Use Cases and 6G Architecture: New Needs and Challenges

Francine Cássia de Oliveira
Integration and Testing Department
Eldorado Research Institute
Campinas, Brazil
Email: francine.oliveira@eldorado.org.br

João Victor Menino e Silva
Integration and Testing Department
Eldorado Research Institute
Campinas, Brazil
Email: joao.menino@eldorado.org.br

Gustavo Iervolino de Morais
Electronic Devices Department
Eldorado Research Institute
Campinas, Brazil
Email: gustavo.morais@eldorado.org.br

Ramon Magalhães Nogueira
Integration and Testing Department
Eldorado Research Institute
Campinas, Brazil
Email: ramon.nogueira@eldorado.org.br

***Abstract*— The cellular network standard is stepping to the sixth generation, 6G. This new standard has been considered a key enabler for the smart information society of 2030. The 6G networks are expected to deliver superior performance over 5G and satisfy new emerging services and applications that integrate space, air, ground, and underwater networks to provide ubiquitous and unlimited wireless connectivity. There is a huge number of uses cases that poses varying requirements which include extreme mobility, extreme low latency, ultra high data rates, high energy efficiency, enhanced security, as well as high reliability. From this perspective, it is necessary to consider some of the key features that can be fundamental for the construction of the 6G network architecture. In this article, we will list some main use cases that will need the main 6G functionalities to work correctly and meet the expected expectations with the main 6G requirements so that it is possible to identify relevant points in the construction of a robust and flexible network architecture.**

Keywords - 6G; use cases; architecture; applications.

I. INTRODUCTION

A. Background

The growing demand for greater data traffic capacity, the staggered growth in the number of users, technological advances and new services drive the mobile communication systems and thus the development of the 5G system of International Mobile Telecommunications-2020 (IMT-2020) [1] was initiated. In International Telecommunication Union-Radiocommunication Sector (ITU-R), the Working Party 5D (WP5D), is responsible for the radio system aspects of the International that includes the IMT-2000, IMT-Advanced, IMT-2020 and IMT-2030. For IMT-2020, the WP5D created a process to be followed from the beginning of the study of trends until the end of the work on standards. The capabilities of IMT-2020 are identified such that IMT-2020 is more flexible, reliable and secure than previous IMT and provides diverse services. IMT-2020 can be considered from multiple perspectives, including the users, manufacturers, application developers, network operators, and service and content providers.

The WP5D commenced its work on the recommendation "IMT Vision for 2030 and beyond" in March 2021. The IMT Vision for 2030 and beyond is being developed with the aim to drive the industries and administrations to encourage further development of IMT by defining the objectives of the future of IMT, including the role IMT could play to meet the needs of future societies. Some of the objectives of the vision towards IMT for 2030 and beyond are: focus on continued need for increased coverage, capacity and extremely high user data rates, focus on continued need for lower latency and both high and low speed of the mobile terminals, full support to the development of an Ubiquitous Intelligent Mobile Society, focus on delivering on digital inclusion and connection with the rural and remote communities, among others [1]. To meet the diverse requirements of the upcoming decade, a robust, scalable and efficient network is thus necessary to be the key enabler for achieving this objective; it will connect everything, provide full dimensional wireless coverage, and integrate all functions, including sensing, communication, computing, caching, control, positioning, radar, navigation, and imaging, to support full-vertical applications.

B. Motivation

In fifth-generation networks, one of the main pillars in their development was the interconnection of everything, but applications involved with the Internet of Vehicles and Industrial Internet, for example, may be far from being met with such technology. Some questions are still unanswered, such as: What will be the problems of 5G for application in the industrial area? What will a green industry look like? Perhaps, these and other questions challenge the capacity of 5G and, probably, only 6G can solve.

Many white papers have addressed some aspects about the 6G network. For example, new 6G applications and

 ISBN: 978-1-68558-036-0

requirements are discussed in [2], 6G enabling technologies are mentioned in [3] and 6G enablers to drive Industry 5.0 are discussed in [4]. However, it is still too early to say exactly what the 6G network architecture will look like as the network and corresponding technologies are still under development.

Therefore, the main objective of this study is to analyze the main use cases that will require a network such as the sixth generation and the indicators related to them that may directly influence the construction of the 6G network architecture.

C. Paper Organization

The remainder of this paper is organized as follows. Section II summarizes the related work. Section III brings some use cases that can be explored in 6G. In Section IV, some target indicators related to these use cases that will bring possible changes in the 6G network architecture. Section V concludes the paper and suggests future works.

II. Related Work

Several studies involving 6G architecture have been carried out to meet the demands of a fully connected, intelligent and digital world. In [5], Huda Mahmood et al., propose an architecture composed of seven functions that have functionalities for essential enabling technologies. The objective of this architecture is to allow the optimization of such functionalities through dedicated network components.

According to Purbita Mitra et al. [6], 6G networks aim for ubiquitous intelligence and high-speed wireless connectivity in air, space and sea. This will require a super fast service with data speeds close to around 1000 Mbps. Marco Giordani et al. [7] have an analysis that suggests that meeting these high demands will require new communication technologies, network architecture and deployment models. Finally, Bariah et al. gave a comprehensive overview of 6G in [8], identifying seven disruptive technologies, associated requirements, challenges and open research questions.

So far, a considerable number of papers have explored possible applications and solutions for the architecture of 6G networks, therefore, the present related work analyzes factors that may influence the evolution of the 5G network to 6G or the construction of a new network architecture with the purpose to fulfill the requirements specified by the IMT-2030 for the next decade of technological evolution.

III. Use Cases

The 5G, through the Massive Machine-Type Communications (mMTC) and Ultra Reliable Low Latency Communications (URLLC) use cases, has resulted in a significant increase in the number of connected devices. New applications in vertical industries emerge every day, bringing a significant impact on people's daily lives. Internet of Things (IoT) solutions will continue to emerge and there are several use cases whose stringent requirements 5G can not meet, its stringent requirements, such as Augmented Reality (AR), Virtual Reality (VR), haptic internet, telemedicine, among others. The sixth generation mobile network, 6G, should support and improve the connectivity and operation of such applications.

Therefore, many use cases will require requirements that can only be met with sixth-generation technology. Three of these cases are listed below.

A. Digital Twins

With the increasing number of connected “things”, in 6G, a self-sustainable system should be proposed, which can be intelligent and operate with minimal human intervention. One technology, which presents itself as a strong candidate for such a requirement, and has received great attention, is the Digital Twins. It is a virtual representation of the elements and dynamics of a physical system [9]. In an ideal scenario, a Digital Twin will be indistinguishable from the physical asset, both in terms of appearance and behavior, with the added benefit of making predictions [10]. Figure [1] illustrates this representation of the virtual elements in relation to a physical system. Advances in other technologies make Digital Twins a powerful solution and contribute to its advancement. For example, recent advances in Machine Learning enable Digital Twins to analyze data and make decisions to be applied to the physical entity. This data can come from a network of sensors, from historical data or even from other Digital Twins (through a twin-to-twin interface). In other words, automation and intelligence will be created in the cyber world and delivered to the physical world through 6G wireless networks [11].

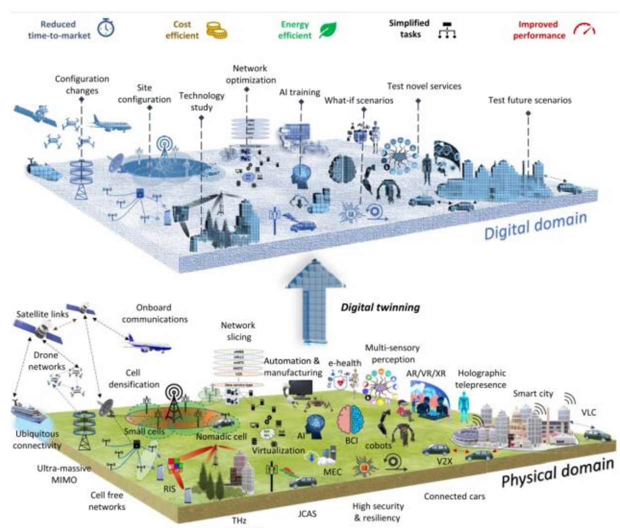

Figure 1. Representation of the virtual elements in relation to a physical system [11].

Another enabler for the Digital Twins has been the significant advances in cloud solutions. The transformation of a physical system into a Digital Twin is mainly based on the concept of decoupling. To enable Digital Twin for 6G with decoupling, Software Defined Networking (SDN) and Network Function Virtualization (NFV) could be promising candidates [8], which are heavily dependent on cloud solutions.

Digital Twins consist of three parts - the physical part, the digital part and the connection between the two for two-way communication. For this two-way communication, there is a unanimous opinion in the research community that the sixth generation (6G) mobile network will play a significant role [12], given that the Digital Twins technology requires a fast and reliable communication network.

In addition to the contribution of 6G, many benefits can be achieved through the technology of Digital Twins. Since the Digital Twin "mimics" the real physical environment and can learn and make decisions through artificial intelligence algorithms, there are several aspects in the research and development of 6G communication systems that could benefit from the application of this technology.

There are several network domains, such as Radio Access Network (RAN), Network Edge, Radio Resource Management (RRM), Edge Computing, Network Slicing, etc., that can significantly improve their performance using Digital Twins technology [13].

B. Human-centric immersive communications

Through the ages, human beings have evolved their cognitive capacity through the use of all the senses in relationships with other individuals and with nature, therefore, the search for a better communication experience has been constant since the invention of the first communication systems. In our smartphones, every year we see the screen resolution being improved to the limit of human perception, which is quite interesting, but it has the limiting factor of having to enter data through only touches on the screen. Therefore, in order to provide an immersive experience, in which the human being can use senses in a more accurate way, new technologies such as AR and VR, as well as holographic communications have been emerging in recent times. Through them, it will be possible to offer new forms of interaction between human beings and their devices and, consequently, new forms of human-to-human interaction. Communication that until then was carried out strictly through a smartphone, mostly with touches on the screen, can evolve so that it is possible to enter data through gestures and even through nerve impulses generated by the brain. Obtaining data will also be improved and synesthesia becomes even more present through, for example, the combination of sounds and three-dimensional elements that can be inserted and merged with the user's perception of the real world through glasses, ocular lenses and devices in-ear audio.

For such technologies to be offered as good user experiences through the 6G network, ultra-high data rates are required, in the order of Tbits/s, which is currently impossible to achieve with the 5G network. In addition to the very high rate, another fundamental requirement for such teleoperations involving the senses and human perception is very low latency. This parameter is necessary in order to avoid dizziness and fatigue when obtaining tactile and visual feedbacks in real time [11].

C. Industry 5.0

Industry 5.0 is the enhancement of Industry 4.0 and brings new goals with resilient, sustainable and human-centric approaches in a variety of emerging applications, for example, factories of the future and digital society. It is a quest to leverage human intelligence and creativity in connection with intelligent, efficient systems, use of cognitive collaborative robots to achieve zero waste, zero defects and mass customization based manufacturing solutions.

The enabling technologies of Industry 5.0 are multiple systems resulting from the continuous convergence of technologies and paradigms that unite physical spaces and cyberspaces. Successfully working the symbiotic relationship between multiple complex systems and supporting technological frameworks together can only enable the true multidimensional potential of Industry 5.0 functions [4]. These Industry 5.0 technology enablers are: Human-Machine Interaction, Real-time Virtual Simulation and Digital Twin, Artificial Intelligence-native Smart Systems, Data Infrastructure, Sharing and Analytics, Bio-inspired Technologies, among others.

The relationship between the 6G and Industry 5.0 is expected to meet with the intelligent information standard that provides high energy efciency, very low latency, high reliability, plus capacity of trafic.

IV. TARGET INDICATORS FOR 6G

Each new use case presents extremely specific advanced requirements and that, in the current scenario, the 5G network does not have the capacity to meet and work with all these requirements. Figure 2 illustrates the comparison between 5G and 6G requirements. Therefore, in order to understand how the new 6G network should be designed, some target indicators will be presented that exemplify the needs of this new generation of network.

A. Latency

As shown, several new end-user and vertical industry applications tend to emerge with the advancement of technology, for example, autonomous vehicles, Virtual Reality, Augmented Reality, holographic communication should be common applications in the future. These new use cases tend to require the same Key Performance Indication (KPI) as seen in 5G, but with new target values, for example, higher throughput, lower latency and better reliability.

 ISBN: 978-1-68558-036-0

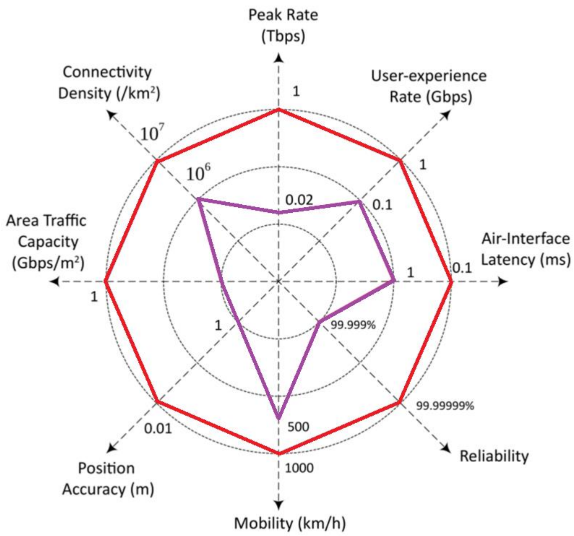

Figure 2. Comparison between 5G and 6G requirements [14].

Latency was a critical KPI in 5G and is expected to continue to be a concern in 6G networks, given that many applications are dependent on this KPI. On 5G, the minimum user plan latency requirement is 4ms for enhanced Mobile Broadband (eMBB) and 1ms for Ultra-Reliable Low Latency Communications (URLLC). This value is expected to be further reduced in 6G, to 100 µs or even 10 µs. In addition to air interface latency, 6G must also consider End to End (E2E) latency [14]. E2E latency is trickier to manage due to the myriad network elements involved, but 6G should overcome this challenge.

B. *Reliability*

As with 5G, ultra-reliable, low-latency communications requirements will continue to guide the future 6G network. Although the 5G system has created an environment for a more secure system, its reliability mechanisms are strictly connectivity oriented, therefore, the handling of failures in the application layer is left to the application itself. From the point of view of mobile networks, any instance outside its domain is considered outside the scope of treatment, but with 6G this should change.

In addition to enhancements to existing 5G security mechanisms, one of the most promising mechanisms for the sixth-generation system is Make-Before-Break-Reliability (MBBR). With it, it is possible to promote an interaction between the application servers and the mobile network, in order to detect failures. In short, MBBR gives the mobile network the possibility of previously detecting problems and security flaws in the application servers and transferring a problem-free copy to a redundant application server. In this way, the communication sections between the end device and the application will receive treatment from the 6G network, which will surely promote another layer of reliability for the system, making it a truly ultra-reliable network [11].

C. *Terahertz Communications*

Communications in Terahertz work between 100GHz and 10THz and, compared to millimeter waves, they brings a great potential for high frequency connectivity, enabling high data rates, in the order of hundreds of Gbps, which is what is expected from 6G.

On the other hand, the main problems in adopting this type of communication are directly linked to problems of propagation, molecular absorption, high penetration loss and major challenges related to antennas and Radio Frequency (RF) circuits [15].

In the case of millimeter waves, the propagation loss can be compensated using antenna arrays and spatial multiplexing with interference limitation.

Terahertz communications can be maximized by operating in frequency bands that are not severely affected by molecular absorption. And, finally, because these are very high frequencies, for indoor scenarios, it will be necessary to enable new types of RF solutions and ultra-small scale antennas.

Based on the characteristics of this type of transmission, the 6G network architecture will be directly impacted. For example, density and high data rates will increase demands on the capacities of the transport network, which must provide more fiber access points and greater capacity than current network backhauls. Furthermore, the wide range of different communication media available will increase the heterogeneity of the network, which will have to be managed [6].

TABLE I. THz WAVE PROPAGATION CHARACTERISTICS AND IMPACT ON THZ SYSTEMS

Parameter	Impact on THz Systems
Free-Space Pathloss	Distances are limited to tens of meters at most
Atmospheric Loss	Significant absorption loss Useful spectra limited between low loss windows
Diffuse Scattering & Specular Reflections	Limited multipath & high sparsity
Diffraction, Shadowing and LOS Probability	Limited multipath & high sparsity Dense spectral reuse
Weather Influences	Attenuation caused by the rain

To overcome these challenges, most of the conventional resource allocation algorithms are designed using high-speed fiber backhaul links, which are not applicable due to geographic limitations in historic buildings.

Fortunately, the very short wavelength in the THz band allows the use of an ultramassive array of antennas, i.e. containing 256, 512 or even 1024 antennas in the transmitter, which can provide a high beamforming gain to compensate for the loss of propagation. Meanwhile, precoding with multiple data streams can be used to provide multiplexing gain to further improve the spectral efficiency of THz systems. In the THz band, hybrid precoding that combines digital and analog domain signal processing is promising, as the number of RF chains is substantially less

 ISBN: 978-1-68558-036-0

than that of full digital precoding, while achieving superior performance. comparable [16].

A good comparison of the key THz propagation characteristics and their impact on THz systems, is depicted in Table 1 [17].

V. CONCLUSIONS

In this article, an overview of 6G was presented, the expectations of society as a whole for the coming years in relation to this new technology, the preparation of the ITU in the construction of IMT-2030 and also a comparison of requirements with 5G. The study was directed towards researching some of the new use cases that will be introduced with the arrival of 6G, in order to present its objectives, characteristics and necessary requirements for its operation.

The Digital Twins use case makes it clear that machine learning, cloud solutions, and fast and reliable communication will be some of your key requirements. The Human-centric immersive communications use case presents needs such as bit rates in the order of Tbits/s and very low latency. Finally, the Industry 5.0 use case presents the requirements already mentioned by the previous use cases as a necessity. After studying these use cases, the requirements, also known as target indicators, were discussed bringing confirmation of the need for a new network architecture.

With ultra-low latencies, in the order of 10 micros, ultra-reliable networks and transmissions in the order of Terahertz, it is expected that new network elements will be introduced, as well as the communication structure between them will be modified. 6G is expected to have intelligent and distributed network management in such a way that it can handle all demands privately and securely. All this must occur so that the success of the 6G deployment is possible and that all the desired objectives are achieved.

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