arcep autorité de régulation des communications électroniques et des postes

RÉPUBLIQUE FRANCAISE

5G: ISSUES & CHALLENGES

March 2017

The issues and challenges surrounding 5G

The telecoms industry is currently in the process of designing the technologies that are due to take over from 4G, which is still being deployed today. A great deal of work is thus underway to prepare these “5G” technologies.

To prepare for the arrival of this new generation of technologies, Arcep wanted to take a detailed look at the industry to better understand what is in the works. This report is the fruit of the interviews and research that Arcep conducted over the course of 2016, and which the Authority wanted to publish as a way to contribute to the public debate over 5G.

Its aim it to provide as objective and exhaustive an overview as possible, and deliver a concise, informative snapshot of the work that is currently underway on the future generation of mobile networks.

This report reflects the views of the stakeholders who were interviewed, but in no way represents Arcep’s positions on or roadmap for 5G. Arcep awarded in 2015 the 700 MHz band and is currently working towards licensing the 3.5 GHz band, both of which have been identified as 5G bands. Arcep is also working with the Direction générale des entreprises and the Agence nationale des fréquences towards enabling spectrum for 5G.

Arcep would like to thank all of the entities (listed on the last page) who agreed to take part in this process, and who were willing to contribute to the regulator’s investigation into the development of 4G’s successor. Arcep is dedicated to sustaining an ongoing dialogue with the market, and invites all interested parties to provide information on the matter or to share their reactions to this report, by contacting Arcep’s Mobile and Innovation Directorate at the following address: 5G@arcep.fr.

Table of Contents

Introduction: the vision for 5G, creating an ultra-connected society

5G wants to be the disruptive generation, the generation that no longer only caters to the needs of mobile operators and consumer communications, but which opens up new prospects and enables an extremely wide diversity of applications and use, unified within a single technology. 5G is setting itself up as an enabler of the digitisation of society and the economy.

The idea that is starting to take shape behind the notion of 5G is that it will not mean just an increase in transmission speeds, as has been the case with previous generations.

Consumer mobile communications, video downloads and the use of mobile apps account for the bulk of 4G networks' radio resources usage today. With 5G, the goal will be to enable a much broader spectrum of uses and a much greater diversity of users.

5G is targeting a wide variety of sectors, which will not necessarily have anything other than this technology in common, but which are central pillars in a society: energy, healthcare, media, industry and transportation.

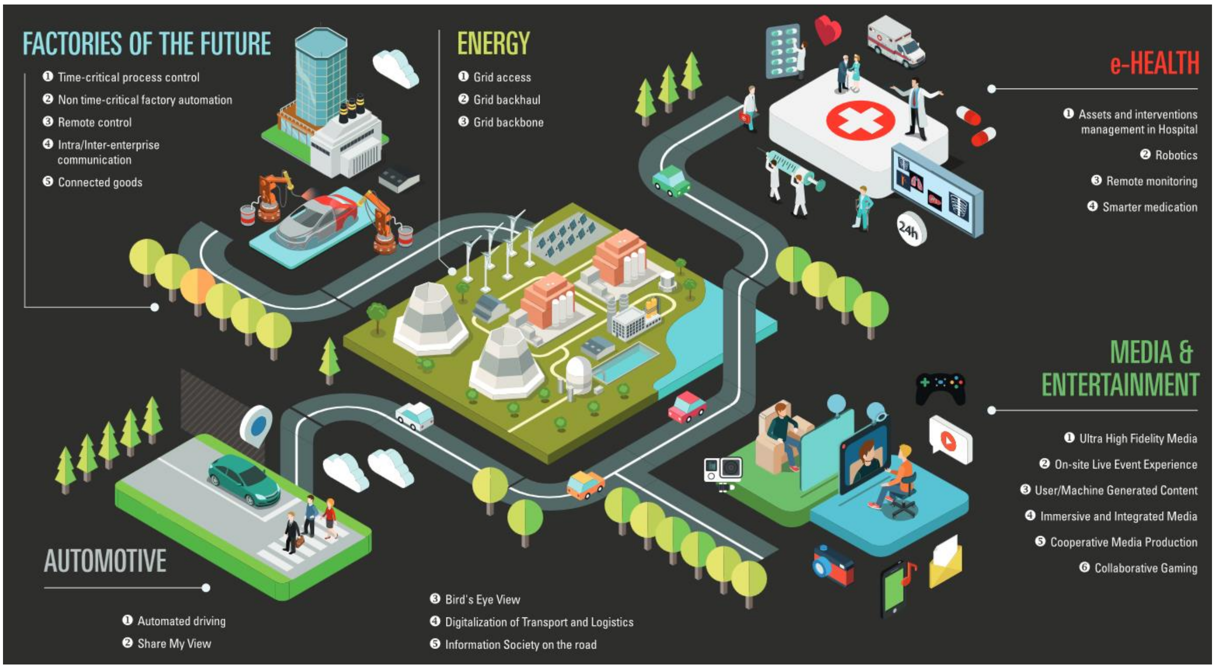


Figure 1. 5G driving industrial and societal changes[1]

The energy sector, for instance, has undergone a great many changes and developments over the past several years in terms of energy production, storage and transport. Rising fossil fuel costs, the introduction of renewable energy sources and markets being opened up to competition have all helped usher in new kinds of energy product and new stakeholders – both independent companies and ordinary citizens – to the energy marketplace. The objective with 5G will thus be to enable better management of these networks (smart grids, smart agriculture, factories of the future) and their interconnections, to achieve more efficient and more agile distribution.

[1] 5G Empowering vertical industries. White Paper, 2016, https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

Healthcare, transportation and media are sectors that are bound up with our fellow citizens' daily lives: any improvements in these sectors thus have a clearly visible impact. The introduction of robots to perform specialised surgical operations, of video on demand or the advent of new connected features in cars have already improved our daily lives. 5G is promising to go several steps further in all of these areas: it would enable remote medical diagnoses and operations in real time, it would democratise streaming of 360° 3D video, it would provide users with a vast selection of video content with a picture quality better than ultra high-definition (4K, 8K…). The automotive universe could rely on these new networks to help cars make decisions without human involvement, and also communicate with one another (this is already possible, for instance, with the first experimental fleet of fully autonomous taxis being tested on the streets of Singapore by the firms nuTonomy and Grab[2]), with reaction times that are compatible with the demands of high-speed travel.

In terms of factories of the future, the improvements brought by 5G are primarily targeting the introduction of new generations of connected robots, the interconnection of production sites and the much heavier use of smart sensors to improve industrial processes. Generally speaking, the aim is to achieve ubiquitous communication between machines, a process that is already well underway.

One thing that it is crucial to understand, through the few examples listed above whose demands might seem mutually incompatible, is that depending on the sector or the application, the network properties and the functionalities required will not be the same. Service providers – whether they are today's mobile operators or other market players – will need to be capable of adapting their network to demand, occasionally in real time. 5G will thus be not so much a universal technology as a polymorphous, or multi-faceted technology, capable of adapting to any use, up to and including the most demanding ones.

[2] http://nutonomy.com/

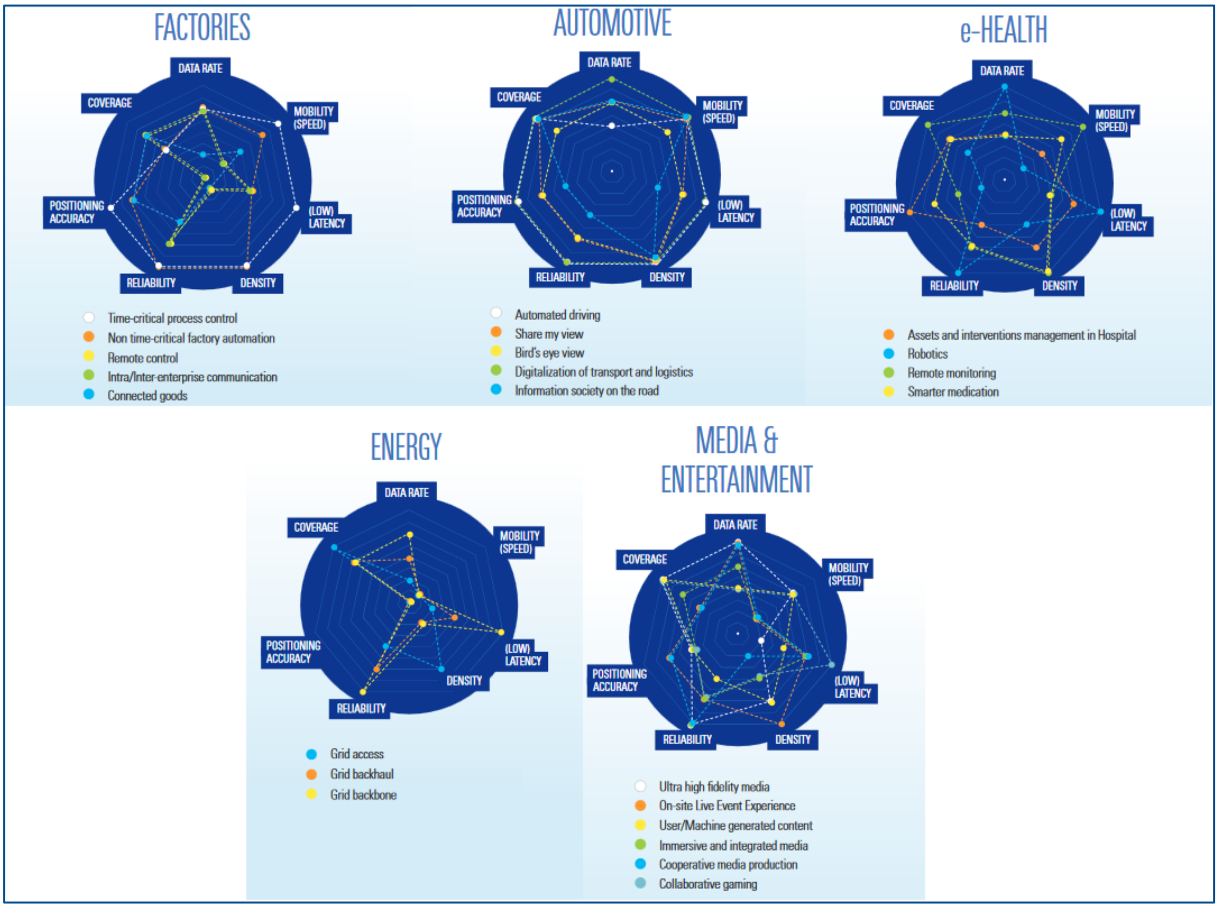


Figure 2. Performances required by vertical sectors[3]

[3] 5G Empowering vertical industries. White Paper, 2016, https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

1 5G objectives

Ever since the first real mobile telephone call, 44 years ago[4], mobile technologies have been evolving steadily and their performances have improved exponentially: as mentioned earlier, calling services and later texting and finally the mobile internet and the use of multi-service mobile applications have characterised the evolution of mobile networks and the transition from one generation to the next. The birth of LTE technology and the fourth generation (4G), coupled with the widespread use of smartphones and tablets, have driven a massive increase in the amount of mobile data traffic being relayed over the networks.

The use of a mobile handset and its applications is now an integral part of our fellow citizens' daily habits. Portable connected devices are increasingly powerful: in many instances they have replaced users' landline telephones, cameras, computers and even televisions. Today, 5 million videos are watched on YouTube and 67,000 images uploaded to Instagram every minute (see Figure 3).

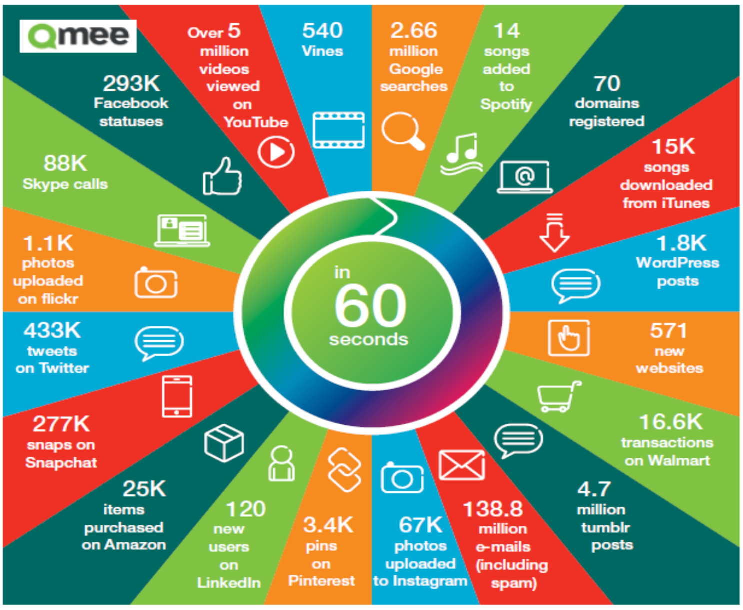


Figure 3. What we do over the network today in one minute[5]

The latest *Mobility Report*[6] from Ericsson indicates that traffic on mobile networks almost doubled in a single year, and that over the next five years it will have increased to 10 times what it is today. New solutions must therefore be found to meet this demand, and to optimise how resources are used.

The increase in the number of applications available, their diversification and the improved quality of mobile networks have all contributed to driving up demand, the emergence of new uses (connected objects, drones, etc.) and new users.

[4] On 3 April 1973, Motorola's Martin Cooper made a call from the corner of 56th street in New York City with the first mobile phone.

[5] https://www.ericsson.com/res/docs/2014/5g-what-is-it-for.pdf

[6] https://www.ericsson.com/assets/local/mobility-report/documents/2016/ericsson-mobility-report-november-2016.pdf

5G is at the crossroads of these news uses; it aims to better and simultaneously satisfy this tremendous variety of needs and these new demands, through a unified technology that takes this diversity into account at the design stage.

The advent of 5G could have a significant impact not only in the technical realm, but also on different countries' economic and social development. As indicated in the introduction, 5G targets a very large number of sectors and, through society's digitisation, is expected to contribute to countries' economic growth.

To give an example, according to a report produced by InterDigital Europe, Real Wireless, Tech4i2 and Connect (Trinity College Dublin)[7], this new technology will require a great deal of money and a great deal of work, but will generate €113.1 billion in profits per annum for the European economy by 2025.

1.1 Technical specifications of 5G

The specifications for a new generation of mobile telephony are set primarily by two bodies: ITU (International Telecommunication Union) and 3GPP (3rd Generation Partnership Project).

ITU is the United Nations agency devoted to information and communications technologies. It carries out research and studies through its Working Party 5D, the sub-group responsible for the overall radio system aspects of international mobile telecommunications (IMT). In 2013, this group began working on defining the characteristics of the new IMT standard, IMT-2020 (5G) (cf. 1.3), as it had done back in the early 2000s to define 4G (IMT-Advanced). Further details on the roadmap established for this work can be found in Annex 1, the objective set by ITU-R being to complete its analyses by 2020.

Parallel to the work being done by ITU are the studies being conducted by 3GPP. The 3rd Generation Partnership Project was created in 1998, and its members include seven standardisation bodies, several hundred industry players, associations and public organisations. It is responsible for developing and maintaining technical specifications for mobile telephony standards[8]. When a new standard is being defined by ITU, 3GPP works on the technical solutions that make it possible to achieve the objectives set by ITU.

Although 5G is one of the most widely debated topics inside international and European bodies today, no standard has yet been defined by 3GPP. The draft of Release 15, the first 5G standard from 3GPP, is still in the works: definition of the new architecture began in December 2016 and work on the New Radio (NR) interface is set to begin in March 2017. A first Release of the standard should be validated in September 2018 to meet the more urgent demands; a second Release (3GPP Release 16) will then be published in March 2020. All of these elements are addressed in more detail in Annex 1.

It should also be said that the transition from one generation to the next takes place gradually. LTE will continue to evolve alongside NR, and these two standards will likely be very complementary initially. In particular, for pioneer 5G rollouts LTE shall probably remain the master of the network and control the NR antennae. Moreover, some of the objectives set for 5G could be achieved thanks to functionalities or technologies introduced in 3GPP Releases 13, 14 and 15 that will not be proper to 5G, but rather evolutions of 4G (which some refer to as 4.9G or LTE Advanced Pro).

[7] http://ir.interdigital.com/file/Index?KeyFile=36051369

[8] GSM for 2G, UMTS for 3G and LTE for 4G

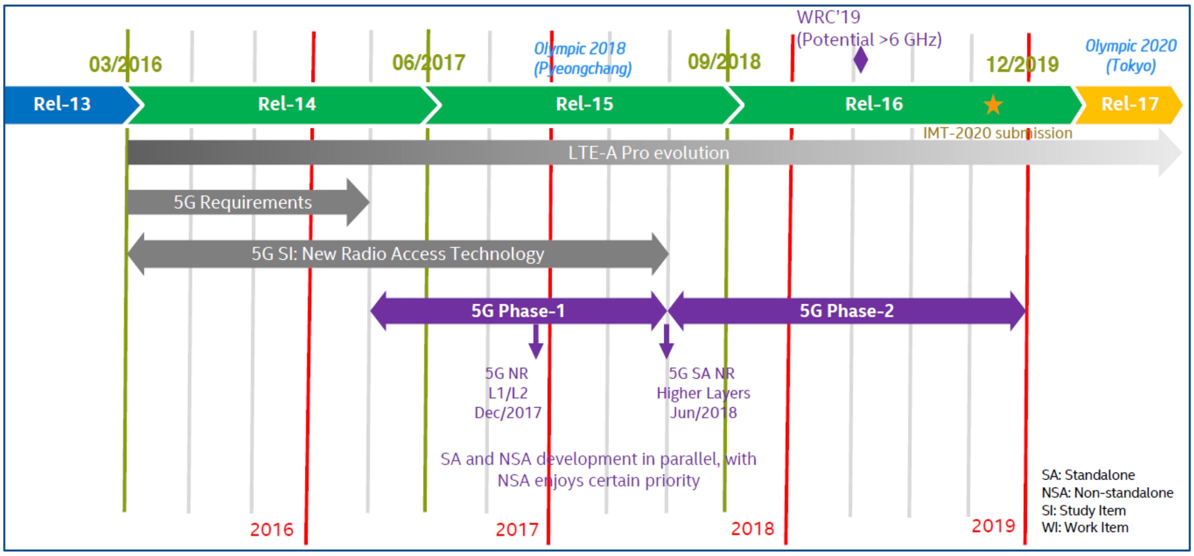


Figure 4. 3GPP timeline for 5G[9]

This same momentum occurred when making the transition from 3G (Release 4) to 4G (Release 10, first Release of IMT-Advanced): the first LTE specifications (Releas*es* 8 & 9) do not achieve all of the ITU targets for 4G, and reprised many of the characteristics of the most advanced form of 3G at the time.

The synergies between the successive generations, the absence in most instances of a great initial jump in performances between generations, and the race between competitors to outperform one another and be the most innovative, can often lead operators and equipment suppliers to give a "commercial" name to each generation of mobile telephony. For instance, in the United States AT&T had called its HSPA network 4G, while in France it is a 3G+ network.

So in all likelihood the first 5G networks deployed on a large scale will be 4.9G systems, using carrier aggregation, massive MIMO (Multiple-Input Multiple-Output) and Network Function Virtualization, or NFV (cf. trials conducted in in France, detailed in Section 1.5.3). These technologies, which will be explored in greater detail further on, represent more of an evolution of the fourth generation than an actual transition to 5G, which will occur when disruptive technologies such as NR carriers in millimetre bands, non orthogonal multiple access (NOMA*)* and mobile edge computing (MEC) can be put into place.

In addition to this commercial race, equipment suppliers – often backed by their respective government at home, notably in the United States, Japan and South Korea – want to get a head start in defining and testing 5G technologies, in the hope of establishing themselves as the technological leaders in international standardisation bodies. Here, the precocity of the first rollouts announced in South Korea (5G deployment for the Winter Olympics in 2018 in Pyeongchang) and Japan (5G deployment for the Summer Olympics in Tokyo) would justify the supposition that only a small portion of 5G technologies will be used, and that these rollouts will be based more on 4.9G or pre-5G technologies.

[9] http://gsacom.com/paper/intel-5g-technology-mm-wave-frequencies/

1.2 5G use cases

Three main use cases (defined by ITU, under IMT-2020), with their respective – and potentially mutually incompatible – demands are in the process of taking shape, and will make it possible to meet the sector-specific needs referred to in the introduction.

1. **mMTC – Massive Machine Type Communications**: A very large number of connected devices with disparate quality of service requirements. The objective of this category is to provide a response to the exponential increase in the density of connected objects;
2. **eMBB – Enhanced Mobile Broadband**: ultra high-speed connection indoors and outdoors, with uniform quality of service, even on the edges of a cell;
3. **uRLLC – Ultra-reliable and Low Latency Communications**: this use case has stringent requirements for capabilities such as latency and packet-loss, to ensure increased reactivity.

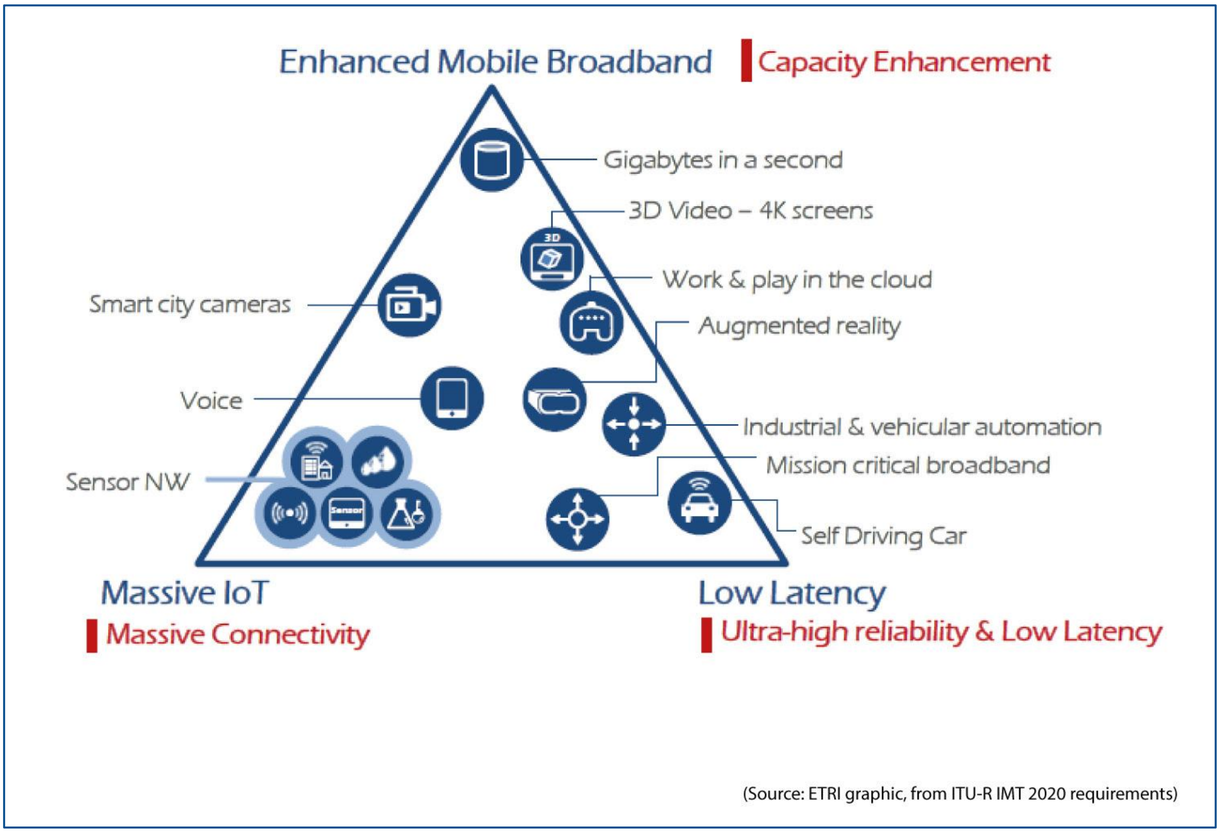


Figure 5. 5G use cases[10]

The first group (mMTC) primarily encompasses all Internet of Things related uses. These services require broad coverage, lower energy consumption and relatively slow transmission speeds. What 5G will deliver compared to existing technologies is the ability to connect objects that are spread out in a very dense fashion across a given area.

Enhanced mobile broadband (eMBB) concerns all of the applications and services that require increasingly fast connections, for instance to watch ultra high-definition (8K) videos or to stream virtual or augmented reality applications wirelessly.

[10] http://5g.ieee.org/standards

Ultra-reliable and Low Latency Communications (uRLLC) include all of the applications that require an extreme reactivity and very strong message transmission guarantees. The sectors where these requirements are particularly prevalent are transportation (reaction time when an accident occurs, for instance) and medicine (telesurgery), and when digitising manufacturing processes in general.

To implement these three use case, ITU established eight key performance indicators[11] (KPI) to specify, quantify and measure the characteristics of IMT-2020 (5G) systems:

- Peak data rate (Gbit/s);
- User experienced data rate (Mbit/s);
- Spectrum efficiency (bit/Hz);
- Device mobility (km/h);
- Latency (ms);
- Connection density (number of connected/accessible objects per km²);
- Network's energy efficiency;
- Area traffic capacity (Mbit/s/m²).

[11] Added to these eight classes, five new indicators were defined and are currently being examined: reliability, mobility interruption time, bandwidth, maximum spectrum efficiency, 5th percentile spectrum efficiency.

1.3 Jump in performance compared to 4G networks

As mentioned in Paragraph 1.1, the deployment of 5G is likely to take place in two stages:

1. The first 5G rollouts will deliver better performances, but as a continuation of what is being provided at the time by 4G systems which will continue to evolve as well (4.5G, 4.9G);
2. Performances will continue to improve with the gradual introduction of disruptive technologies, such as the use of millimetre wave frequencies.

This gradual rollout is very similar to the way in which 4G was introduced, as the performances obtained with pioneer deployments were relatively similar to those supplied by existing 3G networks.

ITU defines the 4th generation of technologies, called IMT-Advanced, by the values for the eight KPI listed above, as indicated in the following chart. The 5th generation, called IMT-2020, is represented as well. Here, it should be noted that the official ITU definition of 4G in fact corresponds to what commercial rollouts supplied later on, under the name 4G+ or LTE-Advanced.

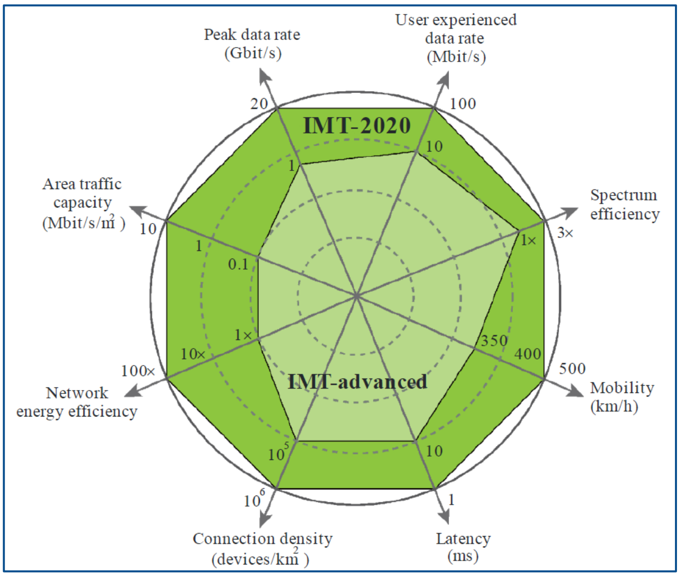
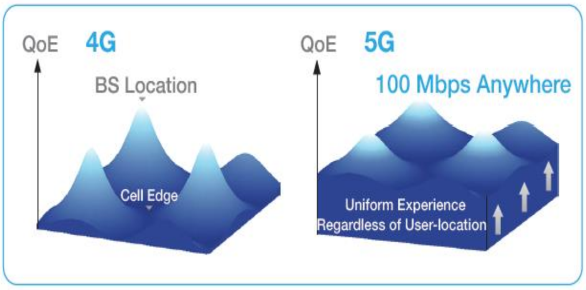


Figure 6. Comparison between 4G and 5G with respect to the eight key performance indicators[12]

According to these objectives, 5G must be able to provide a user experienced data rate and a peak data rate that is respectively 10 and 20 times higher than what is currently available. The maximum connection density will be multiplied by 10 and latency divided by at least 10 (the target point-to-point latency is 1 ms, compared to 30 to 40 ms today).

[12] Recommendation ITU-R M.2083-0 (09/2015), https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf



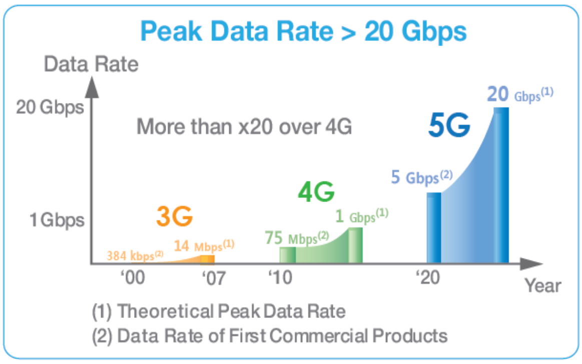


Figure 7. Representation of the "average user experience data rate" KPI for 4G and 5G and "Peak data rate" KPI for 3G, 4G and 5G[13]

As the successor to 4G, the objective for 5G will also be to provide:

- An extremely reliable network, with more consistent performances regardless of the user's position with respect to the base station;
- A stable connection, even when travelling (at speeds of up to 500 km/h);
- Greater network energy efficiency (with batteries that consume up to 100 times less power).

The following table summarises the target performances for 5G and those currently available with 4G:

Performances/Generation	4G	5G
1. Peak data rate (Gbit/s)	1	20
2. User experience data rate (Mbit/s)	10	100
3. Spectrum efficiency	1x	3x
4. Speed (km/h)	350	500
5. Latency (ms)	10	1
6. Connection density (number of objects/km²)	10^5	10^6
7. Network energy efficiency	1x	100x
8. Area traffic capacity (Mbit/s/m²)	0.1	10

Table 1. Comparisons between 4G and 5G performances

13 http://www.samsung.com/global/business-images/insights/2015/Samsung-5G-Vision-0.pdf

1.4 Network slicing and software-defined networks

It is vital to understand that the set of indicators listed in Section 1.3 determine a set of peak performances for 5G. It will not, however, be possible to achieve all these peak values simultaneously: not every requirement or use case is compatible, so a trade-off will need to be made when defining categories of use that each have their own performance envelope, notably for the use cases described in Section 1.2 (mMTC, eMBB and uRLLC). This is the principle of network slicing: each slice has its own set of KPI, which is a trade-off tied to the target use. On a 5G system, the network properties will need to adapt to the chosen environment.

The following diagram positions the three main use cases listed in Section 1.2. with respect to the eight key performance indicators listed above.

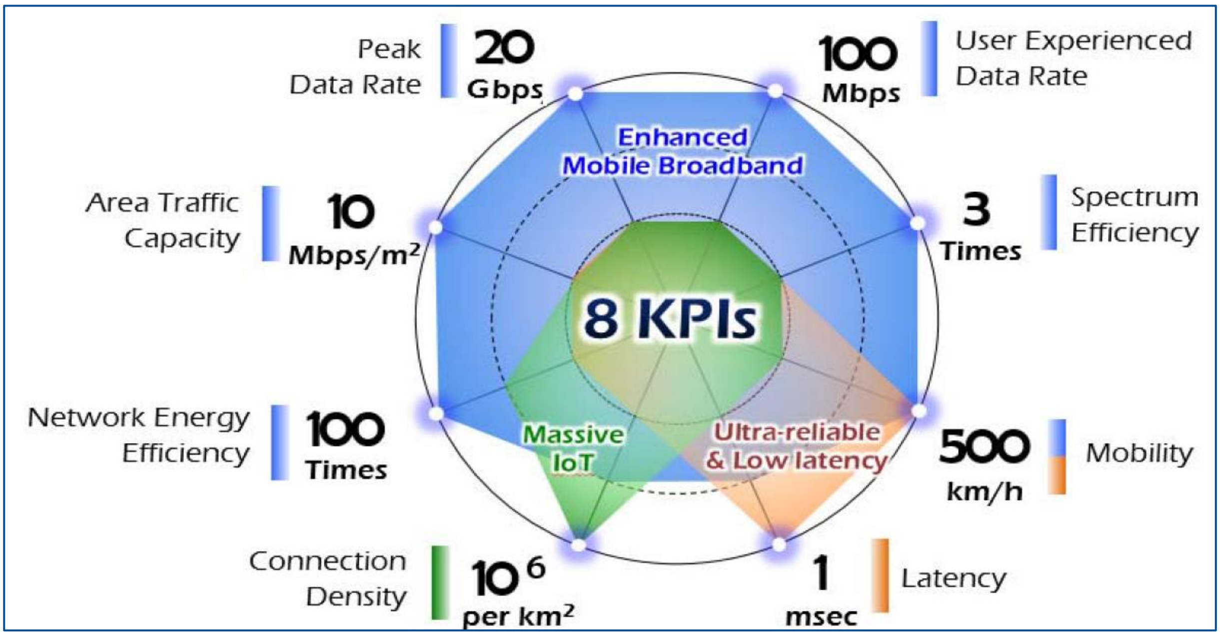


Figure 8. Key performance indicators for the three 5G use cases[14]

So for applications that require enhanced mobile broadband (eMBB), such as 4K, 8K or 3D video or virtual reality, a certain number of performance indicators, such as spectrum efficiency, peak data rate and area traffic capacity, can be reached only at the expense of others, such as latency or connection density.

On the flipside, when a massive simultaneous connection of connected objects (mMTC) needs to be managed, the network will concentrate its resources and use the technologies required to achieve this task, but will not be able, for instance, to use spectrum as efficiently or to guarantee low latency.

Lastly, when ultra-reliable and low latency communications (uRLLC) are required, the number of simultaneous connections, data rates and spectrum efficiency may be reduced.

This flexibility, or ability to adapt, that network slicing brings can only be achieved thanks to the softwarisation and virtualisation of a sizeable number of network components (cf. 1.5.2) – a process referred to as Software-Defined Networking (SDN) and Network Function Virtualisation (NFV). Behind these acronyms is a common idea, namely to use as many generic and reconfigurable components as possible, rather than bespoke ones that are permanently dedicated to very specific

[14] https://5g-ppp.eu/wp-content/uploads/2016/11/06_10-Nov_Session-3_Lee-JunHwan.pdf

tasks. This evolution towards software-based systems has been in the works for several years, but is now becoming possible thanks to improved performances from all of these reconfigurable components, including those that are the closest to the elementary tasks of wireless communications (detection, baseband coding, bitstream management, frequency handover, signal processing, etc.).

1.5 Technological building blocks to achieve the objectives

1.5.1 Air interface

Several, sometimes competing radio access technologies are currently being examined. Some have already been pre-implemented by equipment manufactures and can be used in trials, notably massive MIMO and NFV. Others, such as NOMA modulation and mobile edge computing (MEC), will no doubt take longer before they are ready to be used. In any event, a consensus – which could be painful for certain suppliers whose investments will be lost – will need to be found when defining 5G standards, to ensure the systems' interoperability.

The technologies currently being examined are the following:

- **Millimetre wave frequencies**: the use of millimetre wave frequencies constitutes one of the disruptive 5G technologies. The term refers to the frequencies above 6 GHz which have never been considered for mobile fronthaul network rollouts, for reasons of technological maturity and propagation quality. To meet the demand for ever increasing data rates and traffic volumes, new bands with very wide channels (over 100 MHz per user) will need to be employed: millimetre wave frequencies could provide this spectrum resource, and in certain cases their use would make it possible to achieve the data rates listed in Table 1. Comparisons between 4G and 5G). In exchange, to be able to use these frequencies all of the required, miniaturised low-cost technologies will need to be developed, and ensure a level of energy consumption that is compatible with portable devices (amplifiers, coders, signal processing, antennae, etc.). In particular, because of millimetre waves' poor propagation quality, each cell will have limited coverage and so require the use of beamforming (described below) to better focus the power transmitted by the antenna.
- **Massive MIMO** (Multiple Inputs – Multiple Outputs): this technology involves the use of a large number of smart micro-antennae, located on the same panel (between eight and 128 today, but the number will increase with the use of frequencies above 6 GHz). The appeal of using massive MIMO is twofold: first, the technology makes it possible to increase data rates, thanks to spatiotemporal multiplexing; second, it makes it possible to focus energy on a device to improve its link budget, thanks to beamforming.

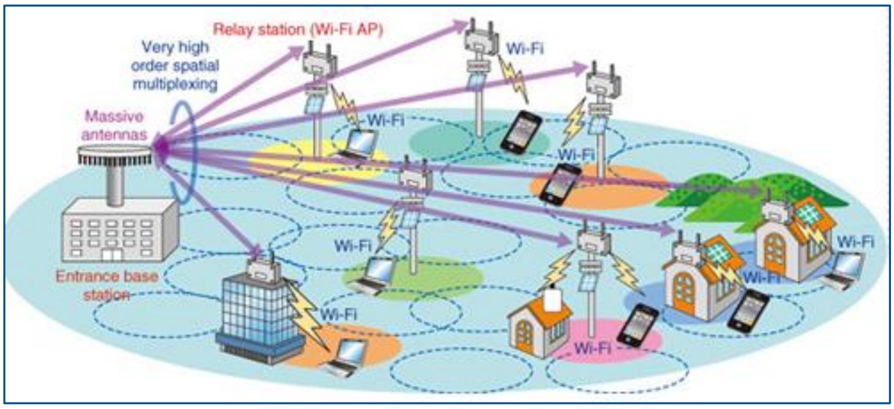


Figure 9. Example of the use of a beamforming antenna to connect Wi-Fi access points[15]

- **Full Duplex**: in classic systems, transmission and reception takes place either on different frequency bands, i.e. frequency division duplexing (FDD) used on all mobile network bands in France, or at different times: time division duplexing (TDD), the top contender for LTE wireless local loop networks in France. The full duplex is intended to enable the simultaneous transmission and reception of data, on the same frequencies, at the same time and in the same location.[16]

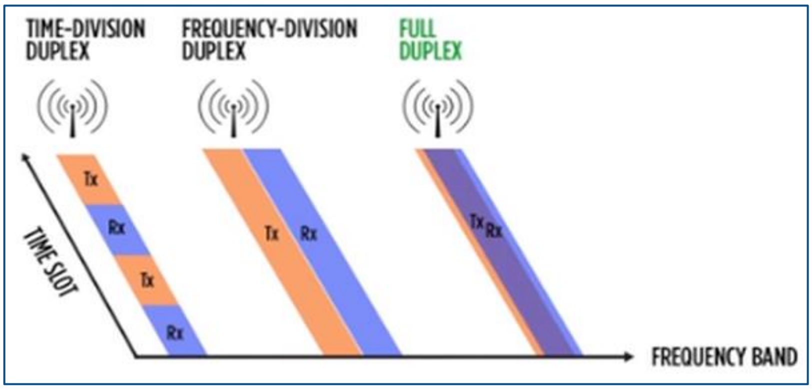


Figure 10. Illustration of full-duplex, compared to FDD and TDD[17]

- **NOMA Multiplexing** (Non Orthogonal Multiple Access): LTE uses what is referred to as orthogonal multiplexing, with each device using a portion of the resource blocks in a unique fashion at any given time. For 5G to provide improved spectrum efficiency compared to 4G, the plan is to use non-orthogonal multiplexing methods, whereby several users can use the same frequencies at the same time. A distinction can be made between several users by assigning different codes to each user – referred to as SCMA or sparse code multiple access – a combination of 3G's code division multiple access (CDMA) and 4G's orthogonal frequency

---

[15] https://www.slideshare.net/100001290086432/massive-mimo

[16] The basic operating principle is the following: an antenna sends a signal at the same time as it is receiving signals coming from devices in the cell. However, the signal received by the antenna is a combination of the signal sent by itself and signals coming from the devices (everyone is "talking" at once). As it knows which signal it itself has sent, the antenna can subtract it during digital processing from the ones it received. So only the signals received from the devices remain.

[17] http://compeng.columbia.edu/biggest-component-full-duplex-wi-fi-radio-antenna

division multiple access (OFDMA) or by playing on the difference in users' signal to noise ratios (power domain NOMA[18], illustrated below). These are the two methods chosen for NR.

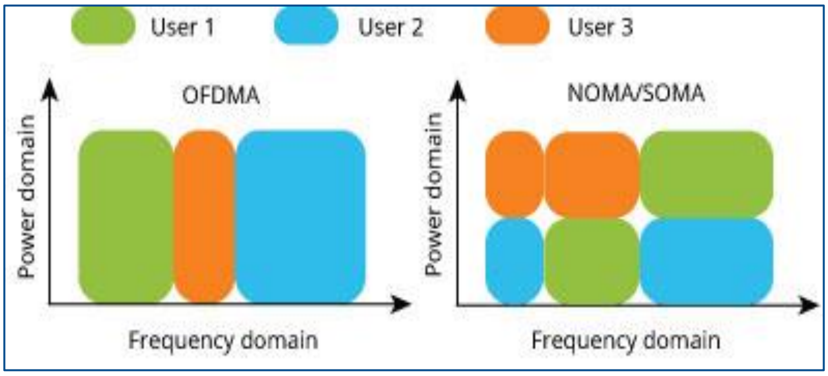


Figure 11. Illustration de multiplexing *power domain* NOMA[19]

- **QAM256**: as with many modern communication systems, 4G uses quadrature amplitude modulation (QAM). In 4G this modulation can achieve QAM64, which means that six bits of information are being transmitted ($2^6 = 64$) at any given time. On wireless systems, the main limitation on QAM order is the signal to noise ratio: when a large amount of information is sent all at once, its transmission will be very sensitive to disruptions (a bit like trying to talk in a noisy environment: it is easy to understand "yes" or "no" but harder to understand more complex sentences). Thanks to an improved link budget, via antenna or signal processing technologies, 5G modulation could reach QAM256, i.e. eight bits of information being transmitted at any given time, which translates into a 33% increase in maximum capacity under ideal conditions. This improved modulation will also be deployed on advanced 4G systems.
- **IoT waveforms**: new waveforms are being explored for the future deployment of 5G IoT in mobile bands. But although mass market IoT is one of the main challenges put forth for 5G, no concrete results have yet been made public. Operators[20] are starting to deploy new standards (EC-GSM or Extended Coverage GSM, LTE-(e)MTC or enhancements for Machine-Type Communications, NB-IoT or NarrowBand IoT) which were defined by 3GPP in Release 13 but, as they are based on 2G and 4G, they do not deliver the performance levels, notably in terms of autonomy, coverage and density, that are compatible with the targets set for future 5G networks.

1.5.2 Network architecture

As with air interfaces, new network architectures are also being explored:

- **Software-defined networking (SDN) and network functions virtualisation (NFV)**: these two functionalities extend beyond the scope of 5G networks per se. They are part of an overall

[18] The basic operating principle is the following: either User 1 (U1) with a good signal to noise ratio and User 2 (U2) with a less good signal to noise ratio. The antenna sends a high power Signal 2 to U2, and superimposes a weaker Signal 1 aimed at U1. U2 will only see S2 as S1 is drowned out by the noise. U1 will decrypt S2 then delete it from the signal received, to create a higher quality S1, thanks to a better signal to noise ratio.

[19] https://www.anritsu.com/en-AU/test-measurement/technologies/5g-everything-connected/5g-everything-connected-detail

[20] http://www.vodafone.com/content/index/what/technology-blog/nbiot-commercial-launch-spain.html

process of network upgrades taking place today and already available with 4G technology (4.9G). The nevertheless remain a key enabler of 5G:

- SDN (Software-Defined Network) is designed to disassociate the network's control plane from its data plane, these two planes traditionally being linked and distributed in a set fashion in the network (see diagram below). Controlling the network, a task previously assigned to specialised and unscalable hardware components, is centralised in the form of software on more powerful servers and, in theory, free of equipment manufacturer specifications. This enables the deployment of high value-added services (load balancing, smart routing, dynamic configuration, etc.) in disparate environments.

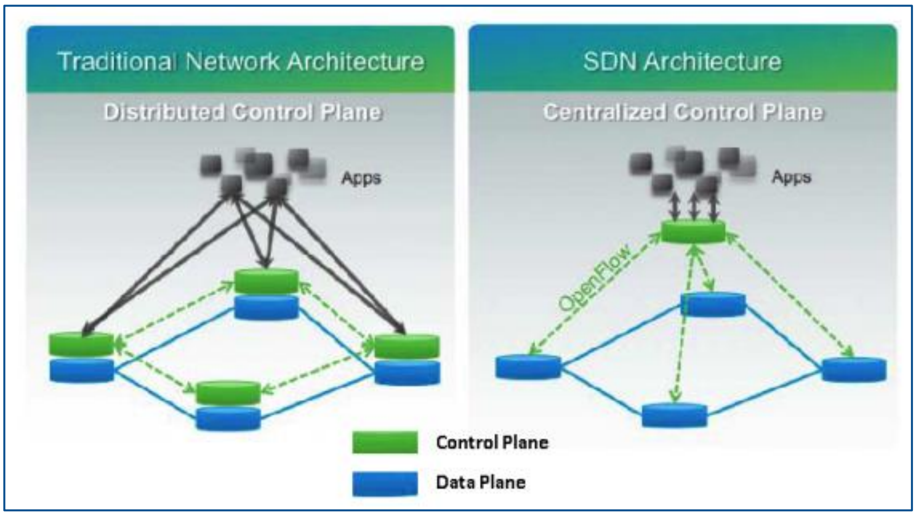


Figure 12. Centralisation of the control plane in a software-defined network[21]

- NFV, which builds upon SDN, is used to virtualise, in other words to replace hardware designed specially to perform certain key network functions (firewall, network core, interfaces between different systems…) with software on a server, to accelerate rollouts and enable rapid changes and upgrades.

- **CloudRAN**: this functionality, also know as centralized-RAN, requires a very different network architecture to what we find today. It is an evolution of SDN: the base stations' signal processing units, currently installed at the base station level, are moved to the cloud and centralised. They communicate with the network radio heads, located closer to the antenna, over an optical fibre network (Radio over fibre technology). This centralisation makes it possible to obtain a complete overview of all of the stations deployed and to coordinate signal processing and manage interference between cells and devices

[21] http://www-igm.univ-mlv.fr/~dr/XPOSE2014/software-defined_networking/sdn.html

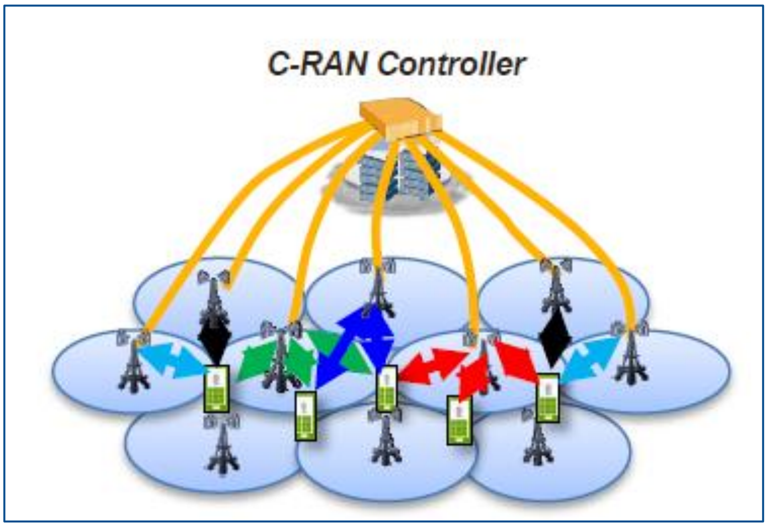


Figure 13. Illustration of CloudRAN[22] network architecture

- **Optimised content delivery, using a mobile content delivery network (mobile CDN)**: corresponds to a set of servers working together in a transparent fashion to optimise the delivery of content to end users over wireless (mobile or Wi-Fi) networks, with high availability and performance. With 5G, the objective for these CDN is to cache content close to users, notably thanks to predictive algorithms, to offload traffic from the networks and decrease latency.
- **MEC (mobile edge computing)**: MEC is an evolution of mobile CDN whose purpose, in addition to bringing data closer to devices, is to provide devices with an accessible computing power with very low latency, within a very specific area for demanding applications. This technology makes it possible to locate a portion of the network's intelligence (managing local critical applications and performance analysis) at the base station level. The "antennae" will be capable of analysing a certain number of data, and so to make decisions very quickly.
- **Device-to-device**: D2D is a direct form of communication between two nearby devices, which does not require the data to travel over the cellular network. Device-to-device communication is not new, as technologies such as Bluetooth and Wi-Fi direct already enable it. But a new mesh networking technology will be introduced with 4.9G and later 5G network rollouts: LTE-direct. Far more energy-efficient than its predecessors, this technology will have a range of up to 500 metres and geolocation capabilities to enable communications. This technology will be very useful for low latency V2V (vehicle-to-vehicle) or V2X (vehicle-to-everything) communications and for certain public-security related uses.

1.5.3 5G: a multi-technology generation cohabitating with existing networks

As stated earlier, 5G is not meant to replace 4G overnight. In practice, the devices will undoubtedly be multi-modal: still connected to the 4G network, which will provide extended coverage for pioneer rollouts, then transitioning to 5G networks when they become available.

While 4G and 5G frequencies will probably be initially segregated, in all likelihood devices will rapidly become capable of aggregating 4G and 5G carriers and, further down the road, 4G carriers will be encapsulated in 5G ones.

[22] https://5g-ppp.eu/wp-content/uploads/2016/11/04_10-Nov_Session-3_Takaharu-Nakamura.pdf

4G is still being deployed, and its technological evolution and certain building blocks will be used by both the first 5G networks and advanced 4G networks. To wit, the latest trials conducted in France are allowing 4G networks to perform better thanks to the use of pre-5G technologies:

- Bouygues Telecom, in partnership with Huawei, managed to achieve a peak data rate of 1 Gbps thanks to the simultaneous use of four-carrier aggregation (800 MHz, 1800 MHz, 2100 MHz, 2600 MHz) and more powerful modulation (256 QAM)[23];
- In the coming weeks, Orange will be launching a massive MIMO (16x16) trial with Nokia[24].

In addition to the strong integration between 4G and 5G, the new generation will no doubt also continue convergence efforts between frequency bands governed by exclusive licences – i.e. bands that are allocated exclusively to an operator, such as mobile operators – and unlicensed frequency bands, governed by a system of general authorisation (e.g. Wi-Fi bands), which already began in 4G with LTE-LAA (Long Term Evolution – License Assisted Access) and LTE-LWA (Long Term Evolution – Wi-Fi Link Aggregation).

LTE-LAA is characterised by the aggregation of one or several LTE carriers, used in licensed bands, with other LTE carriers employing unlicensed 5 GHz Wi-Fi bands. To guarantee cohabitation with very widespread Wi-Fi networks whose deployment pattern is unpredictable, it uses LBT (Listen Before Talk) technology to listen to the radio channel before transmitting, in order to determine whether or not a frequency is available.

LTE-LWA consists of an aggregation of LTE carriers in licensed bands with Wi-Fi traffic. To achieve this, the LTE cell and Wi-Fi access point need to be connected: the Wi-Fi traffic is sent to the cell which sends back the entire aggregated link on the 4G core network. This technology is particularly well suited to indoor environments with small cells, a system which, as detailed in paragraph 3.3 below, will lend itself well to 5G deployments.

[23] https://www.corporate.bouyguestelecom.fr/wp-content/uploads/2016/05/Communiqu%C3%A9-Bouygues-Telecom-et-Huawei-Technologies-r%C3%A9alisent-un-test-de-d%C3%A9bit-4G-%C3%A0-plus-de-1-Gbps-pour-la-premi%C3%A8re-fois-en-Europe-de-lOuest.pdf

[24] https://networks.orange.fr/actualites/actualites-des-networks/orange-et-nokia-partners-pour-developper-les-futurs-services-5g

2 5G development initiatives

With a view to keeping the many promises being made for 5G, a number of initiatives are currently underway around the globe to promote its development. Below, we detail the foremost initiatives put forth by the players with which Arcep met as part of its investigation.

2.1 Government initiatives

The prospect of significant socio-economic repercussions generated by 5G (possible revenue of close to $225 billion a year[25] by 2025) combined with many countries' desire to establish themselves as technological leaders and make their companies more competitive, have propelled a multitude of government initiatives around the globe, aimed at encouraging the mobile ecosystem to begin the work and make the investments required to drive the rapid construction of the first 5G networks.

A selection of the largest initiative is detailed below.

2.1.1 In Europe

5G-PPP

The 5G Public Private Partnership (5G-PPP) is dedicated to 5G research and development, created on the initiative of the European Commission in 2013, with a budget de €700 million in public funding. The main objectives set by 5G-PPP are:

- Create stronger ties between the economic players and academic bodies devoted to the telecommunications sector over R&D projects, along the entire value chain;
- Reduce technological dependence on the United States and Asia while sustaining a strong global market;
- Regain technological leadership, notably in disruptive technologies, by promoting standards in international bodies;
- Allow innovative business models to emerge;
- Facilitate large-scale experimentation.

The results of this work will help clarify the 5G action plan (see below), and fuel the standardisation work that is currently underway.

To achieve its ambitions, 5G-PPP has initiated three stages of work, financed by the European Union, whose roadmap is in sync with the main international initiatives (3GPP and ITU, cf. Figure 14):

- The first stage which is currently underway, will last until mid-2017;
- A second stage focused on systems optimisations, from the end of 2017 to mid-2019;
- And finally a full-size trial stage from 2019 to 2020.

Deploying 5G by 2020 will require Europe to develop leading edge technologies, globally approved standards and especially to achieve consensus over the most suitable frequency bands. This funding and these projects – involving a great many researchers from more than a hundred companies and the finest R&D centres in Europe – are thus vital.

---

[25] https://www.abiresearch.com/press/abi-research-projects-5g-worldwide-service-revenue

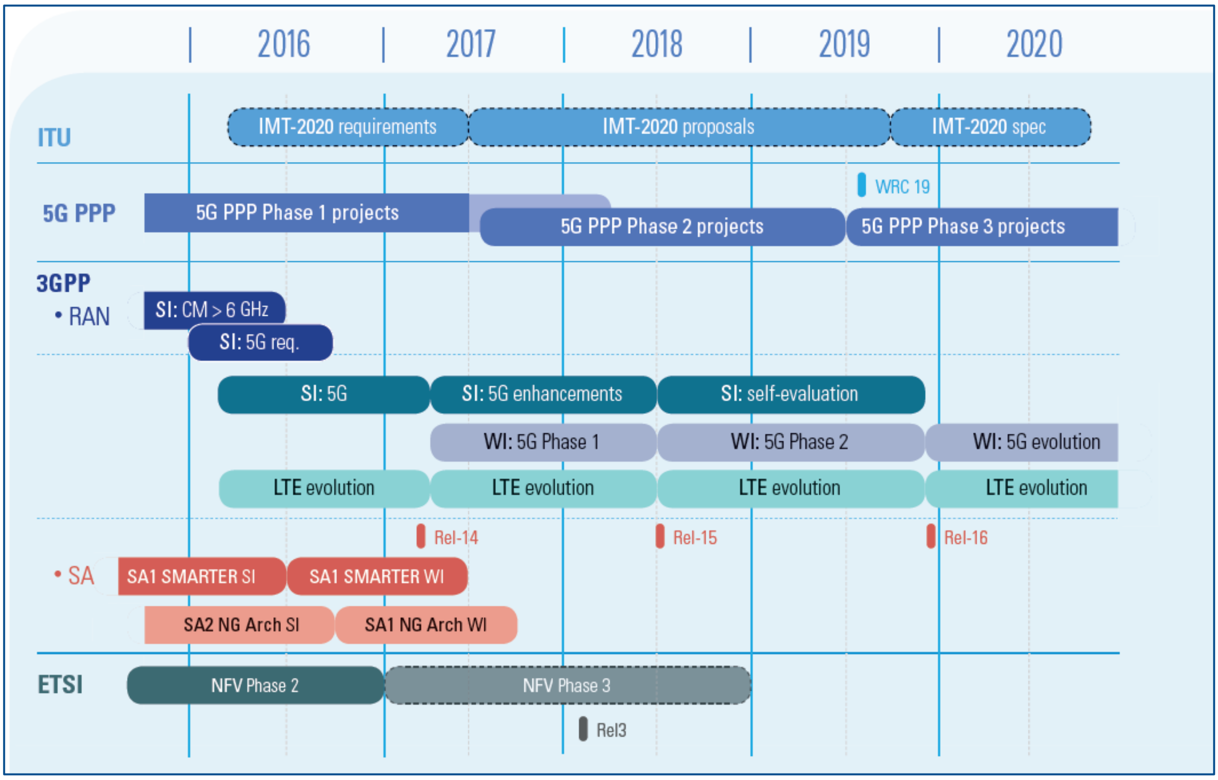


Figure 14. 5G PPP vs. 3GPP and ITU roadmaps[26]

5G action plan

As a complementary measure, on 14 September 2016 the European Commission launched its *5G for Europe Action Plan* to bolster investments in 5G infrastructure and service rollout efforts in the Digital Single Market between now and 2020. This action plan sets out a clear roadmap for public and private 5G investments inside the EU.

The Commission has proposed the following measures to achieve this plan:

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

[26] 5G Empowering vertical industries. White Paper, 2016, https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

The European Commission has given every EU country a certain number of ambitious, numerical targets. One core objective for 5G is thus to have at least one major city in every European country outfitted with this new generation mobile system by 2020, and coverage of every city, motorway and high-speed railway lines by 2025. This comes in response to announcements from South Korea and Japan which are both promising large-scale 5G demonstrations, respectively, at the Winter Olympics in Pyeongchang in 2018 and the Summer Olympics in Tokyo in 2020.

2.1.2 Worldwide (examples in the US, South Korea, Japan and China)

The race is already underway between countries to be the first to begin large-scale 5G trials, and later to introduce commercially available services, so much so that they are willing to employ pre-standard technical specifications.

Several countries are therefore working on standards and seeking to reach a consensus with one another to achieve international backing for the technical specifications that will satisfy their needs, and earn them the best possible return on the investments made thus far. This in turn is creating a certain turmoil, for instance, over the frequency bands that would be the best candidates for 5G.

The United States[27]

5G is seen as an unprecedented opportunity for economic growth, with a tremendous impact on education, job, transportation, etc. According to the US federal regulator, the FCC (Federal Communications Commission), the following three elements in particular need to be the prime focus of attention: spectrum, infrastructure and the backhaul network:

- **Spectrum**: in July 2016, the FCC voted to free up and to open up nearly 11 GHz of high frequency spectrum to be used for fixed and mobile broadband applications: 3.85 GHz of licensed spectrum in the 27.5 – 28.35 GHz and 37 - 40 GHz bands, as well 7 GHz of unlicensed spectrum from the 64 - 71 GHz band. The FCC's stated goal was to provide the assurance and clarity for investments in the telecoms sector. Verizon welcomed this decision, and plans on achieving the first rollouts in 2017, with trials already underway in several cities around the country (cf. 3.3).
- **Infrastructures**: The FCC believes that 5G must be underpinned by a robust infrastructure network capable of handling already heavy traffic that could potentially increase exponentially in the coming years. It will interact in a hybrid fashion between traditional towers with macro cells and small cell deployments, as well as distributed antenna systems. With an eye on the deployment of new towers, the FCC resolved to reduce, or eliminate in certain cases, the regulatory restrictions on installing facilities and antennae that will have very little impact "on historic properties" (tower re-use, small antennae, indoor installations, etc.)[28].
- **Backhaul network**: Because 5G systems will require very high-power backhaul networks, the FCC is in the process of reforming and updating the regulations governing data services markets, including wireless backhaul solutions. The FCC is seeking to protect this market while also creating competition, so that competitive and high quality backhaul network solutions can emerge.

[27] Forging Our 5G Future – Federal Communications Commission: https://www.fcc.gov/5G

[28] https://apps.fcc.gov/edocs_public/attachmatch/DA-16-900A1_Rcd.pdf

Japan

Japan wants to demonstrate its 5G leadership by deploying the first commercial 5G network that complies with international technical specifications, in time for the Summer Olympic Games in Tokyo in 2020.

According to the *Radio Policies Towards 2020*[29] report, published in June 2016 by Japan's Ministry of Internal affairs and Communications (MIC), the 3600 - 4200 MHz, 4400 - 4900 MHz and 27.5 – 29.5 GHz bands were selected to be the 5G candidate bands on a national scale. Although other bands are also being investigated, with a view to WRC19, 5G rollouts are already planned in the 3600 - 4100 MHz, 4405 - 4895 MHz and 27.5 - 28.28 GHz bands as early as 2017 in Tokyo, and will be built out in 2018 and 2019.

China

Like Japan, China too wants to prove its leadership with the first commercial rollouts in 2020. The first trials will be conducted that year in the 3400 – 3600 MHz band. The 3300 - 3400 MHz, 4400 - 4500 MHz and 4800 - 4990 MHz bands are also under consideration and currently being investigated. For higher speeds, the country plans on using spectrum around the 25 GHz and 40 GHz frequencies.

South Korea

South Korea, meanwhile, has set its sights on a pre-commercial 5G service that would be ready in time for the 2018 Winter Olympics in Pyeongchang. Several trials are already underway to prepare for full scale demonstrations in several South Korean cities, including Pyeongchang and Seoul. The country's three national mobile operators are hoping for spectrum in the 26.5 – 29.5 GHz bands.

South Korea's largest mobile operator, SK Telecom, has announced a plan for conducting interoperability tests with Qualcomm and Ericsson, as well as outdoor trials of the new air interface based on the 3GPP NR standards that are being developed today. These trials and experiments will be carried out in the second half of 2017.

If the goal of these trials is to help accelerate the specification of the new NR air interface, which is part of the work being done on 3GPP Release 15, it has not yet been specified which frequency bands will be used for these trials.

2.2 A host of private initiatives – a few examples

5G Open Trial Specification Alliance

In early 2016, South Korean operators KT and SK Telecom, Japanese carrier NTT DoCoMo and American carrier Verizon formed the 5G Open Trial Specification Alliance to carry out collaborative 5G trials.

Due to be conducted between 2016 and 2018, the aim for these trials is to provide a common platform for operators, for exchanging results and shared assessments of the different 5G network components and elements. One of the operators' objectives is to help accelerate the definition of standards and specs, and to enable economies of scale. The findings of these evaluations will provide input for 3GPP discussions, adding simulations to the experimental data produced by the partnership.

[29] http://www.gsma.com/spectrum/wp-content/uploads/2016/08/MIC_Spectrum-for-5G-MIC-Kuniko-OGAWA.pdf

The alliance's founders hope to attract a number of industrial partners to the platform, including other carriers, equipment suppliers, chipset makers, etc. Several of the founding operators' equipment suppliers are already involved in the scheduled trials.

The trials will cover multiple frequency bands, both above and below 6 GHz.

Verizon 5G Technical Forum

The Verizon 5G Technology Forum (V5GTF) was created in late 2015 by Verizon, in cooperation with its partners Cisco, Ericsson, Intel, LG, Nokia and Qualcomm. The goal of the collaboration is to provide a platform for testing radio interface specifications in the 28 and 39 GHz bands.

The first fruit of this collaboration, in July 2016 Verizon announced the completion of the first specifications of their 5G radio interface. These specs should enable the different parties involved to develop interoperable solutions and so to help drive forward the definition pre-standards.

Even though they run the risk of developing solutions that are not compatible with 3GPP or ITU standards, Verizon believes it has a solid enough grasp of the overall concepts being discussed in those bodies. The tests carried out in several US cities were thus able to validate substantially greater capacities than 4G.

Orange/Ericsson

Orange and Ericsson have been working together since October 2016 on developing 5G use cases and services, as well as demonstrations. The purpose is to develop technological building blocks, conduct trials and pilot projects for a range of use cases, including multi gigabits/s wireless internet access in suburban and rural environments, the Internet of Things and connected cars.

Their collaboration made it possible to achieve 15 Gb/s in a laboratory environment, notably thanks to the use of massive MIMO and beamtracking using centimetre waves. The collaboration will also focus on the transition from 4G to 5G solutions, notably in terms of reducing costs and improving energy efficiency, and on the use of SDN and NFV technologies.

Since January 2017, the partnership has included PSA (Peugeot) to carry out trials on connected cars.

5G-ConnectedMobility

5G-ConnectedMobility is a consortium formed by Ericsson, BMW, Deutsche Bahn, Germany's three mobile operators, Deutsche Telekom, Telefonica Deutschland and Vodafone, the 5G TU Dresden laboratory, the BAST research institute and BnetzA, with the goal of galvanising and accelerating 5G R&D in Germany.

5G-ConnectedMobility thus plans on supplying a digital motorway infrastructure and real application environment to be able to test V2V (vehicle-to-vehicle) technologies as well as solutions for digitising railway infrastructure.

To this end, 5G-ConnectedMobility operates with the help of an independent network infrastructure that is not connected to any commercial network. The Ericsson mobile network devoted to this project makes it possible to run live tests: Ericsson thus obtained permission from regulator BNetzA to employ spectrum in the 700 MHz band in the Nuremberg area.

3 The challenges of 5G

In this part we explore the different challenges that lie ahead for 5G, which emerged from the interviews that Arcep conducted over the past several months.

3.1 New business models focused on vertical markets

3G and especially 4G technologies were designed primarily for the superfast mobile internet. 5G continues on in this direction, but also wants to target what are known as vertical markets, which encompass several segments, including:

- Connected vehicles, not only to deliver entertainment and information to passengers, but also to guarantee safety via communications both between vehicles and between vehicles and infrastructure;
- Factories of the future;
- Smart cities with requirements in the areas of public transportation (similar to the needs of connected vehicles), the environment, managing buildings and energy consumption;
- Medicine, healthcare and robot-assisted telesurgery;
- Smart grid flow monitoring and management (electricity, gas, water, etc.).

This section will focus in particular on the connected car and factories of the future segments. Because of their current and future macro-economic context, along with the plurality and effervescence of the pioneer work being done in these areas, these two segments constitute the main avenues of 5G development in vertical markets. Smart cities and smart grids have already begun to soar through existing Internet of Things (IoT) technologies.

3.1.1 The automotive sector

The car is an extremely common form of transportation, and safe driving is a fundamental consideration: human error is the number one cause of all transport accidents. The transportation sector wants to use technological innovations to tackle this problem, and to continue to make transportation more efficient, more sustainable and safer.

There are three areas in which technological progress could help improve automotive transportation. 5G could have a role to play in all three, but particularly in the first two:

- Provide in car internet connectivity, to deliver entertainment to passengers;
- Provide access to driver assistance information, to reduce accidents and improve the fluidity of traffic;
- And, finally, the ability to make cars autonomous, thanks to artificial intelligence algorithms.

The first area is just an extension of the developments occurring today around 4G. The aim is to give passengers access to their messaging services, to the internet, to multimedia content, online gaming, etc. The increased connection speeds promised by 5G will improve the use of all of these services.

The second area aims to make cars more intelligent by using information that was not previously available to them. This in turn will help improve the safety and efficiency of the networks as well as help drivers make the right decisions, and adapt to driving conditions. Such connected vehicles could have access to information about dangers on the road (slow or stopped cars, traffic jam warnings, indications of where construction is taking place on the roads, weather conditions, emergency braking, emergency service vehicles approaching, etc.) or regarding signage (signalling/signage on-board vehicles, speed limits on vehicles, failure to heed signage/safety precautions at crossings, request for right-of-way at traffic lights for designated vehicles, green light optimal speed advisory, etc.). Other services, such as information on refuelling or recharging stations, vulnerable road user protection, managing street parking and traffic information, and smart guidance, could also prove useful. It is still not clear whether, to achieve this, vehicles will simply exchange information with each other or if connectivity with infrastructure will be required along the roads to optimise vehicles' behaviour. In both instances, 5G could have a role to play.

Of the many initiatives that are already underway we can begin with an example from France: the SCOOP@F[30] (cooperative intelligent transport systems) project coordinated by the Ministry of the Environment, Energy and the Sea, and which unites local authorities and R&D centres. Launched in February 2014, new partners subsequently joined the initiative, including Orange and Austrian, Spanish and Portuguese partners. As it is a European project, it receives 50% of its financing from the European Commission, and cross-tests are conducted with Austria, Spain and Portugal. SCOOP@F is a pilot rollout project for cooperative intelligent transport systems; it aims to deploy 3,000 vehicles on 2,000 km of roadway spread across five locations: Ile-de-France, the A4 motorway, the Isère, and ring roads in Bordeaux and Brittany. Its main objectives are to improve road safety and the safety of roadway workers, achieve more efficient traffic management, reduce pollution, streamline infrastructure management costs and participate in defining the car of the future.

In addition, in early 2017, mobile carrier Orange, equipment supplier Ericsson and car-maker PSA Group signed a partnership agreement[31], as part of the "*Towards 5G*" initiative, to conduct technical trials relating to 5G. The aim of this alliance is to test the different paths of technological evolution from 4G to 5G to meet the needs of connected cars, notably in terms of intelligent transport systems (ITS), for safer driving and new on-board services.

The third area concerns the emergence of autonomous vehicles. A number of projects are underway in this area. The first step is to outfit vehicles with algorithms that enable it to make decisions quickly based on their environment. This requires a large number of sensors to deliver a full "understanding" of what is happening around the vehicle. Without pre-judging the technologies that will ultimately be employed to achieve this, as with a human driver (see above), the car could take advantage of connections with other vehicles on the road and with an infrastructure, to have access to all of the aforementioned information.

3.1.2 Industry 4.0

Competitiveness does not depend solely on innovation and the evolution of products, but also on modernising businesses and their means of production. According to certain studies carried out in 2015[32], the digital transition in Europe will enable enterprises to increase their revenue by more than 110 billion euros a year over a five-year period.

A great many countries have set out a strategy for modernising their manufacturing infrastructure (*l'industrie du futur* in France[33], Industry 4.0 in Germany…) of which one aspect will involve digitising processes and trade. The European Commission itself introduced measures in 2016 for strengthening

---

[30] http://www.scoop.developpement-durable.gouv.fr/spip.php?page=sommaire

[31] http://www.orange.com/fr/Press-Room/communiques-2017/Ericsson-Orange-et-le-groupe-PSA-partners-pour-la-voiture-connectee-en-5G

[32] PwC, "Industry 4.0: Opportunities and challenges of the industrial internet" (2015), and Boston Consulting Group, "Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries" (2015)

[33] http://www.economie.gouv.fr/files/files/PDF/industrie-du-futur_dp.pdf

competitiveness in Europe, in which 5G could play a significant role. This included earmarking 500 million euros for the Horizon-2020[34] research programme.

The advent of new technologies (4G, fibre and soon 5G) and new services (the Internet of Things, the cloud, big data) should facilitate businesses' digital transition. 5G in particular is expected to be a very versatile technology, capable of undergirding a very wide array of uses, and could go a long way in furthering companies' transition to digital technologies and solutions.

3.2 Spectrum harmonisation

5G is emerging as a technology that will use both low frequencies (f < 1 GHz), high frequencies (1 GHz < f < 6 GHz) and, for the first time ever in consumer networks, very high frequencies referred to as "millimetre wave" frequencies (f > 6 GHz).

This spectrum diversity is entirely bound up with the promises of 5G: extended coverage (low frequencies), ultra high speeds (very large channels in very high frequency bands), low power consumption. Furthermore, satellite services will also contribute to the development of this new technology, especially in areas that are difficult to cover and to provide backhaul solutions. The satellite industry is thus taking an interest in 5G, and wants to be involved in defining these new generation network.

3.2.1 Millimetre wave frequencies

The "millimetre" band, also referred to as millimetre wave spectrum, aka frequencies above 6 GHz, are essential to enabling 5G to mark a departure from 4G, for the reasons cited in Section 1.5.1.

At the latest World Radiocommunications Conference (WRC-15 in Geneva), a conference under the aegis of ITU whose objective is to change the way frequencies are allocated between users, discussions over the definition of future mobile bands made it possible to focus future 5G studies, for millimetre wave frequencies, on a certain number of bands situated between 24 GHz and 86 GHz (33.25 GHz identified in total): 24.25 - 27.5 GHz, 31.8 - 33.4 GHz, 37 – 43.5 GHz, 45.5 - 50.2 GHz, 50.4 - 52.6 GHz, 66 - 76 GHz, 81 - 86 GHz.

It is important to stress that, even if the above-listed bands have been identified as "5G bands", at this stage there is no way to know whether they can actually be used to deploy this new generation system: only the results of technical studies will make it possible to establish the constraints and rules of compliance, and to validate the feasibility of these hypotheses.

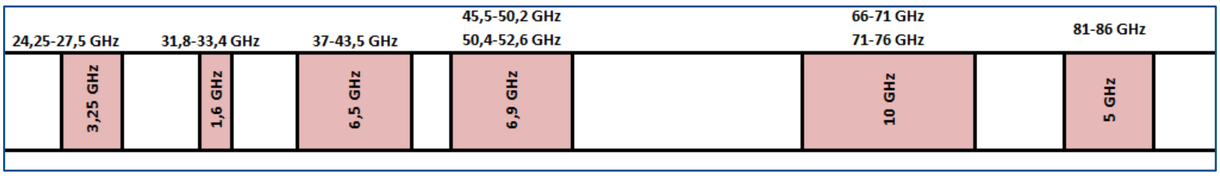


Figure 15. Millimetre wave frequencies identified at WRC-15

Contrary to the conclusions of the Conference, which reflect European recommendations, the United States and certain Asian countries (South Korea, Japan) have decided to perform 5G trials in the 28 GHz band, and equipment suppliers such as Qualcomm and Samsung, have begun manufacturing 28 GHz- band products.

[34] https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020

Meanwhile Europe, following the publication of an RSPG (Radio Spectrum Policy Group within which France is represented by ANFR) opinion[35], decided to focus its first studies on the 26 GHz band (pioneer band), then on the 32 GHz and 42 GHz bands. Later, studies will be carried out on introducing 5G in all of the other bands identified by WRC-15.

The rapid choice of the 26 GHz band as the pioneer band was made to enable economies of scale for equipment production, since it is very likely that dual-mode equipment, i.e. compatible with both the 26 GHz and 28 GHz band, will be available for pioneer rollouts[36].

In France, the 26 GHz band is already being employed for a variety of uses: mobile operators' wireless fixed links (4G infrastructure links), fixed satellite service systems and ground stations for space services. Studies will therefore need to be conducted to take these services into account, and define either the cohabitation or migration of applications to other millimetre wave frequencies.

3.2.2 Frequency bands below 6 GHz

a) The 3.4-3.8 GHz band

It will not be possible for 5G to run entirely on millimetre wave frequencies: the propagation qualities of these bands make it difficult to achieve widespread coverage, particularly in more sparsely populated areas. In addition, these bands are still lacking in technological maturity when it comes to delivering consumer market communication services. As a result, a "core" band below 6 GHz needs to be identified: one that provides sufficiently large channels to enable future 5G operators to provide innovative services and a higher quality of service than with 4G.

The 3400 - 3800 MHz band appears to be a good candidate.

First, it has already been harmonised for ultrafast mobile services inside the European Union. Initially the 3400 - 3600 MHz band and later the 3600 - 3800 MHz band were identified as the "IMT" bands (for high-speed mobile). Second, they have a great deal of available spectrum (up to 400 MHz). Lastly, technological advancements (antenna and signal processing) make these frequencies compatible with their use to establish macro cells, and not only microcells. To give an example, it emerged from the interviews conducted by Arcep that coverage with this band could be similar to coverage with the 2.6 GHz band, the core 4G frequency band.

This analysis has been confirmed by the European Commission (in its 5G mandate to RSCOM[37]) and by RSPG[38] which consider the 3.4 - 3.8 GHz band as the only credible 5G band for deployments taking place before the end of 2020.

In France, the band is assigned to Arcep, in a priority fashion, for the 3400 - 3600 MHz frequencies (and in a non-priority fashion to the Ministry of the Interior and the Ministry of Defence), and exclusively for the 3600 - 3800 MHz frequency bands. It is used for wireless local loop and satellite applications.

The compatibility of future uses with current applications is being examined by the Electromagnetic Compatibility Advisory Committee, which is chaired by the National Frequency Agency and of which

[35] http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf

[36] The tuning range is vital here: a system capable of regulating its frequency from 26 to 28 GHz appears entirely technologically achievable within the timeframe for the first 5G millimetre wave deployments. This would have been less true if a switch between 28 and 32 GHz were required.

[37] https://circabc.europa.eu/sd/a/448dc765-51de-4fc8-b6e0-56ed6a1d0bca/RSCOM16-40rev3%205G%20draft_mandate_CEPT.pdf

[38] http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf

Arcep is a member: exclusion zones, protecting certain locations tied to long-term use of satellite solutions, need to be set up. Military radiolocation systems operating below 3.4 GHz also need to be protected.

b) Other bands below 6 GHz

The bands being used today for 2G, 3G and 4G could be used for future 5G deployments.

Refarming 2G, 3G and 4G could be a delicate undertaking, however, because of the duplexing methods they use. Most mobile communications in Europe use FDD (Frequency Division Duplexing)[39] to exchange information. Technical discussions over 5G are nevertheless anticipating that TDD (Time Division Duplexing)[40] will be the chief, if not sole, form of duplexing used for this new generation, notably because it makes it possible to adjust bandwidth to data rates and because it is particularly efficient when beamforming is used.

For 5G networks, using already harmonised mobile bands will thus require in-depth technical studies to define the terms and conditions of use and sharing with existing services. On this point, the ECC (Electronic Communications Committee[41]*)* decided to assess the potential of certain already harmonised bands, notably the 700 MHz and the L band (1427-1492 MHz).

In France, Arcep allocated the 700 MHz band to mobile operators in late 2015. Even if the country's four operators all obtained frequencies in this band, only Free Mobile, which has no blocks of 800 MHz spectrum, decided to begin its rollouts in the band using LTE (4G) technology.

Arcep is currently analysing the contributions to its public consultation, addressing among other the 3.5 GHz band, that ended recently.

The L band (1427 - 1518 MHz), which was defined to be used exclusively in SDL (Supplemental DownLink) mode, could be considered to meet the constant demand for ever higher data rates and the greater increase in downlink traffic, compared to uplink traffic. In France the band is used by wireless fixed links authorised by Arcep, by the Ministry of Defence for mobile services (excluding aeronautical) and by the Ministry of the Interior. Using it for 4G or 5G would therefore suppose moving the above-mentioned uses over to other bands.

3.3 Increasingly small cells

Today, mobile network rollouts are essentially based on the use of macro base stations: installations that are equipped with high-power antennae deployed to guarantee coverage for a relatively wide area, providing good quality of service. Network configurations are evolving constantly: new radio base stations are installed on a regular basis to increase the networks' capacity, to better meet users' needs in terms of indoor and outdoor coverage, and to improve quality of service.

However, this continually growing demand for capacity already requires operators to increase the density of their networks with smaller and smaller cells.

5G – which will probably bring about a sizeable increase in data traffic, and which will use millimetre wave frequencies whose propagation capabilities are weak – will no doubt require the widespread deployment of low-power base stations (small cells).

---

[39] A technique that consists of sending and receiving data simultaneously, but on two different frequency bands.

[40] A technique that consists of sending and receiving data on the same frequency band but at different times.

[41] The European body that specifies the technical terms and conditions governing the use of frequency bands, which are then set by European Commission decisions.

To satisfy demand and enable the introduction of 5G, estimates indicate at least 10 small cells per macro base station in urban settings[42], where cells are already today relatively tightly meshed to handle traffic density.

Here, the players that met with Arcep raised several questions that will no doubt need to be answered when considering the ubiquitous deployment of small cells.

3.3.1 Taxation

The current regulatory framework stipulates that base stations whose power requires an opinion, an agreement or a statement from the National Frequency Agency (ANFR) are subject to a flat tax on network companies (IFER[43]). The amount of the tax varies according to transmission power, the type of installation and the deployment location. For a deployment in an urban area, the tax stands at €1,607/year/installation for a base station with an effective isotropic radiated power (EIRP) of more than 5W (a COMSIS agreement from ANFR is required to be able to transmit) and €160.70 €/ year/installation for an EIRP of between 1W and 5W (declaration to ANFR is required to be able to transmit).

5G small cells will likely use variable transmission powers of between 1W and 25W. In light of rollout density forecasts, hence the number of small cells to install, some of the stakeholders that Arcep met with raised the question of possibly adapting this tax in such a way as to enable massive small cell deployments without generating an equally massive increase in the total tax amount.

This process is already underway, notably with a view to decreasing taxes on base stations in locations that are hard to cover: Act No. 2016-1888 of 28 December 2016 on the modernisation, development and protection of mountain regions thus exonerates mobile base stations built in mountain regions between 1 January 2017 and 31 December 2020 from paying the IFER tax.

3.3.2 Access to elevated and “semi-elevated” locations

To perform their deployments successfully, mobile operators have traditionally needed to install their base stations in elevated locations (towers, rooftops, etc.). This will continue to be true with 5G networks, but will be even more challenging for two main reasons:

1. 5G antennae will probably be larger (in the m^2 range for some) than current 2G, 3G or 4G antennae, because of the above-mentioned massive MIMO processing that will require the use of a very large number of radiating elements. Moreover, additional antennae compatible with new 5G bands will no doubt also need to be deployed. So the re-use of existing masts could very well be problematic, and new (possibly collocated) transmission sites will need to be found.
2. This search for new sites will also need to be carried out to install small cells in semi-elevated locations, but with extra care as the density of these installations will undoubtedly be high: operators will thus be required to deploy their equipment on urban furniture and infrastructures such as bus shelters, lampposts, public buildings, billboards, etc.

As a result, public authorities will need to keep a close eye on the matter and, if necessary, adopt measures that will facilitate 5G rollouts.

[42] http://www.lemag-numerique.com/wp-content/uploads/2015/10/WP_-Souverainete_Telecoms_PetitesCells_FINAL.pdf

[43] IFER = *Imposition forfaitaire sur les enterprises de réseaux*

3.3.3 5G networks' regional coverage and backhaul

Ensuring regional connectivity will be one of the challenges for this new generation of mobile networks.

The diversity of use-cases envisioned for future 5G networks, the geographical distribution of which is not yet precisely known, must be factored in when addressing coverage issues.

The higher frequency bands that are being put forth for future 5G networks, along with the potentially very substantial bandwidth consumed by these new uses, pose the question of the regional foothold of these networks. As a matter of fact, mobile networks have never before employed such high frequencies whose use will require a large number of relay antennae to be installed.

Moreover, connecting the 5G installations to the network will push to the fore the question of the cost of connecting them via optical fibre, which will no doubt be necessary in most instances to ensure the expected quality of service. The industry needs to design the technologies that will make it possible to minimise the cost of 5G rollouts in rural areas.

3.4 Net neutrality issues

European regulation on safeguarding an Open Internet[44], adopted by the European Parliament and Council on 25 November 2015, for which European regulators required an additional nine months to specify the rules governing its application, introduces the principle of net neutrality as one of the top priorities in the standardisation hierarchy.

Net neutrality is an overriding principle that guarantees equal treatment for all data traffic on the internet. In particular, it excludes any form of discrimination with respect to the source, the destination or the content of data flows.

On 30 August 2016, BEREC (the Body of European Regulators for Electronic Communications) published guidelines for national regulators on the enforcement of the European Open Internet regulation[45].

During the BEREC public consultation[46] on its draft net neutrality guidelines, several enterprises and electronic communications sector stakeholders took the opportunity to deliver a clear-cut point of view in their *"5G manifesto for timely deployment of 5G in Europe"*[47]. This manifesto aims at warning public authorities against a too restrictive approach to traffic management, and especially of the supposedly negative effects that, in their opinion, an overly strong enforcement of net neutrality could have on the 5G rollout roadmap.

---

[44] Regulation (EU) 2015/2120: http://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32015R2120&from=EN

[45] Internet service providers (ISP) can employ reasonable traffic management measures for certain categories of traffic, under non-discriminatory conditions and provided they are transparent, proportionate and justified by objective technical requirements, and not used to serve their own commercial interests. ISPs can also distinguish certain services, called specialised services, from their internet access service, without them affecting the latter, provided these services have specific, objective transit requirements.

[46] http://www.berec.europa.eu/

[47] http://telecoms.com/wp-content/blogs.dir/1/files/2016/07/5GManifestofortimelydeploymentof5GinEurope.pdf

BEREC's opinion[48], in response to the contributions to the aforementioned public consultation, recalls that the rules of net neutrality are technology neutral and therefore apply to 5G networks. Moreover, BEREC guidelines clarify that network slicing which networks will need to use to respond to the different use cases (mMTC, eMBB, uRLLC) planned for this new generation (cf. 1.4) system, may be used to deliver specialised services[49].

The subject of net neutrality as it applies to future 5G networks is still very much open and unexplored, but new analyses could be performed parallel to the work being done on defining 5G. Arcep is open to discussion and will also work, within BEREC, towards bringing the required clarity to the ecosystem.

[48] http://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/6161-berec-report-on-the-outcome-of-the-publi_0.pdf

[49] http://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/6160-berec-guidelines-on-the-implementation-b_0.pdf - footnote 26

Annexes

Annex 1 Definition and standardisation work

A new generation of mobile telephony is defined primarily by two bodies: ITU (International Telecommunication Union) and 3GPP (3rd Generation Partnership Project). These two, respectively public and private, organisations are dedicated to defining the objectives, standards and technical specifications of the new technology in question.

ITU

The first large-scale 5G commercial rollouts are expected to take place in 2020. As mentioned earlier, the exploratory phase – which provides an opportunity to determine demands and identify the most promising techniques and technologies for these future 5G networks – has already begun. Although a number of organisations and consortia are involved in defining 5G, 3GPP will very probably be the central standardisation body for its technical specifications.

Whatever the case may be, ITU (International Telecommunication Union) is vital to defining the technologies and standards that govern any new generation of IMT (International Mobile Telecommunications) at the global level.

These IMT standards are established with the involvement of public authorities and industry players, and have provided the framework for the evolution of mobile communication services around the world, since the beginning of IMT standardisation, with IMT-2000 (3G, UMTS), then IMT-Advanced (4G, LTE-A) and more recently IMT-2020 (5G).

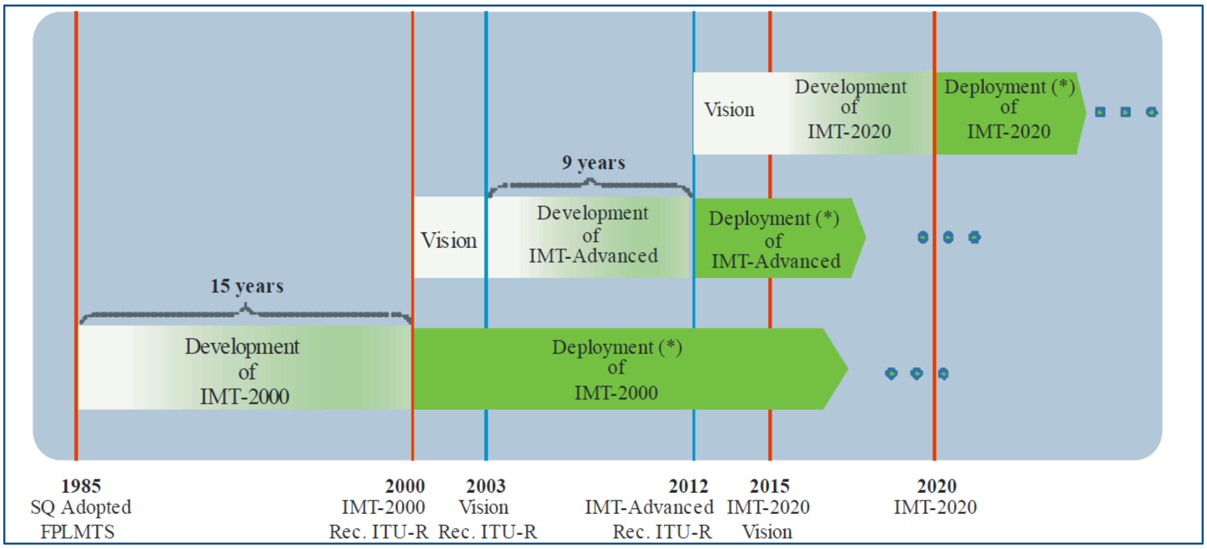


Figure 16. Timeline of IMT developments and deployments[52]

The advent of an IMT standard typically occurs in three main stages : a vision stage, a development stage and a deployment stage.

The vision stage – whose completion is marked by a document that is usually called a Vision Recommendation – is the stage during which ITU sets the framework and objectives for the future technology. The aim of this document is generally to define what the new technology will be in a more or less concrete fashion, what its characteristics will be, the uses it will enable, etc. Whether for

[52]Recommendation ITU-R M.2083-0 (09/2015), https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

IMT-Advanced, the commonly used technical abbreviation attributed to the definition of 4G, or IMT-2020, the abbreviation attributed to definition of 5G, the vision stage lasts around three years.

Recommendation ITU-R M.2083-0 was published in September 2015, bringing to a close three years of work performed by ITU-R (Working Party 5D) on defining the framework and objectives for IMT for 2020 and beyond. It is this document that today serves as the basis of the different 5G research and standardisation work being done around the globe.

Next comes the standards development stage, based on the conclusions of the vision stage. Regarding IMT-2020, this development and standardisation work is already underway, and ITU plans on having completed it by 2020 to be able to satisfy the most pressing needs of the ITU members and organisations that want to deploy 5G as quickly as possible. This is all the more challenging as the development stage will last only five years, compared to 15 years for IMT-2000 and nine years for IMT-Advanced.

The different deadlines set for IMT-2020 within ITU can be found in Figure 17. The spectrum identification phases (indicated by the black triangles) coincide with the World Radiocommunications Conferences, of which the latest was WRC-2015 and the next is WRC-2019 (see 3.2).

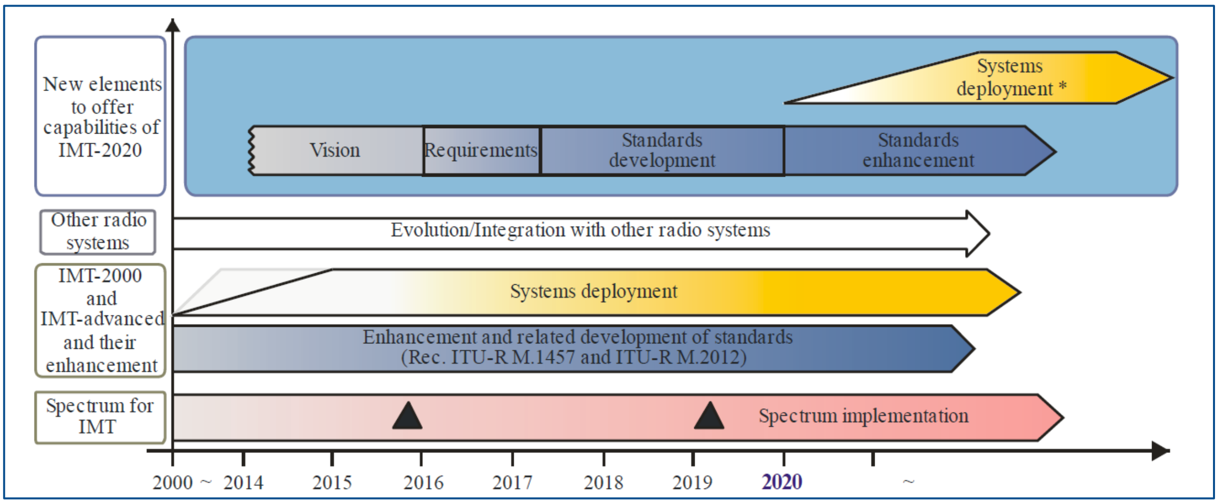


Figure 17. Stages and expected deadlines for IMT-2020[53]

All of the work that ITU is conducting on IMT-2020 is following a roadmap that is detailed in Figure 18, with the completed stages indicated in green and those to come in blue. The work that is underway today concerns 5G spectrum aspects, prerequisites and assessment criteria, along with the different technical studies and proposals, which are a prerequisite to the standardisation phase of the work.

[53]Recommendation ITU-R M.2083-0 (09/2015), https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

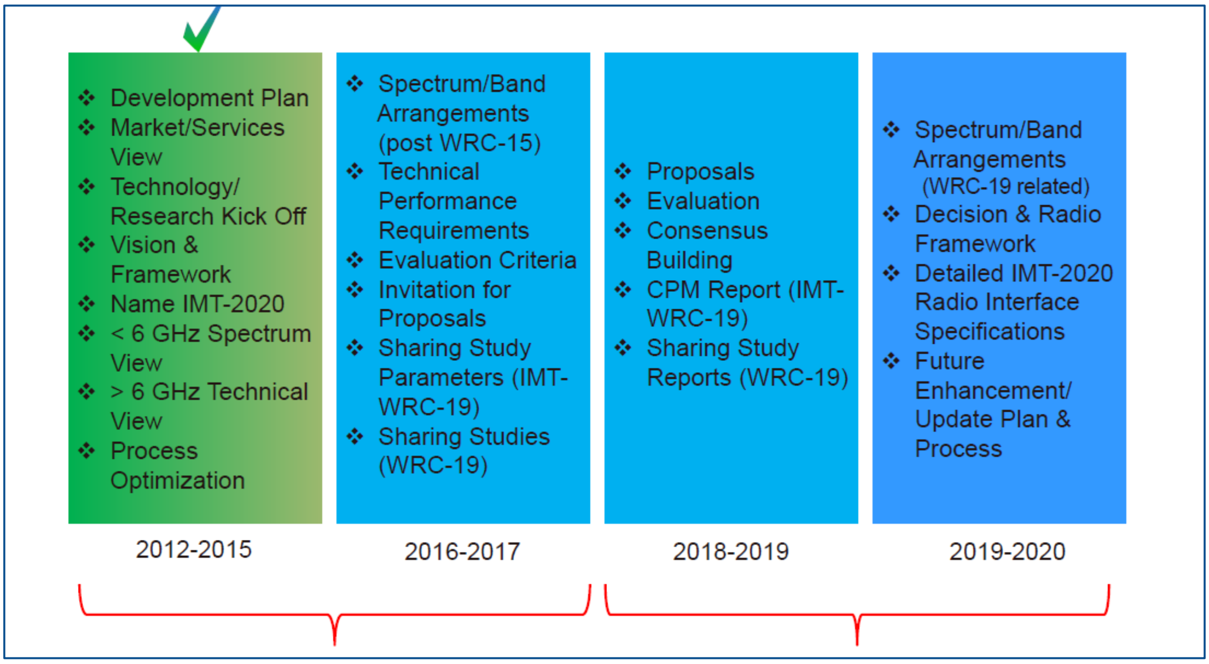


Figure 18. WP 5D[54] work programme

3GPP

Based on ITU Recommendations, 3GPP has played a major role in the success of LTE over the past several years, which has been the fastest growing cellular technology to date: never before has a new radio standard been adopted and deployed as rapidly and as widely from the finalisation of the first version of its standardisation (for LTE Release 8, in December 2008).

For the first time, under the LTE acronym, the entire mobile industry agreed on a single new technology (contrary to 3G where 3GPP and 3GPP2 co-exist, each backing their version of 3G standardisation that complies with IMT-2000 criteria), and so enabling unprecedented economies of scale and momentum in the ecosystem.

After Release 8, the work performed by 3GPP has been centred on the following strategic areas:

- Enhancing LTE radio standards to further improve capacity and performance;
- Enhancing system standards to make LTE and EPC (Evolved Packet Core, the core LTE network technology) available to new business segments;
- Introducing improvements for system robustness, especially for handing exponential smartphone traffic growth.

These areas of focus have made it possible to map out the general path of evolution from LTE to LTE-Advanced (Releases 10 to 12) and later LTE-Advanced Pro (Releases 13 and 14) while awaiting 5G.

The ambitiousness of 5G requirements, the tight timeline “imposed” by the market, along with the different national tendencies have pushed 3GPP to define two stages of specification work:

1. A first stage that will end in the second half of 2018, with the termination of Release 15, and which will address the most urgent matters with respect to commercial requirements;

[54] https://www.itu.int/en/membership/Documents/missions/GVA-mission-briefing-5G-28Sept2016.pdf

2. A second stage that will end in December 2019, which marks the end of Release 16, which will address the other use cases and prerequisites identified in the IMT-2020 Vision Recommendation.

The Work Plan for Release 15, the first set of 5G specifications, was ratified at the plenary meeting of the TSG#72 (Technical Specification Group #72) 3GPP working groups in June 2016. This plan includes a set of intermediate tasks and checkpoints to steer ongoing work in the different groups. This Work Plan sets out the transition from current studies to the standardisation phase of the work:

- Starting in December 2016: beginning of standardisation work by TSG SA2 (Technical Specification Group System Architecture);
- Starting in March 2017: specification begins for the 5G NR (New Radio) interface in the TSG RAN (Technical Specification Group Radio Access Network).

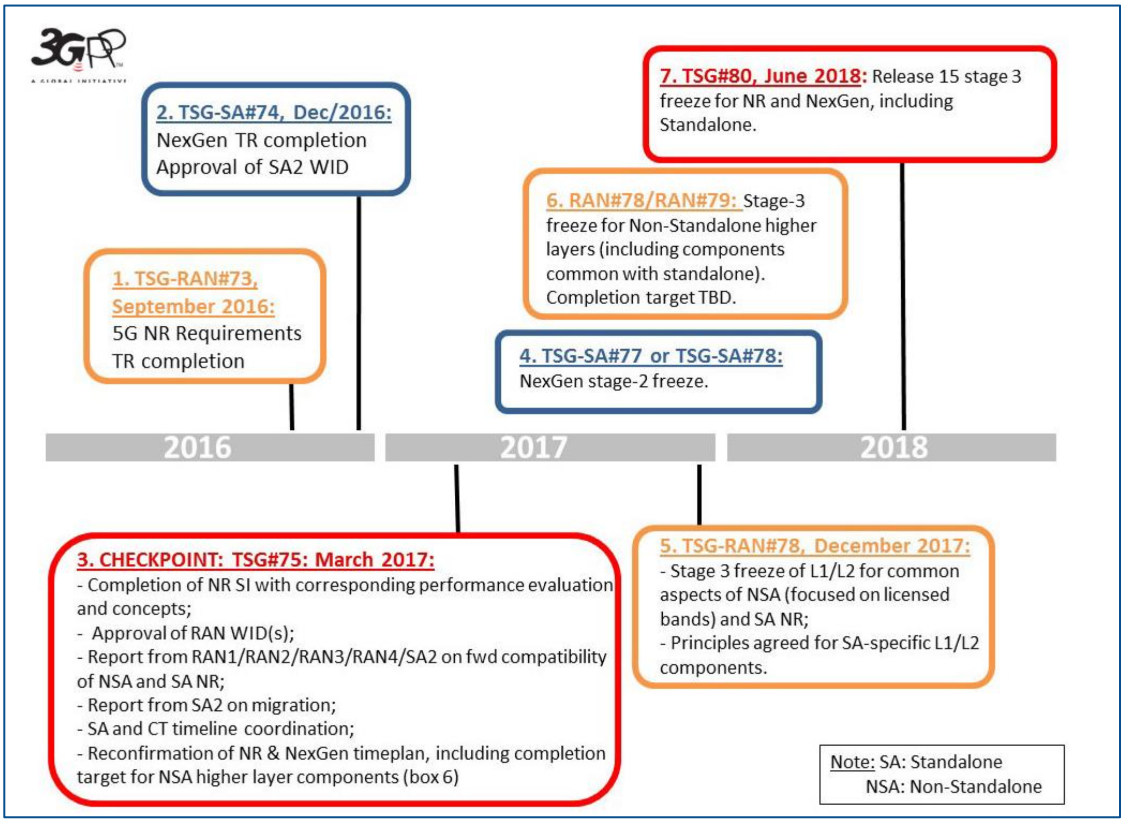


Figure 19. Roadmap for 3GPP standardisation groups[55]

If 5G is viewed as the technology capable of transforming society, and even of ushering in the next industrial revolution by impacting multiple (vertical) sectors with new business models and in a way that benefits the economy, notably in Europe, in all likelihood it will initially be driven forward by eMBB (Enhanced Mobile Broadband, cf. 1.2).

With this in mind, 3GPP defined the framework for Release 15, stage 1 specifications of 5G standardisation, as detailed earlier, whose work will focus on the following:

- Standalone and Non-Standalone NR operation: the Standalone version to work independently of LTE technology, and the Non-standalone NR being highly interoperable with LTE[56].

[55] https://5g-ppp.eu/wp-content/uploads/2016/11/01_10-Nov_Session-3_Dino-Flore.pdf

- Target use cases: starting with Enhanced Mobile Broadband (eMBB) as well as Low Latency and High Reliability to enable some URLLC (Ultra-reliable and Low Latency Communications, cf. 1.2) use cases.
- Simultaneous examination of frequency ranges below 6 GHz and above 6 GHz.

Release 16, the second phase of 5G specifications, will then focus more on other segments such as mMTC (Massive Machine Type Communications*,* cf. 1.2), for instance, to tackle IoT use cases that require higher quality of service than what LPWAN *(*Low-Power Wide-Area Network)[57] can provide.

[56] In its non-standalone version, the NR control plane is LTE's. in other words, the 4G network controls the 5G carriers and spreads users across the different bands and technologies.

[57] Sigfox and LoRa LPWAN

Annex 2 Entities Arcep met with

ERICSSON
QUALCOMM
HUAWEI
SAMSUNG
NOKIA
AIRBUS DEFENCE & SPACE
THALES
RENAULT
Systematic Paris Region Systems & ICT Cluster
TELECOM ParisTech
leti ceatech
Google
ETSI World Class Standards
bouygues TELECOM
free mobile
numericable THD
SFR
orange
GSMA

Annex 3 Figures