06

‘5G’: A BIG STEP FOR TECHNOLOGY, ONE GIANT LEAP FOR MANKIND

‘5G’ is the next big milestone in wireless communications. Expected to start being commercially exploited around 2020, it will represent a new stage in wireless communications, answering the identified requirements that will enable new ways of doing business and establishing societal relationships.

‘5G’ will reflect the already observed trend of an increasingly more ‘wireless’ world, for humans and machines. Thus, even if ‘5G’ must be implemented by technology, supported by significant future improvements, current ‘5G’ discussions are focused in the expected impacts it will have in the way we will communicate, do business, interact with the surrounding world and also foster interactions with and between artefacts. This is why, currently, ‘5G’ represents much more than a pure technological evolutionary aspect, in fact encompassing all the expected evolutions and transformations to be observed in our future communication immersive experience.

As it can be expected, ‘5G’ is flourishing in activity being the focus of all telecommunication’s actors. From researchers to businessmen, ‘5G’ is being worked in many dimensions.

This article aims at explaining what ‘5G’ means, taking a pragmatic approach with an emphasis in standardization, focusing on the technological basis of the fifth generation of wireless communications and in what is expected to be enabled by it.

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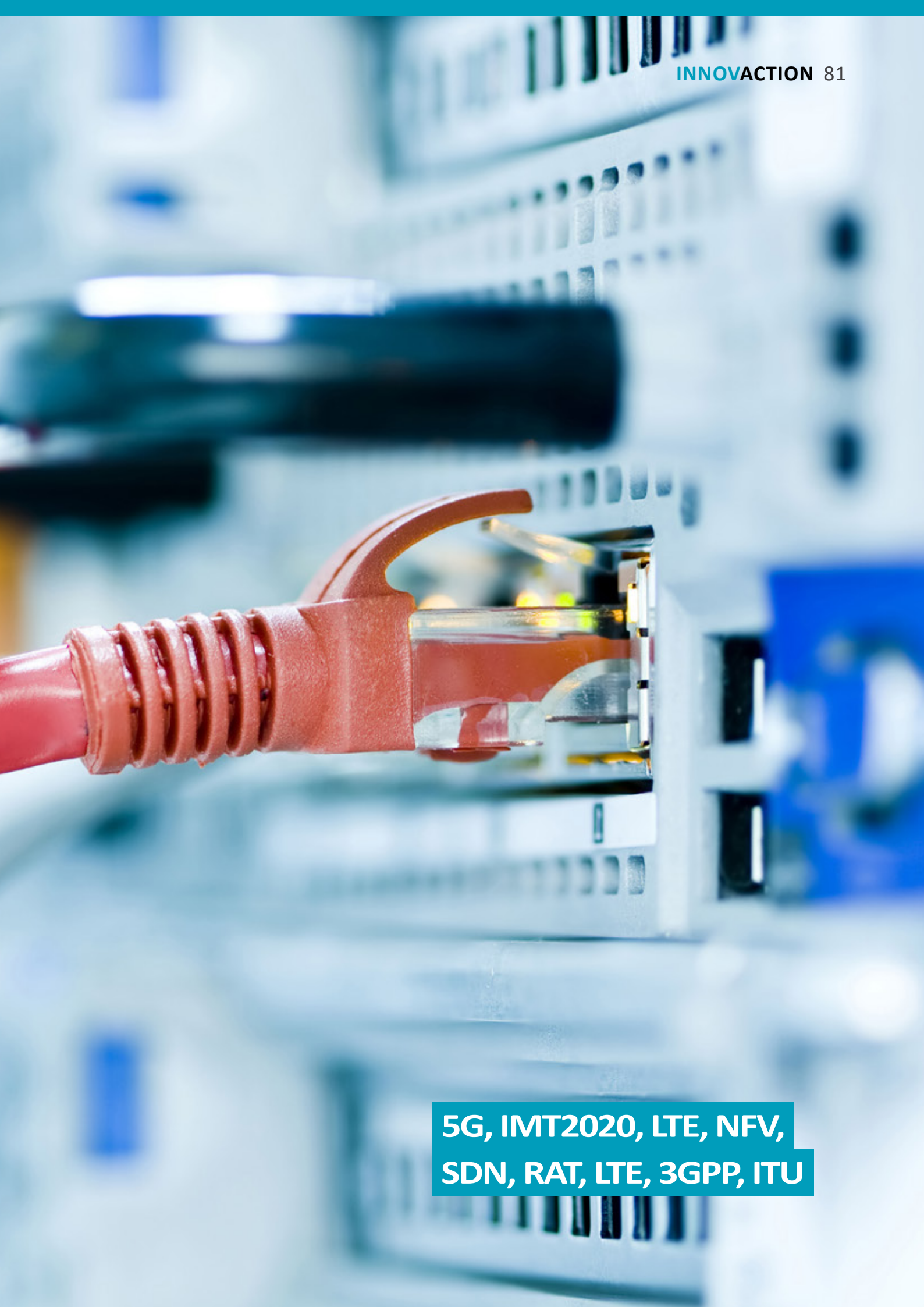

5G, IMT2020, LTE, NFV,
SDN, RAT, LTE, 3GPP, ITU

I Introduction

The following are citations from '5G' (5th Generation) related documents, produced by the identified organizations:

- ITU-R [1]: "enabling a **seamlessly connected society** in the 2020 timeframe and beyond that brings together people along with things, data, applications, transport systems and cities in a **smart networked communications environment**";
- NGMN [2]: "5G is an **end-to-end ecosystem to enable a fully mobile and connected society**. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with consistent experience, and enabled by sustainable business models";
- 5G-PPP [3]: "5G is more than an evolution of mobile broadband. It will be a **key enabler of the future digital world**, the next generation of **ubiquitous ultra-high broadband infrastructure** that will support the transformation of processes in all economic sectors and the growing consumer market demand."

As can be seen, the term '5G' has assumed a quite broad meaning, concentrating on it many different aspects, clearly going beyond previous technical scope of a mobile 'generation' definition. Today, more than technology, '5G' means all the societal and business relationships changes, expected to be observed around 2020 and beyond, supported by telecommunications. This next 'generation' is expected, according to Ericsson's forecast [4], to have 150 million subscriptions, by 2021.

Approximately every ten years a new 'generation' has emerged from 3GPP, marking important milestones in wireless communications, clearly reflecting different communication needs: from first mobile, analogue communications (1G) in the 1980s, to permanently connected and consuming broadband Internet services (4G) (Figure 1). This reflects the fact that the world and the society is increasingly becoming more 'wireless', with expect huge advances in the area, fostered by the '5G' current big excitement.

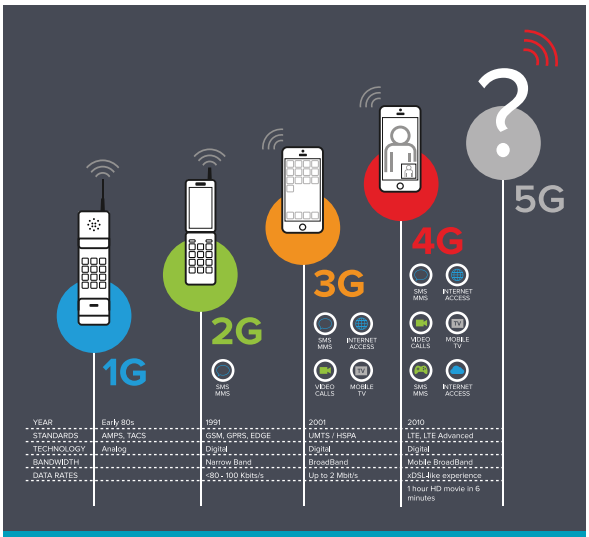

FIGURE 1 Mobile wireless network generations [6]

Currently, '5G' is in the 'wish list elaboration' phase, with many use-cases being elaborated, with the purpose of requirements extraction to, later, be reflected in supporting technological developments and standardization. As an example, the four white papers [5] on vertical sectors (eHealth, Factories-of-the-Future, Energy and Automotive), recently released by the 5G-PPP, can be taken, documenting '5G' expectations and identifying requirements.

While there is much debate related to the definition of '5G', it is widely agreed that this new network must provide improvements in capacity, deployment and operational costs, as well as ecological impact. Technically, in a few words, '5G' will bring significantly improvements on bandwidth and reduce latency, will be ubiquitous, improving geographical coverage and connecting everything, being more energy efficient and reliable, and allowing much more simultaneous connections. '5G' will be leveraged by emerging technologies, like virtualization, cloud and software defined networks, besides all current radio developments.

Recently (October 29th, 2015), ITU endorsed a resolution [7] that establishes the roadmap for the development of '5G' mobile and the term that will apply to it: "IMT-2020", under the motto "IMT-2020 to provide lightning speed, omnipresent, ultra-reliable mobile communications." More information

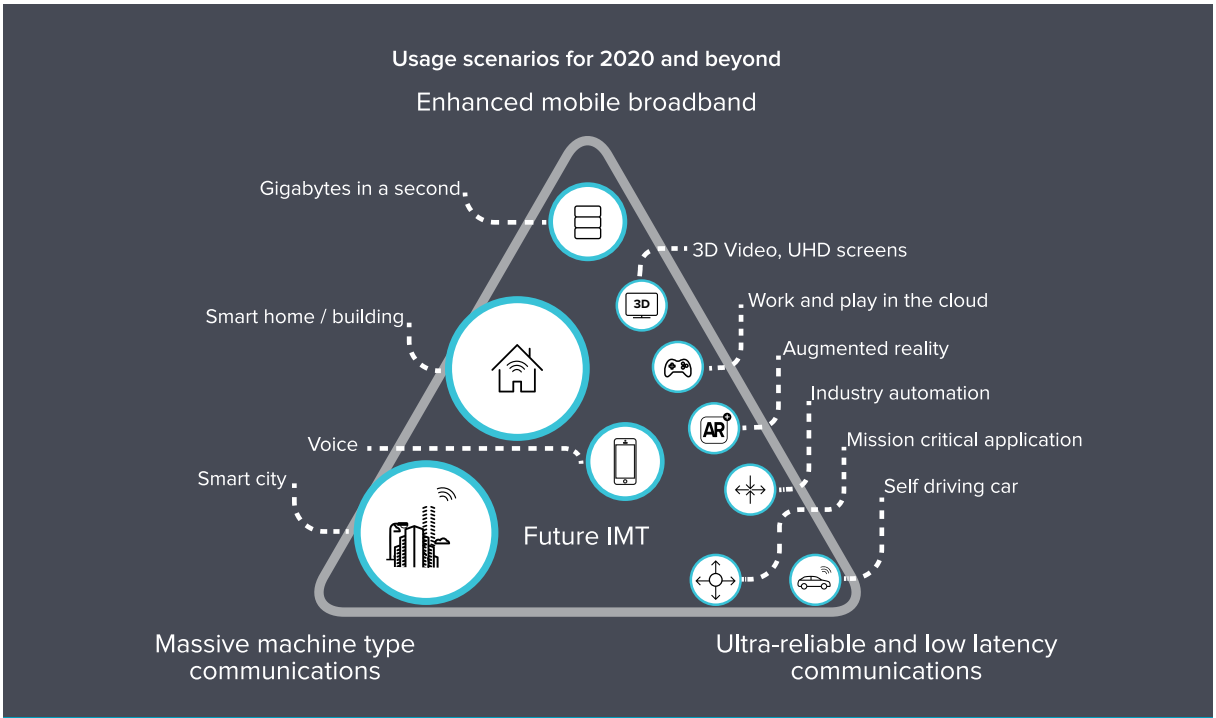

FIGURE 2 IMT 2020 and beyond usage scenarios [8]

about IMT [1] and IMT-2020 can be found at a specific ITU-R web page [9].

‘5G’ use cases and requirements

ITU-R has identified a set of ‘usage scenarios’ for ‘IMT for 2020 and beyond’ [8]. These were organized along three use case categories, as shown in Figure 2.

3GPP, via its SMARTER Study Item (Study on New Services and Markets Technology Enablers) is elaborating TR 22.891 [10], currently encompassing fifty-nine ‘use cases’, extracting requirements to be met in future 3GPP Releases’ features. This is work in progress, being complemented by results from the *NexGen* (SA2 Architecture) and RAN (Radio Access Network) activity.

The target performance enhancements required to address scenarios demands, are summarized by ITU-R in [8] in eight ‘key capabilities’, as shown in Figure 3.

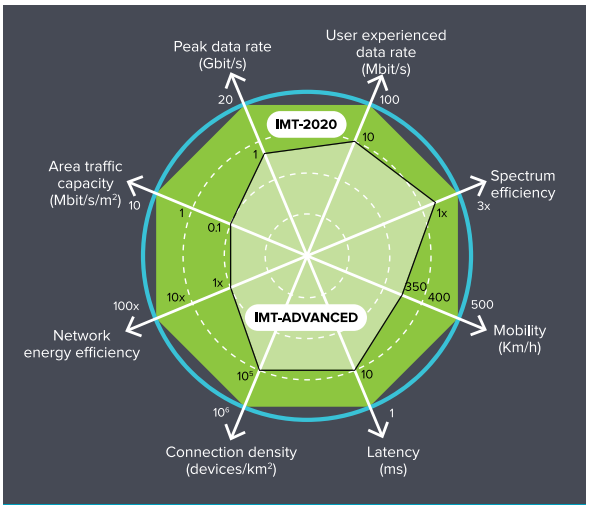

FIGURE 3 Enhancement of key capabilities from IMT-Advanced to IMT-2020 [8]

1 IMT, International Mobile Telecommunications, are standards and systems created by the International Telecommunication Union (ITU), for the creation, operation and management of mobile networks and Internet communications

These can be grouped as follows:

1. Capacity (global area traffic and connections);
1. Throughput (peak and experienced data rates);
1. Latency;
1. Mobility;
1. Efficiency (spectrum and energy).

As can be seen, the challenges are significant, with some parameters requiring enhancements with factors of 100x.

Next figure (Figure 4), also from ITU-R, maps those key capabilities into the identified usage scenarios.

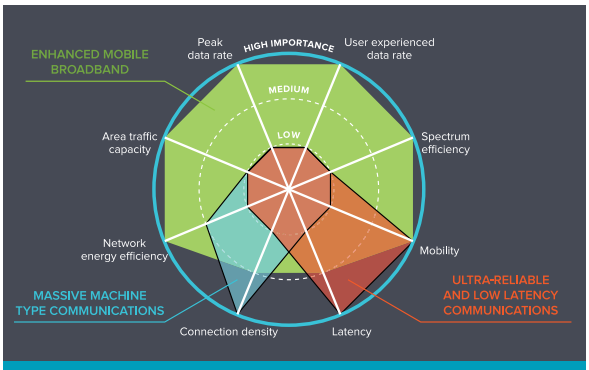

FIGURE 4 Importance of key capabilities in different usage scenarios [8]

It can be seen that eMBB (enhanced Mobile Broadband) presents the wider range of requirements, while mMTC (massive Machine Type Communications) and ultra-reliable and low latency communications have very specific requirements.

Other organizations and vendors present slightly different numbers and also add other parameters, like:

- Reduction to 20% in network management OPEX (5G-PPP);
- Services' deployment time below 90 minutes (5G-PPP);
- Cell spectral efficiency of 30 bps/Hz (Samsung);
- Cell edge data rate of 1 Gbps (Samsung).

Another relevant figure (Figure 5), from GSMA Intelligence [11], goes into more detail and shows the dependency between some identified use cases and delay *versus* bandwidth parameters.

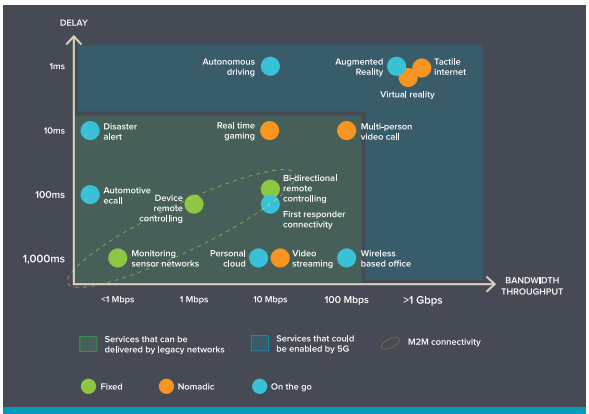

FIGURE 5 Bandwidth and latency requirements of potential '5G' use cases [12]

Based on that required improvements, 3GPP recently held the RAN '5G' workshop [13], concluding on the need for a new radio interface as the only way to answer those. This new RAT (Radio Access Technology) will not be backward compatible with previous radio interfaces (as for previous generations), but must be forward compatible, allowing an easier evolution, although it is stated that "strong LTE evolution continues in parallel."

Evolution at 3GPP towards '5G'

As shown at the introductory section, mobile wireless communications have evolved going through several 'generations' (1G/2G/3G/4G). However these designations, even if sometimes used, most of them as a marketing aspect, are not officially adopted by standardization bodies, like ITU-R and 3GPP. This will become noticeable in the next paragraphs, being referred only to establish the commonly accepted correspondence.

Even if the "original scope of 3GPP was to produce globally applicable reports and specifications for a third generation mobile system, today the project provides complete system specifications for cellular telecommunications network technologies" [14]. With this role, 3GPP is a fundamental SDO in the standardization process related to wireless communications, which "produces Technical

Specifications, to be transposed by relevant Standardization Bodies (Organizational Partners) into appropriate deliverables (e.g., standards)" [15].

LTE was firstly introduced in 3GPP Release 8, representing a significant change from previous mobile network generations: only packet switching ('All-IP') is supported, more intelligence is pushed into network edges and support for non-3GPP RATs. Still, even if branded by many as '4G', Release 8 does not fulfil '4G' requirements (being considered as '3.9G'). Those are expected to be fulfilled by 3GPP Release 10 compliant systems.

LTE-A (LTE Advanced) is the next big step in the 3GPP mobile networks, standardized in Release 10, being the first to fulfil (even to surpass) IMT-Advanced requirements for '4G', providing:

- Increased peak data rate: 3/1.5 Gbps (downlink/uplink);
- Higher spectral efficiency: 30 bps/Hz;
- Increased number of simultaneously active subscribers;
- Improved performance at cell edges: e.g. for downlink 2x2 MIMO at least 2.40 bps/Hz/cell.

The main new functionalities introduced in LTE-A are:

- Heterogeneous Networks (macro/small cells);
- Carrier Aggregation (CA);
- Enhanced use of multi-antenna techniques (MIMO, Multiple Input Multiple Output, or spatial multiplexing);
- Support for Relay Nodes (RN).

Following 3GPP Releases (11 and 12) will further improve LTE-A. These will contribute with, for instance, Coordinated MultiPoint (CoMP) in Release 11, while Release 12 introduces features to accommodate LTE-M (or 'LTE for IoT') requirements, in addition to the introduction of a new UE (User Equipment) category (LTE Category 0). Release 13 and following Releases will advance on these.

LTE-A Pro will be the next major milestone from 3GPP, to be ready in March 2016, with Release 13 freeze. For some, this is '4.5G'. It provides significant improvements, in the path towards '5G': MTC enhancements, D2D (Device-to-Device), CA enhancements, interworking with Wi-Fi, licensed assisted access (at 5 GHz), 3D/FD-MIMO, indoor positioning, single cell-point to multi-point and work on latency reduction.

From Release 13 onwards, 3GPP decided that future LTE releases will adopt the name LTE Advanced Pro (LTE-A Pro). Future Releases (14, 15 and 16) will incrementally standardize '5G', introducing features to be referred in next sections. 3GPP approaches this topic by phases:

- **Phase 1:** to be completed by second half 2018 (end of 3GPP Release 15);
- **Phase 2:** to be completed by December 2019 for the IMT-2020 submission and to address all identified use cases and requirements (end of 3GPP Release 16).

This is summarized here [16] and depicted in Figure 6:

- Release 8, December 2008: LTE is introduced;
- Release 9, December 2009: Enhancements to LTE;
- Release 10, March 2011: LTE Advanced;
- Release 11, September 2012: Enhancements to LTE Advanced;
- Release 12, June 2014: Further enhancement to LTE Advanced;

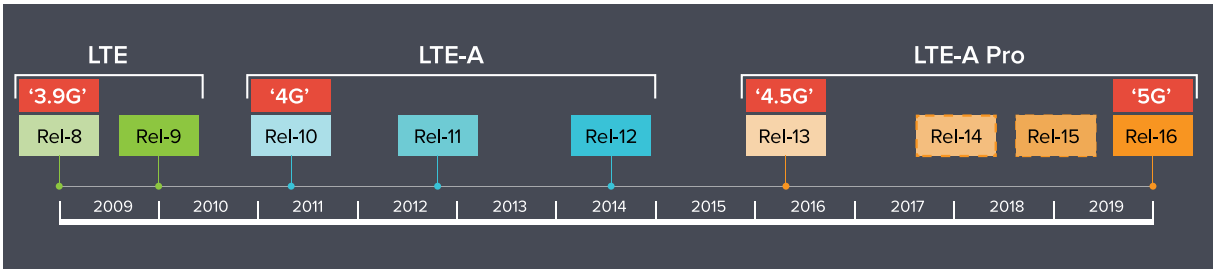

FIGURE 6 3GPP Releases calendar

- Release 13, March 2016 (expected): LTE-A Pro;
- Releases 14, 15 and 16, targeting completion on December 2019: '5G'.

For more detail on the current and future events, a 3GPP '5G timeline' [17] is presented below (Figure 7), focusing in the RAN and showing the dependencies with ITU-R.

The defined ITU-R '5G' calendar, under IMT-2020 scope, is depicted in more detail in Figure 8 [18], which shows two important events (WRC [19] 15, which already took place, and WRC 19) and several milestones.

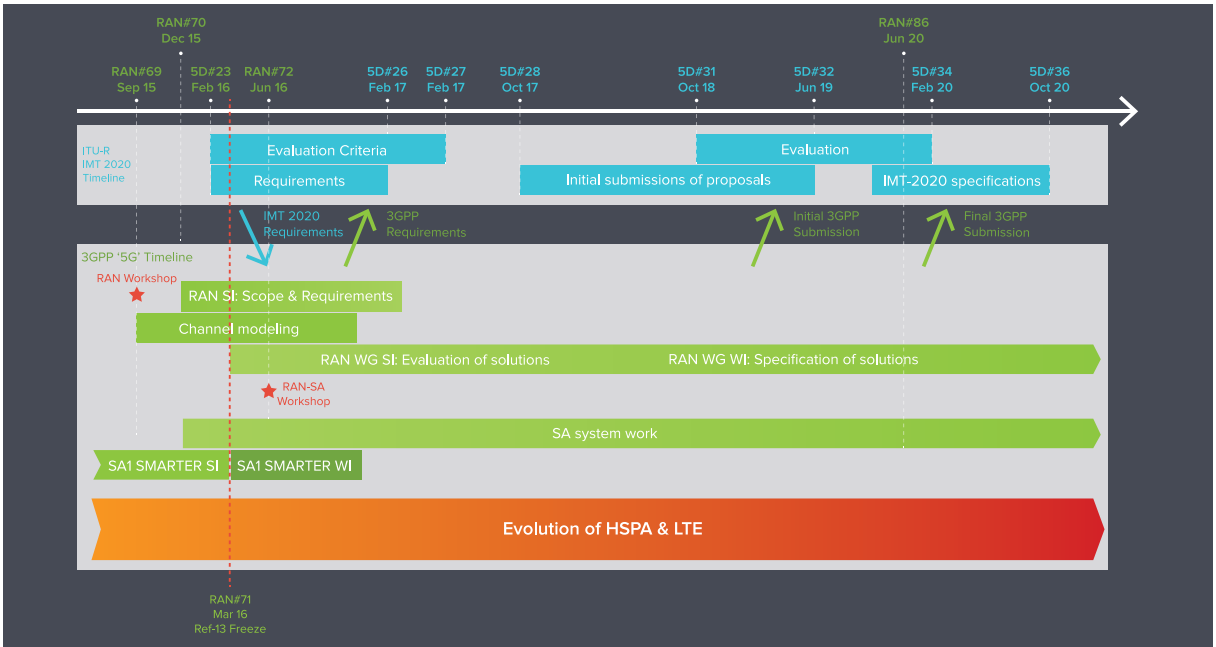

FIGURE 7 3GPP timeline for '5G' [17]

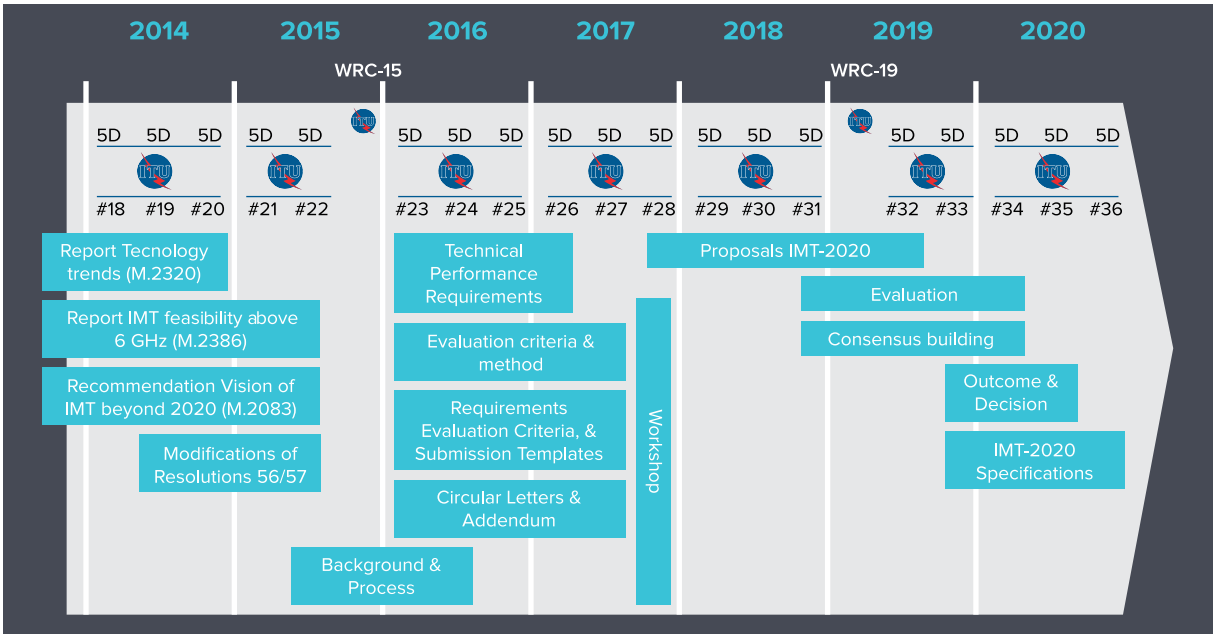

FIGURE 8 Detailed timeline & process for IMT-2020 in ITU-R [18]

IMT-2020 submission deadlines are as follows and must be accomplished by 3GPP:

- Initial technology submission: June 2019;
  - High level description of the technology;
- Detailed specification submission: October 2020;
  - Stage-3 specifications (3GPP plans to do final submission in February 2020, based on specifications functionally frozen by December 2019).

Further information on Releases' features can be found at the 3GPP web page, dedicated to Features and Study Items [20].

I '5G' technological definition

The 3GPP target is to find a "highly **flexible** and **capable** '5G' system to meet **diverse requirements** for the three usage scenarios envisaged for 2020 and beyond" [21]. Besides impacting the radio interface, a modular architecture is required in order to avoid having to answer to all required features in all the future deployments. In addition, 'Network slicing', from terminals to service platforms, heavily based on NFV/SDN, will allow building virtual networks, with specific characteristics, answering to explicit communities requirements (e.g. more data or control intensive data, priority to robustness or high bandwidth).

A large number of technologies and concepts are expected to be part of '5G', progressively evolving and being incorporated into successive Releases, as demonstrated in the previous section. Nevertheless, a revolutionary approach is expected in some areas, since pure evolution and optimization of current solutions is not enough, considering the challenging defined '5G' requirements (see section 2, on identified requirements).

In short, '5G' will need a **new radio interface**, without backward compatibility, and a **new core network architecture** (CN), to be able to provide the expected performance and functionalities for the new digital society of 2020 and beyond. This is particularly true to achieve the sub-1ms latency and the >1 Gbps bandwidth.

These two aspects, new RAT and architecture, will be the major revolutionary milestones of '5G', while other features will be appearing as evolutions from today's situation, as future 3GPP Releases will pop-up, contributing in general to achieve overall '5G' goals.

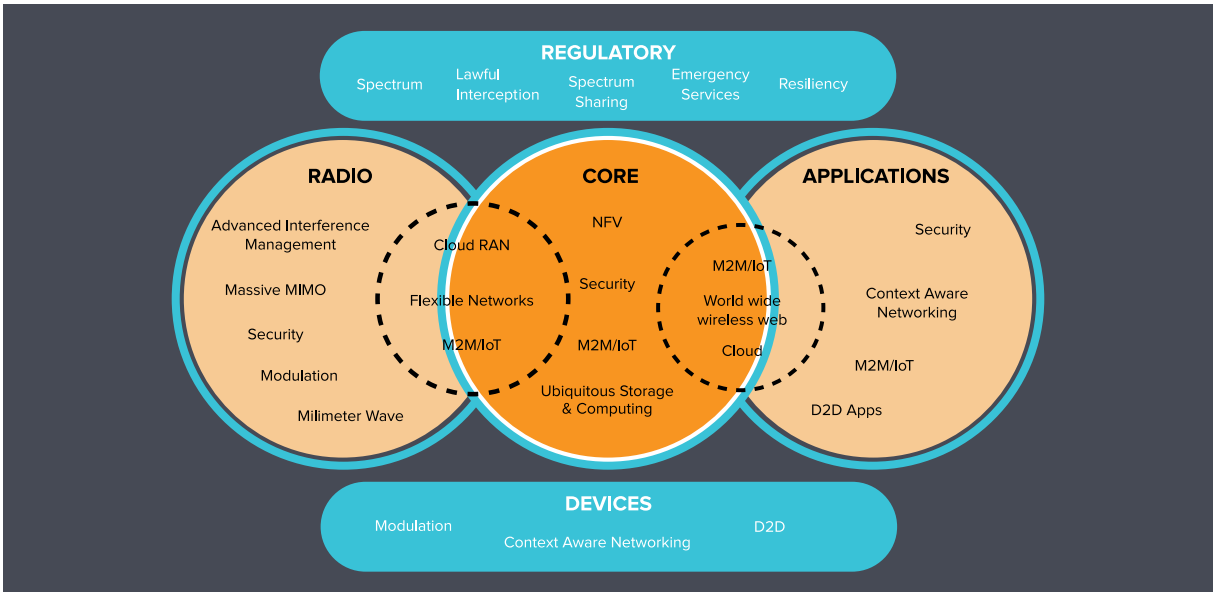

FIGURE 9 4G Americas preliminary view of the end-to-end '5G' ecosystem [22]
(Source: 4G Americas)

The next two sub-sections go into more detail about the core and access evolution. Figure 9, taken from 4G Americas [22], summarizes it, providing a holistic view on what '5G' can be.

Core Network

3GPP is addressing the definition of a new architecture via a new group called "Next Generation" (NexGen). Results are targeting 3GPP Release 14 with the objective to "design a system architecture for the next generation mobile networks" [23].

As stated by 3GPP, "Earlier 3GPP system architectures focused on the 3GPP access part. The just starting work on the next generation system architecture has a wider scope, including also considerations on non-3GPP accesses, certain access independence and convergence aspects." In fact "One of the architectural characteristic of '5G' CN is to minimize access dependencies and to allow its evolution independent of RAN; this '5G' characteristic will be viewed as one of the key requirements."

A number of goals have been identified for the new architecture (modified extract from 3GPP feasibility studies [10]):

- Allow for an independent evolution of core and radio networks;
  - Core and RAN network domains shall be functionally decoupled;
- Support multiple types of access, including new radio, LTE evolutions and non-3GPP accesses;
  - The new architecture shall minimize access dependencies;
- Allow a simultaneous use of multiple access technologies by the UE;
- Have a clear separation between Control and User plane functions (SDN principles);
- Support generic exposure of services and functions by functional elements to enable reuse by other entities (SOA principles);
- Support enhanced MBB, critical communication (CC), massive M2M use cases;
- Support network slicing, with resources isolation between slices;
- Minimize the signalling (and delay) required to start the traffic exchange between the UE and the PDN;
- Support a structural reduction of the round-trip delay to 1ms between UE and the PDN (in active state);
- Support native IP and non IP connectivity services;
- Support broadcast services;
- Support different levels of mobility, service continuity, network resilience and UE power consumption.

In order to achieve that, the new architecture, still to be defined, will integrate and be based in a number of technological components, being the generalized adoption of virtualization the main building block. Based on that, SDR and SDN (Software Defined Radio/Network), MEC (Mobile Edge Computing) and SOA (Service Oriented Architecture) shall be deployed.

Optical technologies (e.g. PON based) will also play an important role, in both backhaul and fronthaul, in order to achieve the required transport capacity, in a very dense radio access network.

Access

As stated before, the '5G' architecture will clearly integrate other access technologies, besides 3GPP defined RATs, including wired ones. Still, a new RAT is required. According to 3GPP, there is a "general consensus that the next generation RAT will be defined by RAN groups in two phases (Phase 1 and Phase 2) in two consecutive 3GPP releases (Release-15 and Release-16)."

Besides required performance, the new radio access will incorporate functionalities for emerging areas as:

- Device-to-device communication (D2D);
- Moving networks (e.g. V2x).

As with the Core Network, virtualization will also make its appearance in '5G'. In addition, several specific radio technologies will evolve and be part of the new RAT. This will include:

- Utilization of centimetre and millimetre wave bands;

  - Up to 6 GHz (Phase 1 – year 2020);
  - Up to 60/100 GHz (Phase 2 – year 2025);
- New radio access modulations, as Universal Filter Orthogonal Division Frequency Multiplexing (UF-ODFM);
- Downlink multi-user transmission using superposition coding;
- Massive/Distributed Multiple Input Multiple Output (MIMO) antenna schemes;
- 3D/FD (Full Dimension) MIMO schemes;
- Advanced inter-node coordination to minimise interference; Interference cancelation/ utilization (ICIC);
- Spectrum sensing and dynamic shared spectrum access;
- Cooperative usage of licensed and unlicensed spectrum;
- Multi-cell cooperation (CoMP);
- Massive carrier aggregation;
- New MAC (Medium Access Control) for light communications;
- Virtualized cloud based radio access (C-RAN) network control and processing;
- SON techniques, for opportunistic and adaptative use of resources;
- Cognitive radio and network;
- Multi radio access technology integration and management, including small cells and HetNets;
- Evolved satellite communications;
- Wired and wireless backhaul integration.

Other standardization bodies work

Besides ITU-R and 3GPP, other SDO are directly or indirectly contributing to '5G' definition and specification. These are a few examples, not being exhaustive in the analysis.

ETSI – European Telecommunications Standards Institute [24]

NFV and MEC are being standardized in the scope of ETSI, and are expected to be part of '5G'. While NFV is a more generic development, MEC is targeting mobile network but in its specification it is stated that no 3GPP standards' changes will occur. In this scope, 3GPP has to look into ETSI NFV work, while ETSI has to look into 3GPP work on LTE standards.

In addition, ETSI is also working in machine type communications, from where requirements are expected to extract from 3GPP in future evolution of LTE.

3GPP work in millimetre communications as to collaborate with ETSI work in mWT (millimetre Wave Transmission), since this is also under ETSI scope.

IEEE – Institute of Electrical and Electronics Engineers [25]

IEEE is further progressing the 802.11 technology: 802.11ac (Wi-Fi)/ad (WiGig)/ax. These technologies may complement or be an alternative to 3GPP developments. Considering the 3GPP architecture aim of being access independent, close work with IEEE must exist in order to integrate IEEE defined access technologies in 3GPP core. Current E-UTRAN already as support for WLAN integration.

In addition, having 3GPP looking into unlicensed spectrum for LTE operation will also need coordination with IEEE.

MEF – Metro Ethernet Forum [26]

ITU and MEF established a Memorandum of Understanding (MoU), in order to align strategies in this emerging area. '5G Cloud Access', 'integrated fixed-mobile hybrid '5G' networks' and 'virtualization' are some of the identified areas benefiting from this MoU.

'5G' research in Europe

The European Commission is heavily promoting '5G' development, funding a large number of projects and initiatives, via the Horizon 2020 (H2020) Programme [27]. H2020 is "the largest-ever European Union (EU) research and innovation programme" [28].

One of the adopted mechanisms to foster '5G' development and put the European industry in

the '5G' lead, is via the creation of a Public-Private Partnerships for '5G' (5G-PPP [29]), one of the H2020 instruments. The private part is represented by the '5G' Industry Association, encompassing almost fifty entities from the European industry and academia. The 5G-PPP contractual arrangement was signed in December 2013 between the EU Commission, representing the public stakeholder/s and the '5G' Association representig the private entities.

Information about the main H2020 '5G' funded projects ('5G' first call [30]) can be found at the 5G-PPP brochure, recently released [31]. Altice Labs is participating in four of those 18 approved projects (*Charisma*, *Selfnet*, *Sonata* and *Superfluidity*).

'5G' European funding already started in the 7th Framework Programme (FP7), with the funding of several relevant projects, addressing directly '5G' or supporting technologies. Examples of success projects from FP7 calls on '5G' are: ADEL, MCN and T-NOVA, some of these with active participation from Altice Labs.

'5G' experimentation and promotion

A significant number of initiatives have started for experimenting/trialling '5G', outside major manufacturers' laboratories. The most significant ones are:

- '5G' Innovation Centre, hosted at the University of Surrey (http://www.surrey.ac.uk/5gic):
  - Supported by Huawei, Fujitsu, Samsung, Telefónica, Rhode&Shwarz and Aircom, among others;
- 5TONIC, hosted at IMDEA (http://www.5tonic.org/);
- 5GLab, hosted at Technische Universität Dresden (http://5glab.de/):
  - Supported by Alcatel-Lucent and Vodafone, among others;
- '5G' Berlin (http://www.5g-berlin.de/) and Open '5G' Core (http://www.open5gcore.org/), both hosted by Fraunhofer FOKUS.

All relevant vendors have announcements related to '5G' experimentation. As an example there is the Munich '5G' VIA (Vertical Industry Accelerator) testbed, launched by Huawei.

'5G' is also the subject of several other organizations, intending to promote the '5G' development, experimentation and standardization. Three of these are the Korean '5G' Forum [32], the Chinese IMT-2020 ('5G') Promotion Group [33] and the Japanese Fifth Generation Mobile Communications Promotion Forum (5GMF) [34]. Agreements and collaborations between them and with the European 5G-PPP have been established. Besides promoting '5G', these organizations conduct research and development activities, aiming at standards contributions.

Additionally a significant number of partnerships and collaborations are continuously being announced, especially between operators and manufacturers, reflecting the global interest in '5G' and the required collaboration among several entities to faster prepare for the '5G' arrival.

Conclusions

Undoubtedly, humans and machines electronic communications' trend is to increasingly become more wireless. Requirements and expectations related to a new generation of mobile communications are identified via a large number of scenarios and use cases, being elaborated by several fora, including standardization bodies.

The perception of no delay ('tactile Internet') and unlimited bandwidth are at the top requirements. Other significant demands include more reliable communications and higher and denser number of connections/devices (IoT). The emphasis is also on energy and spectral efficiency, to reduce energy consumption and increase capacity.

Even if a large community is addressing '5G' and lots of investments are taking placed in technological areas related to it, there is not yet a clear '5G' definition. Standardization activities are evolving, backed by strong investments in research, development and innovation, and the European Commission, via its H2020 programme, is a good example of this effort.

IMT-2020 is the reference for that new 'generation'. From LTE, defined in Release 8, to LTE Advanced Pro, based in Release 13, soon in production, Releases 14 to 16 shall progressively address those IMT-2020 requirements.

From 3GPP point of view, a new RAT is required. However, '5G' must go well beyond that, requiring a new architecture, which shall be access network independent, flexible and service oriented. Thus, '5G' architecture is expected to emerge out of technologies like virtualization, cloud and SDN.

Defined use cases and scenarios clearly demand for a new approach, which must focus on common solutions instead of specific, dedicated solutions for each challenge, simplifying network architecture.

A final word to 'beyond 5G': even not knowing today exactly what '5G' will be, work on what 'Beyond 5G' (B5G) might be has already started [35]. Considering that '5G' will be developed in two phases, 'B5G' intends to provide inputs to '5G' Phase 2' and what will come after this, leading to 6G:

- Phase 1: technically introduced by 2018/20 using spectrum allocated in WRC-15 [36] below 6GHz. This is what is referred in this document as '5G';
- Phase 2: technically introduced by 2025 and maybe lasting to 2030, adding spectrum allocated in WRC-19 above 6GHz.

As it could be expected, inputs at this time are very vague, confirming some of the expected '5G' enhancements and further extending some of those. Extensive 'softwarization' and more 'intelligence' are referred, as well as extending MIMO and a detailed look into optical wireless.

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