Technical Challenges and Categorization of 5G Mobile Services

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***Abstract*—** With the explosive increase in mobile and Internet of Things (IoT) networks, 5G mobile networks is being deployed to improve the user experiences with new types of services, like Augmented Reality (AR), Virtual Reality (VR), Ultra-High-Definition (UHD) videos, smart offices, and seamless interactive user experiences. Based on the performance attributes of such services, the International Telecommunication Union - Radiocommunication Sector (ITU-R) recommended three main categories of usage scenarios for 5G networks: enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC), as well as Ultra-Reliable and Low-Latency Communications (URLLC). Based on the Key Performance Indicators (KPIs) of such scenarios, we propose to divide the services offered into 3 families: broadband multimedia services, Machine-Type Communications (MTC) services, and mission critical services. For each service family, we identify and characterize the most significant categories of use cases, in terms of their main requirements. The proposed service categorization may serve as a guide for operators, and may help them to be efficient in future deployment of 5G mobile services in the world.

Keywords—5G networks; Internet of Things (IoT); Key Performance Indicator (KPI); mobile services; usage scenario.

I. Introduction

With the explosive increase in mobile and Internet of Things (IoT) networks, several problems are anticipated with current mobile networks (3G, 4G) [2]. In this context, 5G mobile networks need to be deployed with the following capabilities [1], [11], [14]:

- Providing higher network capacity and better coverage;
- Implementing a flexible and scalable architecture to adapt to diverse needs of users and services;
- Making efficient use of various spectrum resources;
- Having stronger connection capabilities to deal with the access requirements of huge amounts of IoT devices.

Up to now, 113 operators have launched 5G mobile networks across 48 countries, mostly in mature markets led by the USA, China, and South Korea [5]. Such networks enable to reach high data rates and high reliability required by the consumers while also providing high mobility, which improves the user experiences and enables new use cases, like Augmented Reality (AR), Virtual Reality (VR), Ultra-High-Definition (UHD) videos, and seamless video calling [2]. In addition, more accessible broadband on public transportation and in smart offices will create immersive and interactive user experiences (mobile TV, on demand video) [13]. Service reliability will also be critical in delivering public safety and emergency response services. As a result, the number of 5G subscriptions is expected to increase to over 3 billion at the end of 2025 [5].

In this paper, we propose to categorize 5G mobile services in terms of their Key Performance Indicators (KPIs). Section 2 defines and explains the most significant KPIs of 5G mobile networks, then shows the improvements related to 5G KPIs, compared with those of 4G. Section 3 describes the main categories of 5G usage scenarios, as recommended by the International Telecommunication Union - Radiocommunication Sector (ITU-R) [14]: enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC) and Ultra-Reliable and Low-Latency Communications (URLLC). In section 4, we propose to divide 5G mobile services into 3 families, and we identify, for each service family, the most significant categories of use cases, in terms of their main requirements. Section 5 gives some concluding remarks and perspectives.

II. Technical objectives

5G mobile networks represent a significant shift for the industry, as they outperform previous generation systems [11]. Table I shows the most significant technical objectives, in terms of their KPIs for 5G, compared with those of 4G, as defined by ITU-R [8]. Such indicators include the bandwidth, the user experienced and peak data rates, the latency, the mobility, the connection density, as well as the average spectral efficiency. Each KPI will be defined and explained in the following.

Bandwidth refers to the maximum aggregated system bandwidth. In the context of 5G mobile networks, ITU-R encourages operators to support bandwidths of 1 GHz.

The available bandwidth and site density have a strong impact on the available user experienced data rates. Based on that, user experienced data rates vary from 1 Gbps downlink and 500 Mbps uplink for indoor hotspot environments, to 50

Mbps downlink and 25 Mbps uplink for rural macro environments.

Peak data rate is the highest theoretical data rate when all assignable radio resources for the corresponding link direction are utilized. The targets for peak data rates are 20 Gbps for downlink (DL) and 10 Gbps for uplink (UL).

End-to-End (E2E) latency is defined as the time from when a source sends information to when the destination receives it. The 5G system is being designed to support 1 ms over-the-air latency for ultra-low latency design and 10 ms end-to-end latency. The E2E latency requirement is set to 1 ms for Ultra-Reliable and Low-Latency Communications (URLLC) and 4 ms for enhanced Mobile Broadband (eMBB) services.

Mobility refers to the maximum speed (km/h) at which a user can achieve a defined Quality of Service (QoS) without interruption. In 5G networks, the mobility target is set to 500 km/h. Inter-system mobility refers to the ability to support mobility between 5G networks and other mobile systems (2G, 3G, 4G).

Connection density refers to the total number of devices per unit area (km^2) that can send and receive data or access requests within a given time. In urban environments, the target for connection density should be 1,000,000 devices/km^2 (one million connections per square kilometer).

Also, ITU-R has defined the area traffic capacity as the total traffic throughput served per geographic area (Mbps/m^2). This parameter is only defined for indoor hotspots, such as office environments. The target is 10 Mbps/m^2 for the downlink (DL). However, the capacity targets may be as high as 15 Tbps/km^2 with 250 000 users/km^2.

TABLE I. COMPARISON OF 5G TECHNICAL OBJECTIVES WITH THOSE OF 4G

Key Performance Indicator (KPI)	4G	5G
Bandwidth	Up to 20 MHz/radio channel (up to 100 MHz aggregated)	Up to 1 GHz (single or multiple carriers)
User experienced data rate	10 Mbps	100 Mbps
Peak data rate	DL: 1 Gbps UL: 0.05 Gbps	DL: 20 Gbps UL: 10 Gbps
Latency	10 ms	1 ms
Mobility	350 km/h	500 km/h
Connection density	100 thousand devices/km^2	1 million devices/km^2
Area traffic capacity	0.1 Mbps/m^2	10 Mbps/km^2 (hot spots)
Average spectral efficiency		Indoor - DL: 9 bps/Hz - UL: 6.75 bps/Hz Urban - DL: 7.8 bps/Hz - UL: 5.4 bps/Hz Rural - DL: 3.3 bps/Hz - UL: 1.6 bps/Hz
Peak spectral efficiency	DL: 15 bps/Hz UL: 6.75 bps/Hz	DL: 30 bps/Hz UL: 15 bps/Hz

Average spectral efficiency, also known as spectrum efficiency, is defined as the average data throughput per unit of spectrum resource and per cell (in bps/Hz/cell). The minimum requirements depend on the test environments as follows:

- Indoor hotspot: 9 bps/Hz/cell in the DL, 6.75 bps/Hz/cell in the UL;
- Dense urban: 7.8 bps/Hz/cell in the DL, 5.4 bps/Hz/cell in the UL;
- Rural: 3.3 bps/Hz/cell in the DL, 1.6 bps/Hz/cell in the UL.

The targets for peak spectral efficiency are 30 bps/Hz for downlink, and 15 bps/Hz for uplink. Such improvements promise to have a profound impact, from unexpected use cases to transforming the entire industries.

We realize that, compared with 4G, 5G make significant improvements in each parameter, which enables to achieve sustainability for the next few years in mobile communication networks.

III. TAXONOMY OF USAGE SCENARIOS

Based on their performance attributes, ITU-R has recommended three main categories for 5G usage scenarios [14]: enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC), and Ultra-Reliable and Low-Latency Communications (URLLC).

eMBB addresses human-centric use cases for access to multimedia content, services and data. These use cases generally have requirements for higher data rates and better coverage, providing higher speeds for applications such as streaming, Web access, video conferencing, and virtual reality. This category of usage scenarios also comes with new application areas and requirements, for improved performance and an increasingly seamless user experience. The highest data rates will occur in small cells with limited end user mobility, such as pedestrians.

mMTC usage scenarios are characterized by a huge number of connected devices, transmitting relatively low volume of non-delay-sensitive data in a small area. As a result, such scenarios generally have requirements to support very large device density. In this context, devices are required to be low cost and have very long-life batteries, such as five years or longer.

URLLC, also referred to as critical Machine-Type Communications (cMTC) or "mission-critical" communications, is envisioned to enable real-time control and automation of dynamic processes in various fields, such as industrial process automation and manufacturing, energy distribution, drone control, new medical applications (like remote surgery), and intelligent transport systems. Of the three categories, URLLC enables wireless applications that are not feasible with previous mobile systems (2G, 3G, 4G). These applications and use cases have stringent requirements for throughput, latency, reliability, and availability.

Similarly, IMT-2020 Promotion Group has proposed four 5G technical scenarios which resemble to the above usage scenarios proposed by ITU-R [14]. The main difference is that eMBB scenario is divided into two different scenarios: seamless wide-area coverage, which involves environments with high mobility level; and high-capacity hot-spot, which is related to areas with high user data rate, high user density, and high traffic capacity.

In the same vein, the Next-Generation Mobile Networks Alliance (NGMN) has proposed eight use case families for 5G networks: broadband access in dense area, broadband access everywhere, high user mobility, broadcast-like services, extreme real-time communication, lifeline communication, ultra-reliable communication, and massive Internet of Things [14]. It is important to mention that such use case families are related to the ITU-R usage scenarios as follows:

- The eMBB usage scenario is related to the first four families, *i.e.*, broadband access in dense area, broadband access everywhere, high user mobility, broadcast-like services;
- URLLC corresponds to extreme real-time communications, lifeline communications and ultra-reliable communications;
- mMTC is related to massive Internet of Things.

However, such service classification does not really match the usage scenarios proposed by the main standardization organizations (ITU-R, IMT-2020, NGMN).

IV. A Typology of 5G services

Based on the KPIs presented in Table I and on the conventional usage scenarios presented in Section III, we propose to divide the services offered by 5G mobile networks into 3 families: broadband multimedia services, Machine-Type Communications (MTC) services, and mission critical services. In this section, we characterize each service family and present the most significant use cases for each of them.

A. Broadband multimedia services

For broadband multimedia services, the user experienced data rate, area traffic capacity, peak data rate, mobility, energy efficiency and spectrum efficiency all have high importance, whereas mobility and the user experienced data rate do not have the same importance in all use cases simultaneously. For this service family, we identify 3 significant categories of use cases: in-vehicle media, enhanced multimedia, and broadband access. Table II depicts the main requirements of each use case category.

1) In-vehicle media: Providing enhanced connectivity to vehicle passengers becomes important [3], [19]. In this context, in-vehicle media consists of providing robust communication link and high-quality Internet access for information, entertainment, and interaction in high mobility environments, such as high-speed trains, cars, and buses. This includes features, such as high-definition video streaming, video conferencing, and entertainment media, which may be delivered to smartphones and tablets. This category of use cases is an important driver for 5G, as sufficient data rates and bandwidth to serve all passengers in the vehicle need to be considered.

2) Enhanced multimedia: This category of use cases focuses on different types of multimedia services that include regular live media, on-demand content, user-generated content, virtual reality, augmented reality, and gaming [1]. Recent developments on high-definition and ultra-high-definition, such as 4K and 8K video resolution, 3D video content, streaming audio and video services, and on-demand video over a growing number of video-capable devices, using enhanced data capacity and data rates, are the key driving factors for this category of use cases. The targeted users are the end viewers, operators, broadcasters, content owners, and content aggregators. Such end users are consuming media on a number of devices that include smartphones, tablets, and wearables, and that are capable of recording and capturing daily experiences, which leads to a dramatic increase in user-generated content.

Also, the growing size and scale of social media platforms, like Facebook, Instagram, and Snapchat, are driving the requirements for increased data rates. Furthermore, for mobile-learning (m-learning), many forms of connected-education are being enhanced, including high-resolution, and telepresence-based distance learning. As a result, the category of *Enhanced multimedia* use case requires high data rates and low latency to provide high resolution multimedia content to an increasing number of end users with high QoS requirements. In this context, 5G technologies are expected to play a key role for this category of use cases, providing high-quality media experience to meet the growing demands of multimedia consumption.

3) Broadband access: This category of use cases is characterized by broadband data access across a wide coverage area in crowded locations and office areas [1]. It enables to provide the maximum user experience by providing connectivity both indoors and outdoors while delivering high QoS broadband, even in challenging network conditions. Following are some of the use cases in this category: hot spots, general broadband access, and smart offices.

Hot spots use case enables to provide enhanced broadband access in densely populated areas, such as city centers and crowded areas, where low mobility and high user experienced data rates are required. In particular, o*utdoor events* require providing very high connection density in scenarios, such as stadiums, concerts, and large gatherings, where thousands of users are simultaneously being served at high data rate and low latency.

General broadband access use case enables to guarantee user experienced data rates of at least 50 Mbps everywhere across the coverage area, while high level of mobility is required.

Smart offices use case is characterized by heavy data traffic exchanged in indoor environments that require low mobility level, where hundreds of users may require ultra-high bandwidth to serve intense bandwidth applications.

TABLE II. REQUIREMENTS FOR BROADBAND MULTIMEDIA SERVICES

Use case category	Requirements	Desired Value
In-vehicle media	Traffic density	DL: 100 Gbps/km^2 UL: 50 Gbps/km^2
	User throughput	DL: 50 Mbps UL: 25 Mbps
	Mobility	500 km/h
	Latency	10 ms
Enhanced multimedia	User throughput	4-28 Gbps
	Latency	< 7 ms
Broadband access	Connection density	4,000 devices/km^2
	Traffic density	60 Gbps/km^2

TABLE III. REQUIREMENTS FOR MTC SERVICES

Use case category	Requirements	Desired Value
Massive IoT	Connection density	1,000,000 devices/km^2
	Availability	99.9 percent coverage
	Energy efficiency	10-year battery life
Smart city	User throughput	DL: 300 Mbps UL: 60 Mbps
	Traffic density	700 Gbps/km^2
	Connection density	200,000 devices/km^2

TABLE IV. REQUIREMENTS FOR MISSION-CRITICAL SERVICES

Use case category	Requirements	Desired Value
Autonomous vehicle control	Latency	5 ms
	Availability	99.999 %
	Reliability	99.999 %
Emergency and public safety	Availability	99.9 % victim discovery rate
	Energy efficiency	One-week battery life
Process automation	Latency	< 1 ms
	Reliability	packet loss of less than 10^{-9}
mHealth and remote health monitoring	Latency	< 1 ms
	Reliability	99.999 %

B. *MTC services*

The MTC service family regroups the categories of use cases which require high connection density to support a number of devices or things that may transmit occasionally, at low bit rates, and with zero or very low mobility within the network. In this context, 5G mobile networks enable to achieve easy and smart interconnection between such devices [9]. In this section, we identify 2 significant categories of use cases for the MTC service family: massive IoT, and smart city. Table III depicts the main requirements of each use case category. We consider that, for both categories, low cost and long operational lifetime devices are essential.

1) Massive IoT: The category of massive IoT use cases addresses the needs for the emerging Low Power Wide Area (LPWA) whose operation enables connectivity with low cost devices, as well as extended coverage and long battery life [10], [12], [17]. Thanks to the improvements in data speeds, latency and reliability, 5G mobile networks enable a number of IoT applications, as well as new types of services, by interconnecting the massive number of devices, such as sensors, actuators, and cameras. Among the applications, we can mention those that are pervasive in urban, sub-urban and rural areas, providing metering, lighting management in buildings and cities, environmental monitoring (pollution, temperature, noise) and traffic control.

2) Smart city: Smart city is defined as a city that is instrumented with sensors, smart devices and appliances to collect real-time data from different sources of the surrounding environment [9], [15]. Such data are integrated in order to provide information throughout the city services. In this context, 5G mobile networks enable to support high densities of sensors, surveillance, smart infrastructure, smart lighting, and safety enhancements. In particular, video cameras become ubiquitous, while supporting many applications and improving safety.

C. *Mission critical services*

Mission critical services require communication links with very high reliability and availability, as well as very low end-to-end latency. For this service family, we identify 4 significant categories of use cases: autonomous vehicle control, emergency and public safety, process automation, as well as mobile health (mHealth) and remote health monitoring. Table IV depicts the main requirements of each use case category.

1) Autonomous vehicle control: 5G mobile networks enable to realize the vision of autonomous vehicles that are capable of monitoring the environment and navigating without human inputs, under any scenarios and conditions [3], [19]. More specifically, autonomous vehicles use a combination of technologies, including laser and radar sensing, Global Positioning System (GPS), odometers, computer vision, and advanced control systems, in order to detect their surroundings. In this context, 5G technologies enable to support cooperative driving throughout the exchange of real-time sensor information with the massive number of connections needed to communicate with thousands of vehicles and roadside sensors in the same area.

Also, 5G is expected to provide high performance, reliable and robust communications, and enhanced coverage to support collision avoidance in urban and rural areas. Such communications require strict constraints on latency, availability and reliability in wide coverage areas. The values for such requirements are indicated in Table IV. As a result, the traffic flow will be improved and optimized, whereas the congestion level will be relieved, and the fuel usage will be reduced.

2) Emergency and public safety: This category of use cases requires robust and reliable communications with the ability to send high quality pictures and real-time videos, in case of natural disasters, such as earthquakes, hurricanes, floods, and tsunamis [18]. It requires accurate position location and quick communication exchanges between users. As a result, public safety organizations require enhanced energy efficiency in battery consumption, as the network communications are critical in this category of use cases. In this context, 5G mobile networks are expected to satisfy such requirements.

3) Process automation: Process automation involves communications enabling time-critical scenarios that are required in manufacturing and industrial operations [2]. The applications for this category of use cases include functions related to material handling, filing, labeling, palletizing, packaging, stamping, cutting, metal forming, soldering, sorting, printing presses, web drawing, picking, and placing. Also, remote control of instruments and robots may be used to conduct measurements, handling of hazardous material, digging, and tele-operation of industry vehicles. In this context, 5G mobile networks enable end-to-end operation with broad coverage areas. More specifically, the management of inventory and supply chains takes advantage of a large number of connected sensors and platforms to provide big data analytics in order to automate all management decisions. As a result, energy constraints and efficiencies are important, requiring low-power technology features to support the process automation.

4) mHealth and remote health monitoring: mHealth refers to the application of smartphones and wireless technology for educating mobile users about preventive healthcare services [16]. It relies on the availability of high-resolution and detailed medical records, imaging, and diagnostic video. In this context, 5G technology is expected to bring efficiency and facilitate access to mHealth. Such technology is able to boost mHealth applications in a way that enables additional services, such as personalized or precision medicine initiatives [7], [18].

5G technology also supports remote health monitoring as applications that conduct remote diagnosis and treatment, using various types of sensors and wearable devices [7]. Such devices may be used to collect data and manage health-relevant indicators, such as heart rate, pulse, blood glucose levels, blood pressure, and temperature. Based on the monitored data, the remote treatment and response may be life-critical for a patient requiring immediate response. Also, public health services can combine monitored data with geographic data and other data sources to detect the spread of epidemics.

In the same vein, 5G technology has the potential to enhance the capability of a surgeon to remotely operate a surgical robot for performing surgery on a patient [6]. In particular, remote surgery applications in a mobile scenario in ambulances, disaster situations, and remote areas, require providing precise control and feedback communication mechanisms for the surgeons. Such a process involves interaction between humans and systems, where humans wirelessly control real and virtual objects, and the interaction requires a tactile control signal with audio or visual feedback. Tactile interaction requires real-time reactions, as latency targets for tactile interaction are as low as 0.5 ms [6]. In addition, the transfer of high resolution images and videos to the surgeon requires large bandwidth on the uplink. In this context, 5G technology requirements must include high reliability, ultra-low latencies, and real-time sensing and perception for audio, vision, and haptics to enable these applications.

V. Conclusion and Perspectives

In this paper, based on the conventional 5G usage scenarios, we have proposed to divide the services offered by 5G mobile networks into 3 service families: broadband multimedia services, MTC services, and mission critical services. We realize that such service families are characterized by high variability in the key performance indicators. More specifically, for broadband multimedia services, the user experienced data rate, the area traffic capacity, the peak data rate, mobility, the energy efficiency, as well as the spectrum efficiency, all have high importance, whereas mobility and the user experienced data rate do not have the same importance in all use cases simultaneously. The MTC service family, which includes massive IoT and smart city use cases, requires high connection density to support a number of devices or things that may transmit occasionally, at low bit rates, and with very low mobility within the network. Mission critical services, which regroups autonomous vehicle control, emergency and public safety, process automation, as well as mHealth and remote health monitoring use cases, require communication links with very low end-to-end latency, as well as very high reliability and availability.

In order to support so many daily experiences, 5G mobile networks are expected to be agile, powerful and intelligent. In this context, the proposed services categorization will help operators to be efficient in future deployment of mobile services in such networks.

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