Wireless next generation development

Loreno M. da Silveira
School of Technology
UNICAMP
Campinas, Brazil
loreno.silveira@pos.ft.unicamp.br

Paulo S. Martins
School of Technology
UNICAMP
Campinas, Brazil

Edson L. Ursini
School of Technology
UNICAMP
Campinas, Brazil

***Abstract*— ITU and 3GPP have been working in a very cooperative and productive way to achieve viable standards for mobile wireless networks. This paper provides a demystifying overview of 5G standards development, where the subject matter has been studied, showing how those specifications have been successfully carried out since the definition of 3G mobile wireless systems. Focus is given on performance requirements and main characteristics.**

Keywords—ITU, 3GPP, IP, TCP, UDP.

I. INTRODUCTION

The objective of this paper is to present a research and summary report of the ongoing specification work and field tests, aiming at the development and deployment of 5G systems. A brief history of 3G and 4G system requirements is also presented for illustration.

II. EARLIER GENERATIONS

A. *First standard: IMT-2000*

The standardization process concerning to mobile communications was very chaotic until 1997, when there were many organizations, many groups and many technologies competing, but no agreement achieved. A new family of technologies ensuring global roaming and interoperability between the various technologies, as well as new services and better performances was needed. After substantial harmonization work, ITU-R approved, in the year 2000, the technical specifications for third generation systems under the concept of International Mobile Telecommunications 2000 (IMT-2000), including among others, the following requirements [1], [2]:

- Worldwide usage, allowing smooth migration of 2G Systems;
- Wide range of telecommunications services (voice, data, multimedia);
- Support both packet-switched (PS) and circuit-switched (CS) data transmission;
- Offer data rates up to 2 Mbit/s: a minimum speed of 2Mbit/s for stationary or walking users, and 384 kbit/s in a moving vehicle;

IMT-2000 was the result of collaboration of many entities inside the ITU (ITU-R and ITU-T) and outside the ITU (for example, 3GPP and equipment industries). It took a lot of paper work, and tests to achieve standards on, for example, architecture, interfaces, physical media, protocols, and services.

B. *Standards evolution*

Early 3GPP versions, such as *Universal Mobile Telecommunications Systems (UMTS)* did not meet the ITU-R Requirements (IMT-2000) in their implementations, making clear the need to develop new standards [2].

Furthermore, a fast-growing subscribers plant (at the end of 2008, there were about 4 billion mobile cellular subscriptions worldwide, compared to 740 million in 2000), new services such as multimedia services, Internet services, social networking, among others, demanded a completely new machine, which arrived as a new wireless generation.

The formal definition of fourth-generation wireless known as the International Mobile Telecommunications Advanced project - IMT Advanced was published by the ITU-R in July 2008, including the following requirements:

- compatibility of services within IMT and with fixed networks;
- capability of interworking with other radio access systems;
- enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research).

It is usual to refer to in-between generations, for example, 2.5G or later 3.5G, complying with part of the ITU-R requirements. In-between generations have not a corresponding ITU-R request, and for the sake of simplicity, will not be considered in this document.

When ITU-R formally established the IMT Advanced requirements through [3-4] it was clear that the first *Long Term Evolution - LTE* version (Release 8) of 3GPP did not meet them, particularly as for peak data rates and spectral efficiency (ratio of maximum net transfer rate per carrier to bandwidth per carrier). Consequently, work on IMT Advanced (4G) continued in 3GPP later versions, under the technological name of *LTE-Advanced*. Release 10 was the first to comply with performance parameters established by the ITU-R, Release 13 is frozen since March 2016, and it makes available a lot of interesting technologies, including the *Internet of Things*. Other

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features are to come, and LTE-Advanced should continue to evolve.

However, since 2014 a new wireless next generation is worldwide expected, aiming at a new set of applications, mainly built over IPv6, and enabled by very different technologies [5].

III. NEXT GENERATION ITU-R VISION

ITU-R defined the objectives, process, and timeline for the development of IMT-2020 (or 5G, as it is known) at [6]. ITU-R also published at September/2015 at [7], its vision concerning applicable requirements on 2020 mobile wireless systems. Three different usage scenarios were envisaged:

- *massive Machine-Type of Communications (mMTC)*: Applications where a very large number of devices are interconnected exchanging a low traffic of non-delay sensitive data. Examples include Internet of Things (IoT), e-health, e-Farm, smart city, smart home etc.;
- *enhanced Mobile Broadband (eMBB)*: The demand for traditional human-centric mobile broadband communication does not stop to increase, leading to performance and seamless improvements, and sometimes to very different figures like hotspots and wide area coverage. Expected new functionalities are Virtual Reality, Augmented Reality, Holograms, High Mobility cases (Planes, trains), etc.;
- *Ultra-Reliable and Low Latency Communications (URLLC)*: Critical applications, with very stringent Quality of Service (QoS) requirements. Examples include industrial control processes, smart grid distribution automation, Drones & Robotics, transportation security, Driving support systems, autonomous cars, etc.

Fig.1, adapted from [7, p. 12, FIGURE 2] depicts the scope of the foreseen 5G applications:

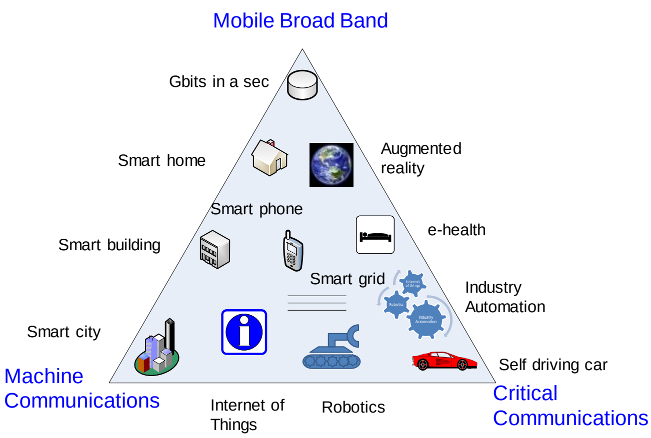

Figure 1: 5G applications

Table I summarizes the main characteristics of each ITU-R defined generation, comparing to 5G:

TABLE I. MOBILE WIRELESS GENERATIONS

MOBILE WIRELESS GENERATIONS	***3G***	***4G***	***5G***
ITU-R Year/Name	2000/IMT-2000	2012/IMT Advanced	2020/IMT-2020
Peak data rate	2 Mbit/s	1 Gbit/s	20 Gbit/s
Peak spectral efficiency	Not specified	15 bit/s/Hz	30 bit/s/Hz
Latency (User Plane)	Not specified	10 ms	4ms-eMBB 1ms-URLLC
Latency (Control Plane)	Not specified	100 ms	10-20 ms
Supported Services	Multimedia Messaging, Medium Speed Data	Broadband Multimedia, Social networks	mMTC, URLLC, eMBB

Summary, extracted from [1-9]

ITU-R based that concept on Market and technological trends as follows:

A. *Market trends*

Users expect some very clear features:

- Enhancements on the QoS for current human-centric communications. QoS parameters include throughput, latency, availability, and others;
- High user density (communications usage in crowds);
- Introduction of critical and massive machine type of communications;
- Convergence of applications.

B. *Technological trends*

- Radio Interface enhancements: new modulation, coding, and multiple access schemes like filtered OFDM, new antenna technologies, such as MIMO and Beamforming enhancements, new access techniques such as flexible backhaul and dynamic radio access configurations, technical feasibility of usage the spectrum resources between 6 GHz and 100 GHz, etc.;
- Network technologies: Software Defined Networking (SDN), Network Function Virtualization (NFV) for processing of node functions and increase of the operational efficiency of the network. NFV involves network functions implementation in software resident on standardized servers, and that can be instantiated in various locations in the network, without the need to install new hardware/software.
- Terminal technologies: terminals are evolving to be predominantly a multi-purpose portable computer and a hand-held device to control other wearable smart devices.

C. Capabilities

Under this title, ITU-R defines eight performance parameters to cater for the different scenarios:

- Peak data rate (in Gbit/s);
- User experienced data rate (in Mbit/s or Gbit/s);
- Latency (in ms);
- Mobility (in km/h).
- Connection density (connections per km^2);
- Energy efficiency (in bit/Joule);
- Spectrum efficiency (bit/s/Hz);
- Area traffic capacity (in Mbit/s/m^2).

Fig. 2 (extracted from [7, p. 14, FIGURE 3]) compares the general needs of IMT-2020 with IMT-Advanced capabilities:

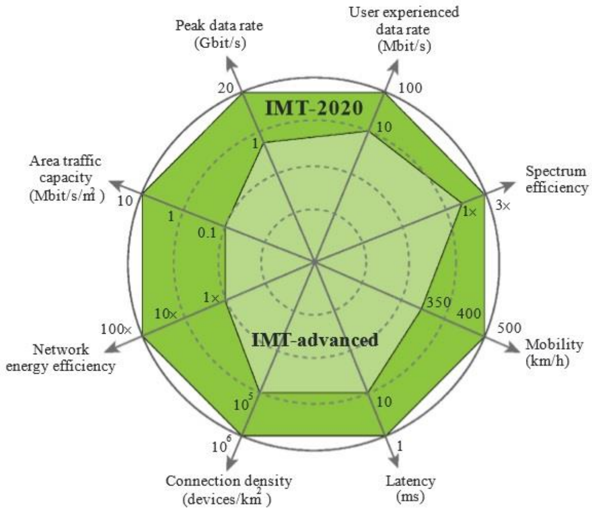

Figure 2: Enhancement of key capabilities from IMT-Advanced to IMT-2020

The peak data rate of IMT-2020 for enhanced Mobile Broadband is expected to be 20 Gbit/s (Downlink-DL) and 10 Gbit/s (Uplink-UL). For wide area coverage applications, a user experienced data rate of 100 Mbit/s is expected. In hotspot applications, the user experienced data rate is expected to reach higher values (1 Gbit/s indoor). The spectrum efficiency is expected to be three times higher compared to IMT-Advanced for enhanced Mobile Broadband. IMT-2020 is expected to support 10 Mbit/s/m^2 of area traffic capacity, for example in hot spots. The energy consumption for the radio access network of IMT-2020 should not be greater than IMT networks deployed today, while delivering the enhanced capabilities. The network energy efficiency should therefore be improved by a factor at least as great as the envisaged traffic capacity increase of IMT-2020 relative to IMT-Advanced for enhanced Mobile Broadband. IMT-2020 would be able to provide 1 ms over-the-air latency, capable of supporting services with very low latency requirements. IMT-2020 is also expected to enable high mobility up to 500 km/h with acceptable QoS. This is envisioned for high speed trains. Finally, IMT-2020 is expected to support a connection density of up to 10^6 connections/km^2, for example in massive machine type communication scenarios.

D. Timeline

As for ITU-R detailed timeline, Working Party 5D developed a work plan, for the future development of IMT-2020. It was agreed that the same process and deliverable formats utilized for both IMT-2000 and IMT-Advanced should be used for IMT-2020. Results achieved so far include a study on the need and feasibility of frequencies in the range above 6 GHz (centimetric and millimetric wavelengths), and the 2020 Vision document [8].

Figure 4, adapted from [8, p. 2, FIGURE 1] depicts the main steps to accomplish the IMT-2020 specifications. During 2017 the work was concentrated on evaluation criteria and submission templates, circular letters were sent, and after a workshop held in October, proposals will be expected and later evaluated during 2018 and 2019 respectively.

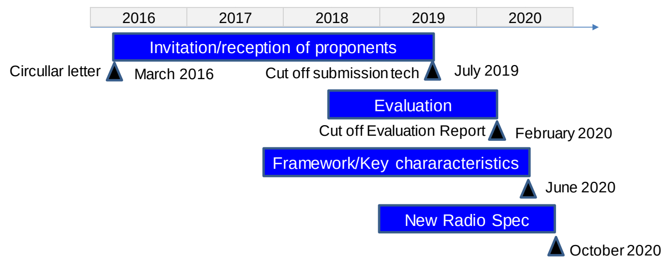

Figure 3: Present Time schedule

IV. RELEASES ON 3GPP

Fig. 4, extracted from [10, p. 7, Figure 1.1] 3GPP RAN Progress on 5G presents how 3GPP planned to meet ITU-R requirements.

Figure 4: 3GPP execution

3GPP has established a two-step approach to study new technologies needed to meet the IMT-2020 requirements, corresponding to two releases, after Release 14, i.e., Release 15 and Release 16, with the objective that only in Release 16 the full functionality and performance necessary to meet IMT-2020 requirements will be achieved. 3GPP planned date for Release 15 is June/2018 and for Release 16 is March/2020.

High level requirements considered for Release 15 were:

- As a minimum, interworking and migration with LTE-Advanced deployed systems;

- Access Agnostic, meaning that WiFi, WiMax, and LTE access are allowed;
- IP Multimedia Subsystems - IMS / Voice over LTE - VoLTE support;
- Mobility Management and Roaming;
- Session Management and Session Continuity;
- QoS and Policy Frameworks;

Therefore, a completely new architecture was considered, regarding the co-existence of radio technologies (LTE and 5G) and Core Network concepts. Draft Technical Specifications for Requirements, Architecture, and Stage 2 (System Flows) [11] were completed, with the focus on Stage 3 freezing process by June to September of 2018.

V. Trials and Studies

A lot of 5G trials, all over the world, are taking place. Reference [10] reports some of them, which had happened in USA:

- In the beginning of 2016, AT&T started 5G trials in Austin, Texas, after having assured special licensing from the U.S. government. Outdoor testing began in July and field trials to provide wireless connectivity to fixed locations in November to December. AT&T's fundamental technology approach to 5G is built on its industry leading positions in Software-Defined Networking (SDN), data analytics, security, and open source software;
- In June 2016, Sprint demonstrated elements of 5G at a large scale public event (Copa America Centenario). The Sprint demonstration with a leading vendor used carriers on the 73 GHz millimeter wavelength spectrum to deliver peak downlink rates of more than 3 Gbit/s. Sprint also demonstrated with another leading vendor using carriers of 15 GHz centimeter wavelength spectrum to deliver downlink rates up to 4 Gbit/s;
- Leading vendors are also launching their laboratory and pre-standard field trials. There are various 5G Radio Prototypes, which can be deployed by operators in live field trial environments, showing exceptional performance under real-world conditions, achieving a peak throughput of 27.5 Gbit/s and latency as low as 2ms in a live demonstration in August 2016. The 5G available Core combines flexibility and efficient management; it is based on the five key technologies already mentioned, i.e., Network Function Virtualization (NFV), Software-Defined Networking (SDN), Distributed Cloud, Network Slicing and Orchestration and Management. Dynamic resources management allows service providers to create network slices on-demand, software-defined, and amenable to environments where there is at least one third-party service provider. This successful Proof-of-Concept for dynamic network slicing technology for 5G core networks was demonstrated in June 2016 (USA);
- A leading semiconductor company was first to announce a prototype system and trial platform for 5G New Radio (NR) with frequencies below 6 GHz to test, demonstrate and trial 5G. In addition, that vendor demonstrated also robust 5G Radio design for millimeter wavelength carriers in the spectrum above 6 GHz.

Other countries and operators have extensively tested solutions and parts of the 5G architecture, e.g., Japan (NTT DoCoMo), Australia (Vodafone Australia), China (China Mobile), South Korea (Korea Telecom), Turkey (Vodafone Turkey and Turkcell), Canada (Bell Canada), Verizon (USA), France (Orange), UK (Vodafone), etc. The range of frequencies used for trial has remained between 3 and 90 GHz. For some vendors, the objective could be to test methods of improving spectral efficiency, to test new core network technologies or to test only 5G terminal devices.

The academic research in recent years has mainly addressed performance parameters evaluation, for example, Özçevik et al [12] presents and compares three end-to-end delay optimization solutions to avoid bottlenecking of UDP traffic by TCP traffic on 5G systems or procedures optimization, e.g., Cominardi et al in [13], which addresses the issue of handover procedure after establishing the communication with the destination data network. The new procedure releases the previous gateway and forwards the packets directly to the destination, avoiding the internal retransmission of packets in the 5G Core Network.

VI. Conclusions

The paper has shown the technical motivation behind the concepts of 3G and 4G. New services and capabilities do require a new generation of mobile wireless networks. It is a huge task to converge so many trends and approaches into a new product, moreover when new service exploitation scenarios are being introduced or expected, like network virtualization or slicing.

The Next Generation, however has an additional challenge: it needs to be flexible to overcome a paradigm shift. Instead of one operator, future IMT systems will be shared by multiple stakeholders, instead of cell phones, interconnected devices are the target market, instead of dedicated hardware and software, business expect dynamic resources management and network slicing [10]. Fortunately, the industry has been very responsive concerning construction of a robust 5G environment.

It may be noticed that, since 3G, the two standardization bodies ITU and 3GPP have had proposals somehow different or complementary, especially concerning the performance requirements. Therefore, this work entailed a careful study of their performance specifications to evaluate occasional gaps or inconsistencies which may eventually appear in the future.

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