", IHS economics and IHS technology, January 2017: <https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf>

The European Commission (EC) estimates the total cost of 5G deployment across the 28 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 generally. Most of the benefits are expected in urban areas while only 8 per cent of benefits (EUR 10 billion per annum) will be realized in rural areas.⁴

Other reports have also indicated significant economic benefits and productivity enhancements resulting from investment in 5G networks.⁵ Such estimates set out to provide a quantification of the benefits of 5G while assuming ideal investment conditions. The true economic benefit for each country will vary depending upon market structure and the availability of digital and supporting economic infrastructure.

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

Despite the potential economic benefits, the industry remains sceptical about the commercial case for investment in 5G. Given the significance of required investment, scepticism remains among some European operators over 5G hype and question whether they can make money from it. These concerns are supported by the 5G Infrastructure Association (5GIA), an EU-backed body, and by senior telecoms executives cautioning against premature 5G launch announcements.⁶

Many 5G announcements – some are highlighted in this report – are simply regional 5G pilots and trials rather than full-scale commercial deployments. 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 finding: Until the investment case for 5G is demonstrable, 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

The industry takes the view that initial deployment of 5G networks will be in dense urban areas and will offer services such as enhanced mobile broadband (eMBB) – it will be commercially challenging to deploy 5G networks in rural areas where demand tends to be lower – consequently, rural areas may be left behind, thereby increasing the digital divide.

However, the use of sub-1 GHz frequency spectrum if available, can counteract this in rural areas. This part of the spectrum allows mobile operators to cover wide areas at lower cost than with higher frequency spectrum.

While data speeds and network capacity in this part of the spectrum are not as high as in higher frequency bands, the sub-1 GHz spectrum will enhance the coverage of rural networks.

Key finding: Local authorities and regulators should recognize the risk of increasing the digital divide and support commercial and legislative incentives to stimulate investment in affordable wireless coverage through sub-1 GHz spectrum, where possible.

⁴ “Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe”, European Commission, 2016: https://connectcentre.ie/wp-content/uploads/2016/10/EC-Study_5G-in-Europe.pdf

⁵ “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

⁶ <https://www.techradar.com/news/eu-backed-groups-warns-about-5g-claims>

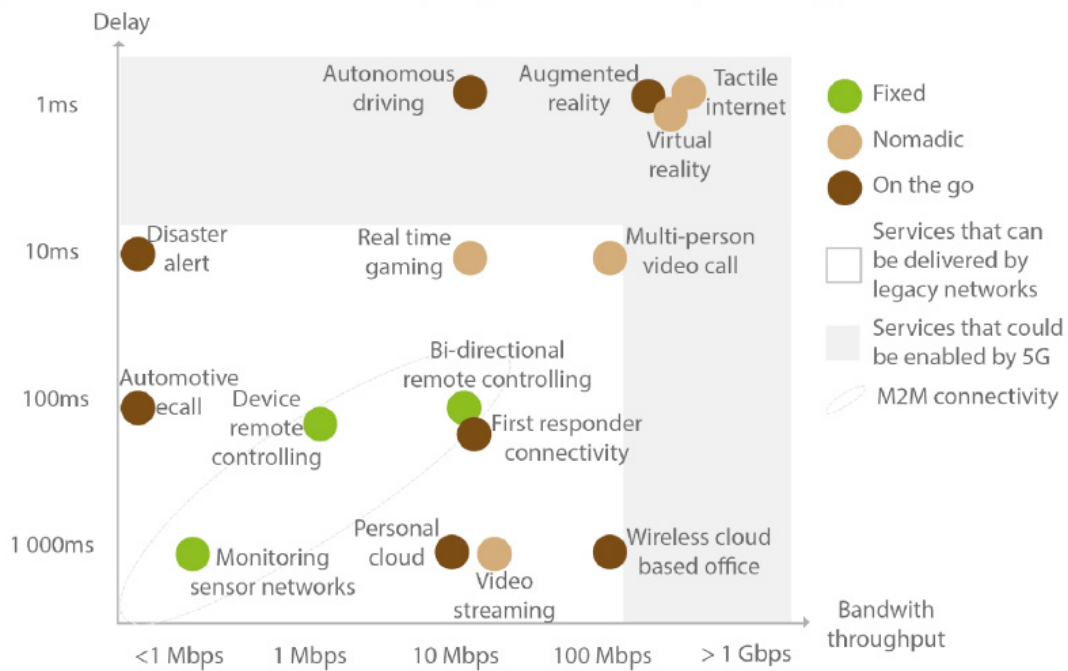
3 5G technology and spectrum requirements

Radio spectrum, backhaul, softwarization of core networks and radio access networks will be vital in early deployment of 5G networks particularly where enhanced mobile broadband is concerned.

3.1 Radio access networks

Most outdoor 4G mobile network deployments are currently based on macro-cells.¹ However, 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



Source: GSMA Intelligence, 2015.

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

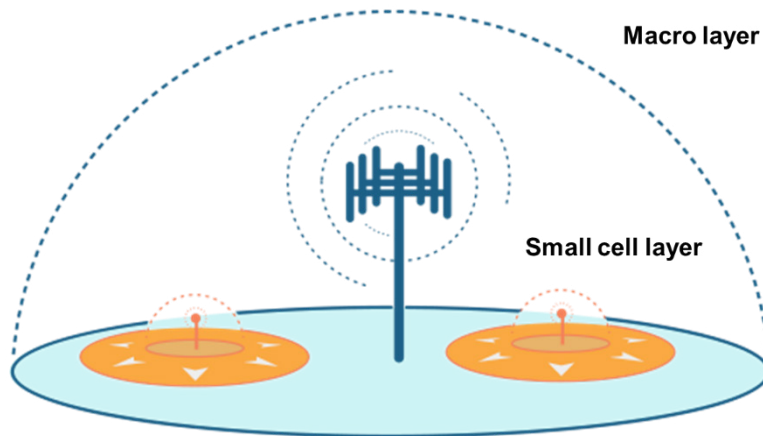
The deployment of small cells is one way of boosting the capacity and quality of existing 4G networks while laying the foundation for commercial 5G networks and early eMBB services. Small cells are already being used by some wireless operators to boost the capacity and coverage of their existing 4G networks particularly in a dense urban setting, see Box 3 as an example.

Small cells boost network capacity without the need for additional spectrum, making them attractive to operators with a low spectrum holding or where spectrum is scarce. Furthermore, the industry view is 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 eMBB services.²

¹ <https://www.mobileworldlive.com/blog/blog-global-base-station-count-7m-or-4-times-higher/>

² 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 5: Macro versus small cell networks

**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/>

Due to the dense coverage that small cells need to provide, small cell antennae need to be installed onto street furniture – bus shelters, lampposts, traffic lights, etc. These are 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 as well as its supporting street cabinet.

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



Massive MIMO (multiple input, multiple output) scales up to hundreds or even thousands of antennae, 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.³

³ IEEE: <https://ieeexplore.ieee.org/document/7881053/>

3.2 Core networks

End-to-end flexibility will be one of the defining features of 5G networks.⁴ This flexibility will result in large part from the introduction of network softwarization where the core network hardware and the software functions are separated. Network softwarization – through network functional virtualization (NFV), software defined networking (SDN), network slicing and Cloud-RAN (C-RAN) – aims to increase both 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** – 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.

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 network 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-9678-0f16dccc0e16?version=1.0

Other technology enhancements being considered include signal coding techniques which 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 applications. 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, cuts down on transport costs and 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. Fibre 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.

⁴ ITU: <http://news.itu.int/5g-update-new-itu-standards-network-softwarization-fixed-mobile-convergence/>

However, fibre 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 fibre networks in these areas can often be prohibitive in terms of cost for operators. In this case, a portfolio of wireless backhaul technologies should be considered in addition to fibre, including point-to-multipoint (PMP) microwave and millimeter wave (mmWave). PMP is capable of downstream throughput of 1Gbit/s and latency of less than 1ms per hop over a 2-4 km distance. mmWave has significantly lower latency and is capable of higher throughput speeds.

While most focus is being given to terrestrial technology, there is also a role for high altitude platform systems (HAPS) and satellite technology in 5G. HAPS and satellite systems (including non-geostationary constellations) can deliver very high data rates (> 100 Mbit/s – 1 Gbit/s) to complement fixed or terrestrial wireless backhaul networks outside major urban / suburban areas and can deliver video transmission to fixed locations. HAPS and satellites may be integrated with other networks rather than function as a standalone network to provide 5G, thereby augmenting the 5G service capability and addressing some of the major challenges regarding the support of multimedia traffic growth, ubiquitous coverage, machine-to-machine communications and critical telecom missions.⁵

Key finding: A portfolio of wireless technologies may be considered in addition to fibre, including point-to-multipoint (PMP) microwave, millimeter wave (mmWave), HAPS and satellites.

In summary, a realistic 5G backhaul strategy is likely to consist 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 a 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 for 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 fewer processing functions can then 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.⁶

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

- Supplement 55 to G-series Recommendations “Radio-over-fibre (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 Fibre systems” (under development)

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

⁶ 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>

- Draft Supplement to G-series Recommendations (G.sup.5GP) “5G wireless fronthaul requirements in a PON context” (under development)
- Recommendation ITU-T G.709(.x) series: Optical transport network (OTN) beyond 100 Gbit/s
- Draft Recommendation ITU-T G.ctn5g: Characteristics of transport networks to support IMT-2020/5G (under development)
- Draft Supplement to G-series Recommendations G.Sup.5gotn: Application of OTN to 5G transport (under development)
- Recommendation ITU-T G.695: Optical interfaces for coarse wavelength division multiplexing applications
- Recommendation ITU-T G.698.4: Multichannel bi-directional DWDM applications with port agnostic single-channel optical interfaces
- Recommendation ITU-T G.959.1: Optical transport networks physical layer interfaces

3.5 Spectrum for 5G

More spectrum bandwidth will be required to deploy 5G networks (than 4G) to the high capacity requirements, increasing the need for spectrum. In consequence, the industry is making concerted efforts to harmonize 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 in producing the standards for the technologies and architectures of the wireline elements of 5G systems.

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 6).

The challenge for NRAs will be to select globally harmonized spectrum bands for 5G. 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,⁷ it could be used differently in parts of Africa to enhance 4G coverage. It is expected that by 2020, only 35 per cent of the Sub-Saharan population will be covered by 4G networks, with many rural areas enjoying little or no 4G mobile coverage. This compares to a global average of 78 per cent.⁸ For this reason, policy-makers in Sub-Saharan Africa might well consider using 700MHz spectrum as the ideal way forward to increasing rural 4G coverage rather than using this for 5G.

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

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 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 harmonized – and therefore well positioned to drive the economies of scale needed for low-cost devices.

Key finding: Policy-makers may consider grouping together to reach agreement on harmonized spectrum bands for 5G. NRAs would then benefit from an exchange of best practices in regard to shaping markets through the granting of spectrum licences.

⁷ EC: https://ec.europa.eu/commission/commissioners/2014-2019/ansip/blog/700-mhz-must-digital-single-market_en

⁸ 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 help wireless operators to deploy small cells, fibre backhaul as well as 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 through 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 more 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 used 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):** exposure limits differ across countries, and in some cases are unduly 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 (International Commission on Non-Ionizing Radiation Protection) limits should be used. Where new antennae are added, all regular steps should be taken during the deployment phase to respond to any public concern. One factor contributing to public concern is the visibility of antennae, particularly on rooftops. Here, multi-band antennae can be used to reduce visual impact by maintaining the same number of antennae on rooftops. Without any spectrum or technology re-farming strategy, the 5G network will increase the localized exposure resulting from wireless technologies, at least during the transition period. It is thus important to include national authorities at an early stage in establishing how 5G can be deployed and activated – and how compliance with national limits can best be assessed and met. This has already proved difficult in countries where exposure limits are more restrictive than those recommended by the World Health Organization (WHO), based on the ICNIRP RF-EMF exposure guidelines.¹
- **Access and code powers:** wireless operators² 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.

¹ From Supplement ITU-T K.Supp.9 “5G technology and human exposure to RF EMF”: <https://www.itu.int/rec/T-REC-K.Supp9/en>

² 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, a telecoms provider must apply to and be recognized by OFCOM, the UK telecoms regulator.

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 – these include excessive fees, prohibitions on small cell placement, unreasonable aesthetic restrictions and prolonged permitting processes. According to Crown Castle, its 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 fibre backhaul, which may not be the case in other markets.

4.2 Fibre backhaul

Deploying fibre 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 the poor availability of fibre networks in many cities.

The UK, for example, has one of the lowest fibre penetration rates in Europe at 2 per cent penetration. This compares to a European average of around 9 per cent.³ To incentivize investment in fibre networks, the UK Government has introduced a five-year relief from business rates on new fibre networks infrastructure.⁴

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

Key finding: Policy-makers may consider removing tax burdens to reduce investment cost associated with fibre in order to facilitate the deployment of 5G networks.

Some of the other challenges faced by operators are described in Box 8.

Key finding: Local authorities may consider agreeing upon standardized wayleave agreements to reduce the cost and time of deploying fibre 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. This represents one of the largest challenges for NRAs in the successful deployment of 5G networks. Harmonized allocation has many advantages since it minimizes radio interference along borders, facilitates international roaming and reduces the cost of equipment. This overall coordination is the main objective of the ITU-R in the process of World Radiocommunication Conferences (WRCs).

³ <https://www.ispreview.co.uk/index.php/2017/02/uk-shunned-2017-ftth-ultrafast-broadband-country-ranking.html>

⁴ The UK's valuation office agency has recently undertaken a revaluation of business rates which will increase the tax likely to be paid by fibre operators. High business rates could adversely affect the commercial model to deploy fibre connectivity to support small cell deployment.

Box 8: Barriers to deploying fibre 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 while 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

For WRC-19, this process is currently at the stage of building consensus on the allocation and identification for IMT of large contiguous blocks of world-harmonized radio spectrum above 24 GHz, where large bandwidths are available. WRC-19 decisions on this topic will be based on ITU-R studies on extensive sharing and compatibility between the mobile service and the incumbent services in these and in adjacent frequency bands.

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

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

Key finding: Policy-makers should consider using globally harmonized spectrum to maximize the efficient use of available spectrum.

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 can therefore 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 should 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 finding: Policy-makers may consider a spectrum roadmap that supports exclusive, shared and unlicensed models with a predictable renewal process. Policy-makers should avoid artificially high 5G spectrum prices and instead opt for procedures that favour investment when awarding spectrum.

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 these “create significant uncertainties around 5G return on investment”. Furthermore they stated that they would *not* introduce high-speed 5G networks unless BEREC took a softer approach to net neutrality.⁵

⁵ “5G manifesto for timely deployment of 5G in Europe”, various industry players, July 2016: <http://telecoms.com/wp-content/blogs.dir/1/files/2016/07/5GManifestofortimelydeploymentof5GinEurope.pdf>

5 What does 'good' look like?

This section reviews what can be learned from the way in which wireless providers, NRAs and governments across the world are working 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 local government fees – and some go further to ensure no exclusive arrangements are made with wireless providers.

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

Box 9: Streamlining the deployment of small cells

In September 2017, a California bill was passed streamlining small cell deployment by permitting its use and making such deployment no longer subject to a local discretionary permit or with specified criteria. The new legislation standardizes small cell deployments across the state. In addition, the bill:

- Grants providers non-discriminatory access to public property
- Allows local governments to charge permit fees that are fair, reasonable, non-discriminatory and cost-based
- Limits the costs charged by local governments of attaching equipment to USD 250
- Stops local governments putting 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 time-scales. The bill also proposes that authorities may not enter into any exclusive arrangements entitling 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 finding: Local authorities may consider improving access to government-owned street furniture and streamlining engagement processes as alternatives to lengthy procurement exercises.

5.2 Policy intervention - fibre and spectrum

Leading economies like the UK have low fibre penetration, according to the FTTH Council, because of underinvestment in pure fibre networks. Box 10 describes the actions being taken by UK policy-makers to improve fibre penetration in the run up to 5G.

Box 10: UK fibre investments

In 2016, the UK Government announced a GBP 740 million challenge fund to invest in local full fibre 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 (see Box 11).

Box 11: 5G working group, Australia

The Australian Government is developing a 5G Directions Paper which outlines a 5G policy approach for Australia including the establishment of a 5G working group to facilitate ongoing dialogue with industry. The paper highlights actions which make spectrum available in a timely manner and which streamlines 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 Finding: Where market failure has occurred, governments may consider stimulating investment in fibre networks and passive assets through setting up PPPs, investment funds and offering grant funds, etc.

5.3 Infrastructure sharing

Where fibre is the preferred method of backhaul, it may not be commercially attractive. Modest levels of duct sharing, and re-use can generate significant savings in the development of fibre networks. Regulatory policies that promote infrastructure sharing and re-use can help significantly lower 5G deployment costs – although they can be complex to implement (see Box 12).

A study undertaken by Vodafone suggests that the duct access regime is commonly used by NRAs in France, Spain and Portugal, ensuring minimum bureaucracy and maximum transparency to all parties. In contrast, where SMP infrastructure access has been mandated, as in the UK and Germany, many of these detailed provisions are lacking.¹

Key finding: Policy-makers may consider continuing the duct access regime to encompass 5G networks, thereby helping reduce the cost of investing in 5G fibre backhaul networks.

Commercially led network-sharing agreements are preferred by most NRAs and seem to have gained significant market traction. These can speed up the deployment and reduce costs for 5G networks where network sharing ranges across mobile infrastructure as well as fibre (see Box 13).

¹ "Best practice for passive infrastructure access", WIK-Consult, 2017: <https://www.vodafone.com/content/dam/vodafone-images/public-policy/reports/pdf/best-practice-passive-infrastructure-access-050517.pdf>

Box 12: Mandated network sharing

- In November 2017, the Netherlands passed a bill designed to accelerate broadband roll-outs. It mandated 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.
- Indonesia's Ministry of Communications and Information Technology is working toward new rules to encourage the development of passive infrastructure sharing such as ducts, poles, towers, cabinets, etc.
- UK telecoms regulator Ofcom is running a market consultation to mandate the incumbent operator and significant market player BT to offer duct fibre access to rival operators. Previous attempts to mandate dark fibre access failed.
- In Italy, ultra-fast broadband legislation has enabled TIM and UTILITALIA (the federation of electricity, gas, water and 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 fibre networks.

Sources: <https://goo.gl/kqYCRM> (Netherlands), <https://goo.gl/vWq7aD> (Indonesia), <https://goo.gl/vdFz9> (Ofcom, UK), <https://goo.gl/m24g32> (Italy)

Box 13: Commercially driven network sharing

- In Spain, telecoms operator MASMOVIL has passed the ten million household threshold using a fibre 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 fibre network that will be marketed to around 2.6 million homes and businesses. The two companies provide access to each other's networks on agreed commercial terms.
- New Zealand's wholesale network operator, Chorus, is calling on the government to begin formulating plans for a single 5G mobile network – one which can be shared by all service providers, a more sustainable approach than having a separate 5G network for each of the country's three mobile operators.
- 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 services contract with Nokia to manage their shared mobile networks run by one infrastructure company (TT-Netvaerket).
- Econet Wireless (Zimbabwe), has stated it is open to infrastructure sharing, under an equitable 'one-for-one' infrastructure.

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, reducing deployment costs, promoting retail competition and increasing service coverage. Wireless provider Crown Castle (US) for example, increased its small cell

revenues by over 40 per cent between 2015 and 2016² as mobile operators move to densify their networks in preparation for 5G roll-outs.

5.4 Transition to fibre

At present, lower wholesale copper access prices are competitive when set against the price of fibre services, adversely affecting the take-up of fibre. There is no consensus on the most appropriate approach to pricing during the transition from copper to fibre. NRAs should consider allowing incumbents to *withdraw copper-based access products* as soon as they offer fibre-based access services, to prevent the undermining of the business case for more expensive fibre services (see Box 14).

Box 14: Transition to fibre

- The Government of Australia has imposed a deadline of 2020 by which all premises are to be migrated from copper to fibre. In 2014, Telstra (Australia) began to switch off services being delivered over its copper networks. The government-funded NBNetCo initiative, which has driven wholesale fibre connectivity across Australia, will switch off copper networks in areas where NBNetCo already provides fibre services.
- Verizon (US) has requested regulatory permission to migrate its copper network in selected markets from 2018. Verizon delivers services via its fibre infrastructure and wishes 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 launched a consultation on the potential of its incumbent operator, Eir, to transition from copper in some parts of the country, particularly in areas of extensive fibre coverage.
- Singtel (Singapore) announced plans to discontinue its copper-based ADSL network in April 2018 as it accelerates fibre-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 fibre access networks from 2020.

Sources: <https://goo.gl/2YVKsd> (Australia), <https://goo.gl/VCyfab> (US), <https://goo.gl/X3EeKa> (Ireland), <https://goo.gl/mRKu1C> (Singapore), <https://goo.gl/n6kqVb> (New Zealand)

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

5.5 Addressing local planning challenges

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

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

² <https://www.telegeography.com/products/commsupdate/articles/2017/02/07/tower-talk-a-guide-to-the-latest-major-cell-site-developments/index.html>

Standardized wayleave agreements used among local authorities can significantly reduce the cost and time to implement fibre networks such as that developed by the City of London Corporation (see Box 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 fibre investment was the complex wayleave process. The corporation developed a standardized wayleave toolkit to facilitate the delivery of fibre 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 giving operators the appropriate permission to undertake relevant street works when laying fibre networks or deploying small cell equipment onto street furniture (Box 16). It is also best practice to undertake consultations with the market to understand potential issues and solutions arising in deployment.³

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

Box 16: Efficient planning processes

In 2015, the City of Centennial (Colorado, US) 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 has allowed the city to coordinate investments, saving time and costs.

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

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

5.6 Spectrum harmonization

The focus for early 5G applications has been on the bands above 24 GHz and below 6 GHz (see Box 17). NRAs should coordinate their proposals on the millimetre bands to maximize the opportunity for global spectrum harmonization.

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

³ http://webarchive.nationalarchives.gov.uk/20100402171309/http://www.ogc.gov.uk/documents/Early_Market_Engagement_Guidance.pdf

Box 17: 5G spectrum proposals by some NRAs

- **Ofcom, UK:** working closely with European NRAs, Ofcom 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 expand the use cases for the 57–66 GHz band.
- **The FCC, US:** 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
- **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.

Note that WRC-15 excluded the 28GHz band from the scope of study toward the international harmonization of millimetric bands for IMT by WRC-19.

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

5.7 Spectrum licensing

The design of selection procedures and conditions attached to 5G licences can significantly impact the structure of mobile markets – by enhancing competition or limiting it.

Traditionally, NRAs have granted spectrum licenses to mobile operators giving exclusive rights 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 that ensure that the allocated spectrum is used effectively, particularly in rural areas.

Licensed, shared-access spectrum can improve spectrum utilization in rural areas. For example, the granting of spectrum use to some secondary users in such areas will not interfere with the primary licence-holder's radio signals.

Current examples of shared spectrum include aeronautical telemetry, broadcast and wireless cameras. This shared licence model may well provide the 5G ecosystem with sufficient flexibility to make good use of spectrum now underutilized by other services to provide additional capacity at lower cost.

Following a study, ITU-R has approved regulatory tools to support enhanced, shared use of the spectrum⁴ – as well as spectrum management principles, challenges and issues related to dynamic access to frequency bands via radio systems employing cognitive capabilities.⁵

Spectrum auctions have traditionally awarded exclusive spectrum rights to wireless operators paying the highest fees. Policy-makers view auctions favourably as a means of generating significant incomes. However, auctions can be counterproductive in that they reduce funds available for infrastructure,

⁴ See Report ITU-R SM.2404: <https://www.itu.int/pub/R-REP-SM.2404>

⁵ See Report ITU-R SM.2405: <https://www.itu.int/pub/R-REP-SM.2405>

diluting economic impact.⁶ As 5G investment becomes more critical to the digital economy, it will be important for NRAs to select spectrum award procedures favouring investment in infrastructure and maximizing economic impact.

Unlicensed spectrum enables NRAs to allow access to spectrum – but this arrangement leads to uncertainty as regards tenure of investments, because of obligations to operate on a basis of non-interference and non-protection. In addition, controlling interference can be difficult, if not impossible to manage. For this reason, unlicensed spectrum is more appropriate in high-frequency bands – such as the mmWave band with poorer propagation characteristics – and with low-power equipment to meet stringent limits of primary services, and for more localized usages. In view of these factors, the use of unlicensed spectrum may be considered by NRAs for instance in small cell deployments.

The GSMA consider that licensed spectrum is essential in guaranteeing high-quality 5G services, while unlicensed spectrum can play a complementary role in enhancing user experience.⁷

Key finding: Policy-makers may consider the use of licensed, unlicensed and shared spectrum to create a balanced spectrum ecosystem – one 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 5G technologies (see Box 18).

Box 18: Government-led 5G initiatives

- The Government of Korea (Rep. of), 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). Small cells will be deployed along a route through Coventry and Birmingham where the CAVs will be tested.
- The FCC (US) has encouraged applications from the research community for experimental licences for radio frequencies not granted or assigned, to promote innovation and research through experiments in defined geographic areas.
- The EC Horizon 2020 work programme (2018-2020) is promoting innovation in 5G involving the EU, China, Taiwan, China and the US. Activities include 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.

⁶ 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>

⁷ “5G Spectrum Public Policy Position”, GSMA, 2016: <https://www.gsma.com/iot/iot-knowledgebase/gsma-public-policy-position-5g-spectrum/>

Box 18: Government-led 5G initiatives (continued)

- The Russian Ministry of Communications concluded an agreement with Rostelecom and Tattetelecom to create 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> (US), <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 19).

Box 19: Commercially led 5G test beds

- Telstra (Australia) is working with Ericsson on key 5G technologies including massive MIMO, beamforming, 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 completed a 5G trial with Huawei, reaching the fastest speeds in Australia so far of 35 Gbit/s.
- Italian mobile operator Wind Tre, Open Fibre (Italy's wholesale fibre 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 was 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 (US) announced it is planning 5G tests in several US cities. The roll-outs will be based on wireless backhaul rather than fibre. 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 fibre-to-the-home (FTTH) services.
- Huawei and NTT DOCOMO 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> (US), <https://goo.gl/Veuiaw> (South Africa), <https://goo.gl/Teq6e2> (Japan)

Key finding: 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

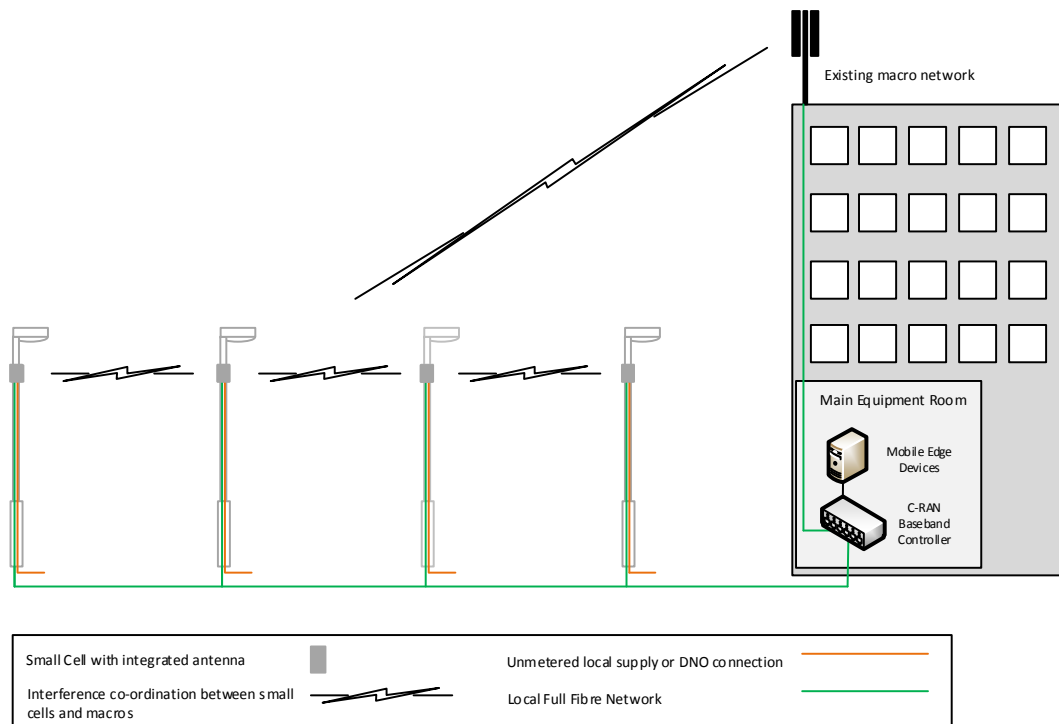
The deployment of small cells in dense urban areas is likely to represent a key investment for mobile operators in the run up to 5G. This section develops an example of a high-level cost model to estimate the potential investment required by a wireless operator to deploy a 5G-ready small cell network.

6.1 Overview

In the run up to 5G, operators are likely to focus on enhancing existing 4G coverage in urban areas through the deployment of small cells. These 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 occur 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 US is depicted in Figure 7. Although this approach assumes a fibre backhaul strategy, wireless backhaul can be considered in cases where it is not commercially feasible to deploy a fibre backhaul network.

Figure 7: Typical neutral host wholesale small cell solution



The solution is comprised of the following elements:

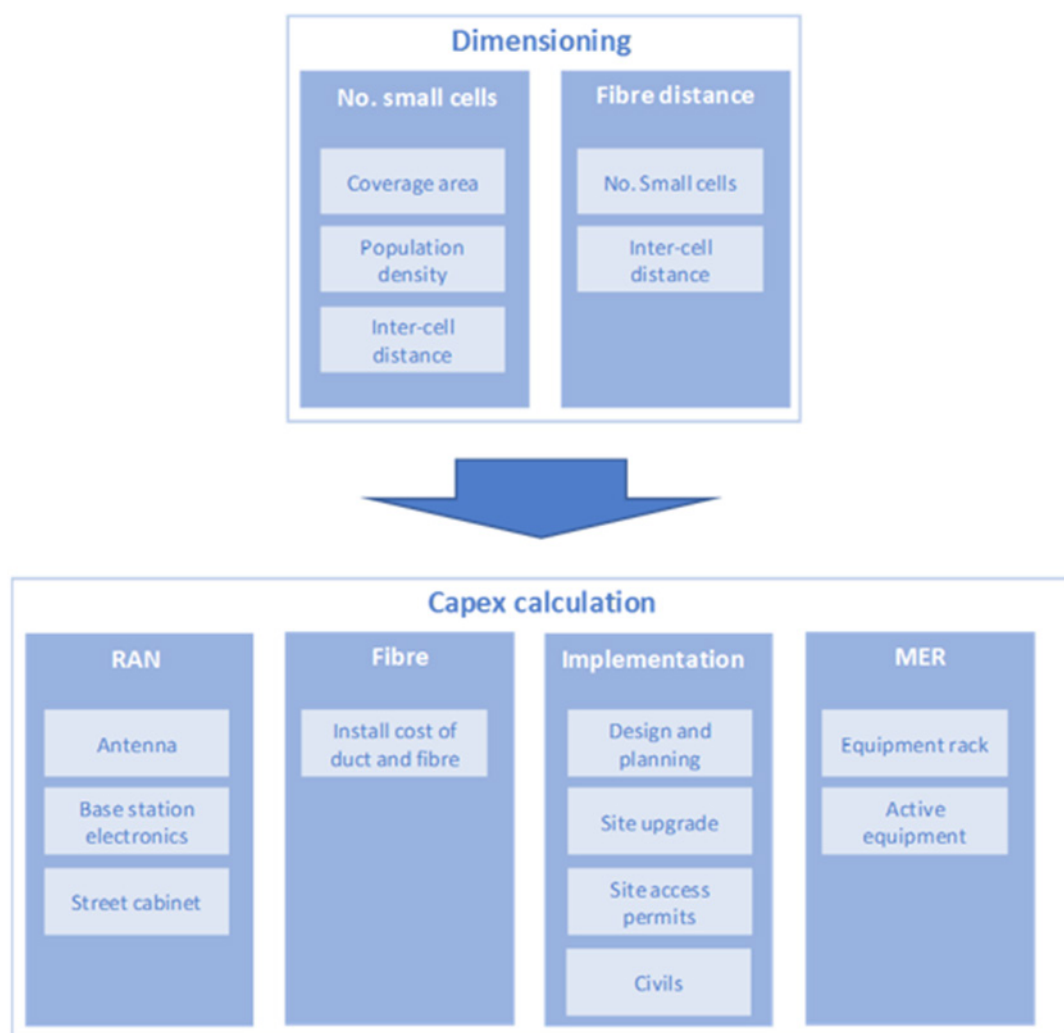
- **Antennae** – discreet high-performance antenna system which shapes the mobile operator's signal to maximize service performance for end users.
- **Street lights** – deployment of antennae on existing street lights to minimize aesthetic disruption.

- **Street cabinets** – shared accommodation hosting mobile operator radio equipment, battery backup and control equipment.
- **Fibre network** – high speed fibre 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 localized, 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 the initial capital expenditure investment of deploying a small cell network; the model only takes capital expenditure into consideration and excludes operating costs such as electricity, rent and maintenance. 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 which 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



Network dimensioning estimates the number of small cells and amount of fibre needed and are calculated based on the required coverage area, population density and intercell cell-site distances. The outputs of the dimensioning step are then used to determine the total investment CAPEX required

to implement the small cell solution for the RAN, fibre, 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.
- **Fibre network**, which includes the provision of 144 fibre 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 fibre network in a co-location site.

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

6.3 Scenarios

The above methodology is used in two scenarios to provide an estimate of the cost of deploying a fibre connected small cell solution in the central business district – scenario 1 is a large, dense city and scenario 2 is a small, less dense city. In both, 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 fibre is commercially attractive.

Scenario 1 – large densely populated city

In this scenario the following assumptions are made:

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

Scenario 2 – small medium density city

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

A larger, 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 lower in scenario 1 compared to scenario 2.

6.4 Results

Figure 9 and Figure 10 show that the CAPEX required to deploy a fibre-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 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

The total CAPEX incurred by each operator will vary according to population, population density, current 4G coverage and the proposed coverage area. In addition, the cost of fibre deployment will be lower in cities where there is a high availability of, and easy access to, dense fibre networks or ducts. Where wireless backhaul is more cost-effective than fibre, 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. Similarly, mobile operators with large spectrum assignments need not 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 implementation costs are the most significant cost element. In regions where labour costs are low, 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%
Fibre (provision of 144 fibre along the route of activated street assets)	25%	30%
MER (single rack and termination equipment)	<0.1%	<0.1%

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 fibre backhaul for sites, something AT&T has in abundance.^{1,2} 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.

¹ <https://www.rcrwireless.com/20170814/carriers/att-small-cell-cactus-antenna-concealment-tag17>

² <http://www.telecompetitor.com/cfo-extensive-fiber-assets-firstnet-give-att-an-advantage-on-5g-backhaul/>

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, built in 2020 and operated until 2030. This reduces to GBP 38 billion when infrastructure sharing is encouraged.³

Other reports estimate the cost of deploying 5G across the US as being in the order of USD 300 billion. In Europe investment costs are expected to range between EUR 300 billion to EUR 600 billion according to one mobile operator.⁴

Although these reports do not state the frequency spectrum used to derive the analysis, it is assumed that much of the cost results from network densification (through small cell deployment) – necessary for the smaller cell sizes required because of the use of higher mMWave frequency spectrum used by 5G, e.g. above 24GHz (mentioned in Section 3.5).

6.6 Investment models

Given the considerable CAPEX investment required in deploying 5G, operators face major challenges in making the investment case for 5G. Policy-makers will need to consider alternative investment models (for example PPPs, loans, challenge funds and investment vehicles) to ensure high upfront CAPEX costs are not a barrier for wireless providers.

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

Other approaches include offering grants to local authorities, as in the UK, to construct and upgrade passive assets (such as ducts, fibre networks, data centres, street furniture, etc.). Governments can also offer low-cost loans to operators 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 then support operator network expansion programmes.

Many other PPP models for incentivizing investment in telecom networks do exist and have been written about extensively.⁵

Not all 5G deployments require government intervention. Some small cell and pre-5G deployments to date have been privately financed, as demonstrated in previous sections.

³ <https://www.itrc.org.uk/wp-content/PDFs/Exploring-costs-of-5G.pdf>

⁴ <http://www.lightreading.com/mobile/5g/how-much-will-5g-cost-no-one-has-a-clue/a/d-id/733753>

⁵ “Investment strategies for broadband deployment and access to the digital economy”, ITU, 2016

7 Conclusion

Until the investment case for 5G is compelling, the industry and policy-makers should approach 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 such benefits, care must be taken in establishing the commercial case and whether 5G is a real priority for the economy. A 5G investment decision must be backed by a sound investment case.

Operators are sceptical about the return on investment because of high investment levels. They are currently investing in 5G test beds and pilot networks in large dense cities with advanced 4G deployments and with supporting infrastructure more suited to network economics.

This 'city led' strategy is likely to have an adverse impact on the digital divide since the case for 5G in rural areas is less convincing. Local authorities and regulators should recognize this risk and should counter it. This can be done by supporting commercial and legislative incentives to stimulate investment for the provision of fibre networks and affordable wireless coverage through the use of sub-1 GHz bands.

An overhaul of the regulatory, government and local authority approach to digital policy is needed to boost the roll-out of 5G networks. Importantly, this includes ensuring affordable access to public assets thereby strengthening the commercial case to invest in small cell infrastructure and 5G spectrum.

Annex A

In preparation for WRC-19, ITU-R is undertaking sharing and compatibility studies in the frequency bands agreed at WRC-15, and which could potentially be identified for implementation of IMT-2020 (5G).

ITU-R Study Group 5

ITU-R Study Group 5 (Terrestrial systems) is responsible for the overall radio system aspects of IMT systems and for 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 – assisting 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 – including studies of several radiocommunication solutions, such as satellite communications, the use of high speed radio relays and high-altitude platform stations (HAPS).

ITU-T Study Group 13

ITU-T Study Group 13 (Future networks) is ITU’s lead group for 5G wireline studies and 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.

ITU-T Study Group 15

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-fibre (RoF) technologies and their applications” provides general information on radio over fibre 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 Fibre 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)
- Draft Recommendation ITU-T G.ctn5g: Characteristics of transport networks to support IMT-2020/5G (under development)
- Draft Supplement to G-series Recommendations G.Sup.5gotn: Application of OTN to 5G transport (under development)
- Recommendation ITU-T G.695: Optical interfaces for coarse wavelength division multiplexing applications
- Recommendation ITU-T G.698.4: Multichannel bi-directional DWDM applications with port agnostic single-channel optical interfaces
- Recommendation ITU-T G.959.1: Optical transport networks physical layer interfaces

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

ITU-T Study Group 12

Related work underway in ITU-T Study Group 12 (performance, quality of service, quality of experience), includes:

- Draft Recommendation ITU-T G.IMT2020: QoS framework for IMT-2020. Review of SG12 QoS frameworks in the context of IMT-2020.
- Draft Recommendation ITU-T Y.cvms: Considerations for realizing virtual measurement systems. As network service providers seek to take advantage of the scale, flexible deployment, and cost reductions first realized in cloud computing, they have begun to define new architectures for their infrastructure in order to realize network function virtualization (NFV). At the same time, measurement functions will be implemented for deployment as virtual functions. This

document makes recommendations in key areas such as on-demand deployment and accuracy considerations. Development of virtualized measurement systems in areas highly relevant to SG12 work are in the early stages, so this Recommendation is timely.

- Draft Recommendation ITU-T G.QoE-5G: Quality of experience (QoE) factors for new services in 5G networks.

In addition, SG12 is developing Recommendations concerning the quality of experience of augmented reality (AR) and virtual reality (VR), which are among the most talked about 5G use cases.

ITU-T Study Group 11

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 BNG architecture, needed to achieve outstanding benefits like easy deployment of network services, fine grained network services, etc.

ITU-T Study Group 5

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 “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://itu.int/en/publications/Documents/tsb/2017-IMT2020-deliverables/mobile/index.htm>

The preparatory work of ITU-T for the introduction on IMT-2020 is depicted in the “5G Basics flipbook, 2017”:

<https://itu.int/en/publications/Documents/tsb/2017-IMT2020-deliverables/mobile/index.htm>

See ITU-T webpages at: <https://itu.int/en/ITU-T/>

International
Telecommunication
Union
Telecommunication
Development Bureau
Place des Nations
CH-1211 Geneva 20
Switzerland

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