6G Architecture: New Use Cases, New Needs and New Challenges

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

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

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

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

***Abstract*—Reliable data communication is essential for connections that are increasingly intelligent and automated. The fifth generation of mobile networks offers major improvements over the previous generation, 4G, but is still not capable of offering a ubiquitous connection to meet the demands of the new applications and needs that are emerging. On the basis of this, the cellular network standard will require a new communications network and this will come in the new generation of mobile networks, called 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 use cases that pose 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 like Digital Twins, Global Ubiquitous Connectivity, Remote Communications, and others, that will need the main 6G functionalities to work correctly and meet the expectations of the main 6G requirements so that it is possible to identify relevant points in the construction of a robust and flexible network architecture.**

***Index Terms*—6G network(s); use cases; architecture; application; THz communication; energy efficiency; fog computing**

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 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, 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 the 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 the continued need for increased coverage, capacity and extremely high user data rates, focus on the 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 [2]. 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 of the 6G network. For example, new 6G applications and requirements are discussed in [3], 6G enabling technologies are mentioned in [4] and 6G enablers to drive Industry 5.0 are discussed in [5]. 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 subsequent sections of this paper are organized as follows: A synopsis of related work is given in Section II, along with an analysis of relevant studies and literature. Potential use cases in the context of 6G are examined in Section III, providing insight into a range of applications. In Section IV, the difficulties of Remote Communications are examined, along with their complexities and obstacles. In Section V, target indicators associated with the identified use cases are analyzed with respect to their possible impact on 6G network architecture. Section VI, which concludes the study, provides a thorough summary of the structure and contributions of the work by synthesizing the findings and suggesting possible avenues for further research.

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 [6], 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., [7], 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. [8] 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 [9], 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 of fulfilling 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 strict requirements 5G can not meet, such as Augmented Reality (AR), Virtual Reality (VR), haptic internet, and 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. Some 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, that 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 [10]. 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 [11]. 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 [12].

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 [9], 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 [13], 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

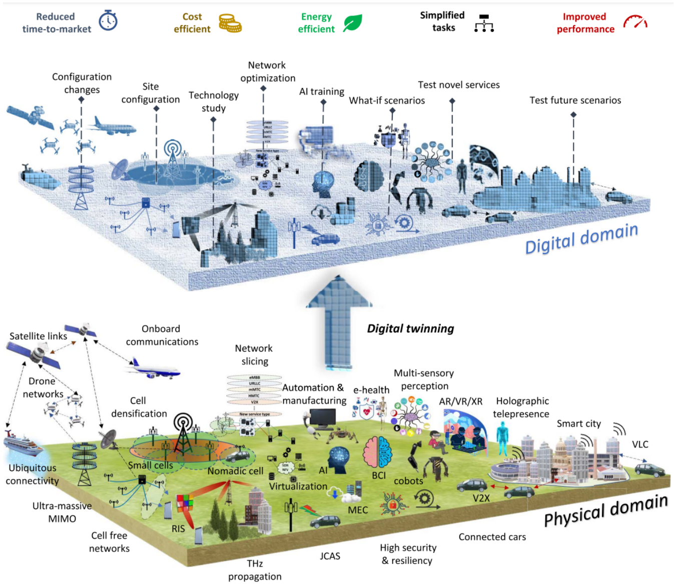

Fig. 1. Representation of the virtual elements in relation to a physical system [12]

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 [14].

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 smartphones, every year, the screen resolution is 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 feedback in real time [12].

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, the 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, and Bio-inspired Technologies, among others.

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

D. Global Ubiquitous Connectivity

As it is known, legacy mobile communication systems aimed to provide connectivity with a focus on dense urban areas, resulting in many sparsely populated regions lacking adequate connectivity and basic Information and Communication Technology (ICT) services. However, especially in countries with vast territorial expanses, a significant portion of the population resides in remote areas. This is particularly intensified in countries that are major agricultural and agribusiness producers, where a large part of the population chooses to develop their production in more suitable locations, generally distant from major urban centers, as is the case in Brazil, for example.

Besides the extensive terrestrial territories, it is essential to remember that over 70% of the planet's surface is covered by water, making the development of communication systems in these areas equally crucial. However, achieving total global coverage with adequate capacity, high-quality service (QoS), and affordable cost is still far from reality. Nevertheless, it is of maximum importance for mobile systems to develop in these areas to avoid significant digital divides among people worldwide. This development is necessary not only for enhancing security with improved geolocation and emergency response methods, but also for enhancing consumer goods production through the use of IoT devices, for instance.

In summary, providing means of global connectivity through resilient infrastructure is essential for enhancing security, production, and overall quality of life. These purposes align with the Sustainable Development Goals defined by the United Nations (UN) [15], which aim to provide ubiquitous Internet access for anyone or any device anywhere. However, it is technically impossible for terrestrial networks to cover remote areas such as oceans, deserts, and high mountainous regions, and furthermore, providing communication services to sparsely populated areas is not attractive to major players in the industry.

Attaining ubiquitous global coverage necessitates overcoming challenges spanning political, market, and chiefly technical issues. Technically, the development of 5G in Releases 15, 16, and 17 initiates the addressing of concerns regarding architecture interoperability with various technologies. However, the call for global coverage surpasses the current definitions of these Releases and can only be tackled with the establishment of 6G Networks. Simultaneously, the analysis of 3GPP Release 18 is focused on enhancing coverage for handheld devices in the sub-6 GHz band with added antenna gain losses in the device. Combining the attenuation due to long propagation distances with the reduction in antenna gain within the device yields a diminished signal-to-noise ratio (SNR) in both Downlink (DL) and Uplink (UL) directions. Increasing transmission power, whether in the device or satellite, stands as a solution. However, the utilization of a legacy waveform design from 3GPP NTN yields an inefficient solution with increased complexity due to peak-to-average power ratio (PAPR) and out-of-band (OOB) power leakage [15].

Hence, currently, the best alternative for achieving total coverage of the planet Earth is through the use of satellites. Geostationary satellites (GEO), despite being expensive to deploy and having a capacity of only a few gigabits per second (Gbps) per satellite [16], may not be suitable for common uses, but they can be harnessed for critical applications, such as in the maritime and aviation sectors. Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) satellites can be a viable option for everyday uses, given the possibility of building low-cost satellite constellations and providing highly profitable global communication services [17].

In other words, satellites will not only collaborate with existing terrestrial networks but will also be integral to the architecture of the 6G network, with common management besides other network elements. Satellite constellations can be formed, and furthermore, other elements can contribute to ubiquitous coverage, such as Unmanned Aerial Vehicle (UAVs), drones, balloons, and aircraft, each serving different roles within the system, such as gateways, relays, or even radio base stations [18].

E. Pervasive Intelligence

The dissemination of mobile devices and the emergence of new intelligent devices such as cars, drones, IoT devices, and robots, for example, lead to significant growth in over-the-air intelligent services. As the use of these devices continues to advance, the need for artificial intelligence technologies to collaborate in providing fundamental functions like Simultaneous Localization and Mapping (SLAM), facial, speech, and image recognition, natural language processing, and motion detection, among many others, becomes increasingly essential. However, AI services require high computational capabilities that may not always be available to the devices intending to use them. Therefore, 6G presents itself as an excellent alternative to offer generalized AI services, falling under the AI-as-a-Service model [19].

A particularly promising scenario for the use of pervasive intelligence can be identified in the utilization of humanoid robots as cooperative partners. These robots aim to physically resemble human beings to perform risky functions, arduous tasks, and other daily life activities. An example where pervasive intelligence can be observed is in humanoid robots like Atlas, developed by Boston Dynamics [20].

Such robots and other devices can utilize computational resources offered through the 6G network to spare their own resources and optimize computational load, thereby increasing energy efficiency. By receiving processed instructions from a central core provided via 6G, they can save their own resources, prolong battery life, and preserve computational capacity for more critical functions.

In addition to handling intensive computational tasks, pervasive intelligence also enables the execution of real-time AI operations. This is particularly advantageous as it overcomes the latency limitations associated with cloud computing, enabling quick decision-making and immediate responses to real-time conditions.

IV. Remote Communications

Connectivity in remote areas has been a challenge for many years. However, the COVID-19 pandemic has highlighted the importance of connectivity more than ever before. The pandemic accelerated the transition to remote work and learning, but unfortunately, it left many people out of this digital age. according to the state of broadband 2022 report [21], in 2019, 54% of the world's population was using the internet, with this number growing to 66% in 2022. However, there are still many people around the world who do not have access to the Internet, especially in rural and remote areas.

The numbers from the mobile economy 2023 report [22] show that there are still 3.5 billion disconnected people, and thus excluded from the digital age. The majority of these individuals live in developing countries, especially in Sub-Saharan Africa and India.

The exclusion of these individuals from the digital age has a significant impact on their lives, as connectivity plays a crucial role in a wide range of activities, spanning sectors such as education, health, business, and public administration.

One field that has shown remarkable advancements is the e-health sector, as documented in successful cases in the future of virtual health and care reports [23]. A notable case in India, where there was a significant 300% increase in the number of teleconsultations between March and May 2020. Consequently, these initiatives contribute to reducing disparities and enhancing the quality of life in rural and remote regions.

It is believed that 6G will be developed taking these needs into account, in order to enable the population in rural and remote regions to be integrated into the digital age, facilitating their participation in the opportunities offered by this new era. However, for this to become a reality, it is necessary to delve into the analysis and research of a set of solutions, in order to address the challenges that contribute to limited internet connectivity in these remote areas.

A. Lack of Energy Sources

Many remote or rural regions face challenges in accessing the electrical grid, making the provision of energy for telecommunications networks is a difficult task. In the context of 6G, potential solutions may involve the use of generators or, preferably, the adoption of renewable energy sources such as solar or wind. However, it is important to note that this approach may lead to an increase in deployment costs and make the network more susceptible to failures. For this reason, other lines of research include the development of energy-efficient equipment to mitigate these challenges.

B. Spectrum Availability

One of the biggest barriers to network deployment in rural areas is spectrum licensing, as participating in spectrum auctions is difficult for small ISPs [24]. Additionally, spectrum frequency regulation in remote areas adheres to national standards, although the possibility of flexibility could be considered, given that many frequency bands remain underutilized (unallocated) in these isolated locations [25]. Therefore, it might be necessary to have two sets of regulations: one for urban areas and another for remote and rural areas.

C. Maintenance and Operation, Access Difficulty, and Qualified Workforce

Understanding the inherent complexities of maintaining and operating telecommunications networks in remote regions presents a significant challenge, both in practical and financial terms. This complexity arises from the difficulty of accessing such areas due to the often-present topographical adversities in remote locations, which lack proper road infrastructure, making transportation to these points challenging.

Furthermore, this scenario is exacerbated by the scarcity of qualified workforce, as the regions in question often face financial constraints inherent to their situation, frequently being situated in developing nations. Possible solutions can stem from advances in Self-Organizing Networks (SONs), which can be employed to automate as many resources as possible, encompassing various network components and engineering phases [26].

By automating network management tasks, SONs can contribute to improving network performance and user experience in remote and rural areas, while also reducing the need for manual intervention and maintenance. Moreover, the digitization of these remote areas could enhance the level of skills in that region, bringing new opportunities to the population and possibly encouraging the government to invest in education in that area.

D. Critical Infrastructure

Another challenging issue concerns the lack of infrastructure in these areas. The deployment of cables, fibers, and even communication towers faces obstacles due to terrain characteristics. Consider, for example, the complexity involved in deploying fiber optic networks in the Amazon region, aiming to provide connectivity to an isolated indigenous community.

Various alternatives have been discussed as potential solutions, among which the utilization of existing infrastructure stands out, such as those used in TV and radio transmissions [24]. Another strategy involves the adoption of Integrated Access And Backhaul (IAB) technology to replace the use of fiber optics, which proves to be a cost-effective solution when compared to fiber optics. IAB offers a more flexible implementation approach. Based on a wired connection to the core network, the IAB donor can provide communication access to mobile users and act as a wireless backhaul for IAB nodes. These IAB nodes are capable of providing network service access to the mobile user as well as backhaul traffic [27], as illustrated in Figure 2.

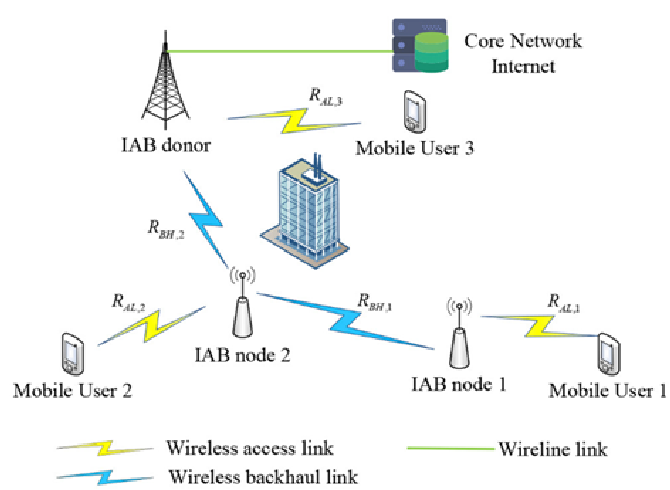

Fig. 2. IAB structure [27]

E. Low Return on Investment/High Cost/Low Income of the Target Population

Each of the mentioned points above requires a considerable allocation of resources for their resolution, resulting in a relatively reduced return on investment (RoI), as the target population often consists of individuals with less favorable socioeconomic conditions. As a result, national operators often lack interest in investing in such areas, therefore, new business plans and mechanisms that facilitate the entry of local and micro-operators will be necessary. To reduce costs, integrating various solutions is feasible.

The discussion about the use of Non-Terrestrial Networks (NTNs) has gained prominence, as well as Device-to-Device (D2D) connections, which ensure coverage in the network's peripheral regions. Non-Terrestrial Networks (NTNs) encompass Unmanned Aerial Vehicles (UAVs), High Altitude Platform Stations (HAPSs), and satellites (such as a Low Earth Orbit (LEO) constellation). These solutions could provide connectivity both in the front (fronthaul) over vast geographical areas and in the back (backhaul), potentially replacing the use of fiber optic networks.

V. Target Indicators For 6G

Each new use case presents highly specialized and demanding requirements that the 5G network lacks the capacity to meet and work with. Figure 3 illustrates the comparison between the requirements of 5G and 6G, where the vertices of the inner polygon represent the Key Performance Indicators (KPIs) of 5G, while the vertices of the outer polygon represent the KPIs of 6G. In this image, we can see a noticeable improvement in all the majorly considered KPIs.

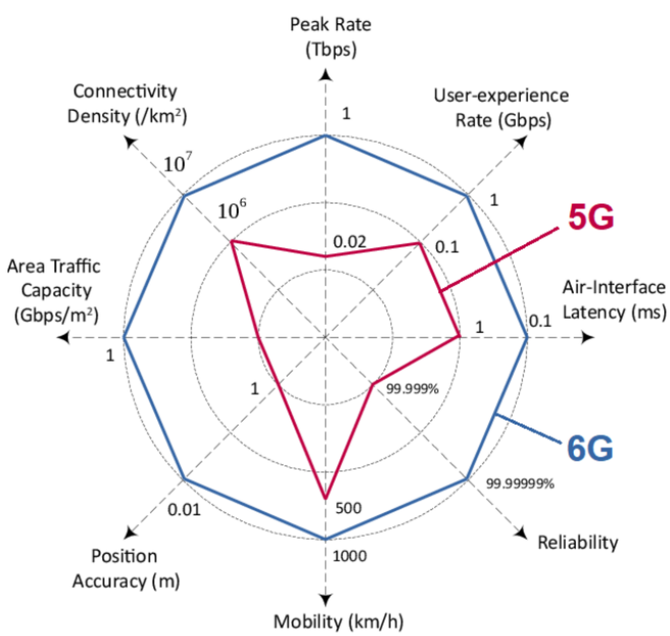

Fig. 3. Comparison between 5G and 6G requirements [21]

Nonetheless, different use cases demand distinct KPIs. For example, Ultra-Reliable Low Latency Communications (URLLC) applications require the lowest possible latency, with the other KPIs not being as important. In contrast, Massive Machine Type Communications (mMTC) applications demand high connection density and energy efficiency, with the other KPIs being less relevant. Figure 4 shows the significance of each KPI for different use scenarios.

Furthermore, Figure 4 shows a fresh use case that hasn't been discussed yet. As we've seen, the deployment of infrastructure faces significant challenges in remote and rural regions due to the high costs involved. This situation could give rise to a new usage scenario in 6G, in addition to the well-known eMBB, URLLC, and mMTC. This new element, represented as the fourth pillar, would involve "basic internet connectivity" [28]. This approach would provide inferior performance in various KPIs but would still ensure minimum connectivity for users in remote and rural areas.

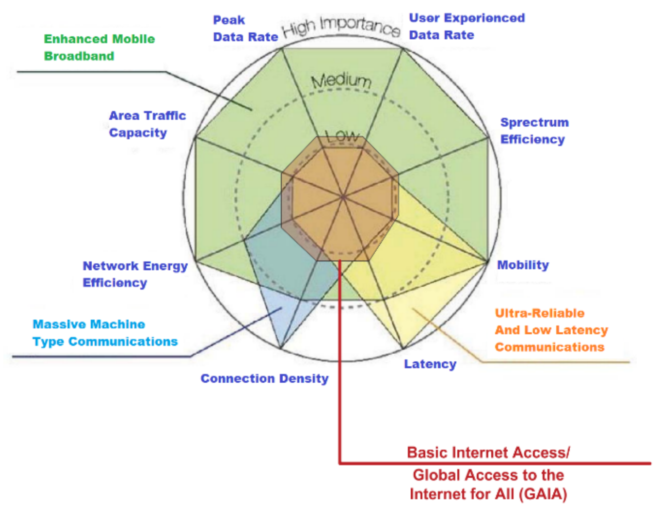

Fig. 4. Four pillars for 6G [28]

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 networks.

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, and 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.

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 [28]. 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 [12].

C. Terahertz Communications

Communications in Terahertz work between 100GHz and 10THz and, compared to millimeter waves, they bring 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 [30].

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 [7].

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 than that of full digital precoding, while achieving superior performance [31].

A good comparison of the key THz propagation characteristics and their impact on THz systems, is depicted in Table 1 [32].

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

D. User-Experienced Data Rate

The user-experienced data rate, as the name suggests, is the throughput that users will perceive in the vast majority of their interactions with the system. This indicator is important because the majority of revenue for operators still comes from regular users and their smartphones, making it essential to offer high data rates.

In the 5G context, in a dense urban scenario, the user-experienced data rate is 100 Mbps for downlink and 50 Mbps for uplink. For 6G, it is expected to provide 1 Gbps or more in the downlink, which is ten times faster than 5G.

It is also important to note that users have a 95% chance of receiving this data rate at any time and in any location within the coverage area. The remaining 5% is allocated to moments of network overload or regions where the signal level is not as favorable, such as at the cell edge, for example. Furthermore, measuring the perceived performance by the user at the cell edge is also crucial as it can reflect factors such as appropriate site density, system architecture, and optimizations, among others. These indicators are valuable for operators, as they can provide adequate coverage and optimize operational costs [33].

E. Energy Efficiency

One of the most discussed aspects currently is the reduction of carbon emissions in the atmosphere, and although the implementation of a mobile system does not generate a direct impact in this scenario, the energy efficiency of the system is certainly a factor to be taken into account, as part of the energy used to power mobile systems may come from non-renewable and polluting sources.

During the deployment of 5G, energy consumption was a closely observed aspect by the industry and standardization organizations, resulting in a significant reduction in energy required per bit compared to previous systems. As for 6G, this indicator suggests that there will likely be an increase in energy efficiency by an order of 10 to 100 times compared to its predecessor [33].

F. Fog Computing

Related to the topic mentioned above, there is another Target Indicator, which is called Fog Computing.

The Fog Computing has great importance in relation to energy efficiency, especially in cases of Massive IoT type communications where the majority of devices in IoT networks are battery powered with limited computational and communication resources.

This technology can provide storage and computational services for 6G networks and allows edge devices to perform computing and storage operations closer to the edge [33]. One of the great strengths of Fog Computing is the inclusion of decentralized computing services compared to the centralized computing offered by the traditional cloud.

Additionally, improved latency can be achieved as data and tasks are accessed and analyzed closer to end devices. The Fog Computing also improves the use of the frequency spectrum and increases network capacity.

Still on energy efficiency, in order to maintain the energy supply of any device, it is necessary to have the collaboration of other devices that can be called helper nodes. The function of helper nodes is to perform tasks on behalf of other devices. This process of sharing resources is called task offloading. Tasks are divided into tasks executed by any device and offloaded tasks that are executed by auxiliary devices. In offloaded tasks, there is an important point, which is the time restriction or maximum time limit for completing the task. Task offloading can improve latency through parallel processing of tasks, but it can also, unlike, increase latency through uplink transmission of the task to task helper nodes and downlink transmission of the result to the local device [35].

IoT networks that are based on Fog Computing do not have a standard architecture and can be represented through layers. Although the three-layer architecture is the most commonly used, there are proposals for architecture based on four and six layers.

In the three-layer architecture, there is a cloud layer, fog layer, and edge layer, and the resources are distributed in a hierarchical manner, that is, servers in the cloud layer with more resources, nodes in the fog layer with mid-features, and edge devices with fewer features.

In addition to layer-based architectures, it is possible to consider three other types: a) Clustered Architecture, b) Centralized Architecture, and c) Distributed Architecture. The Clustered Architecture is widely used in Wireless Sensor Networks (WSNs) as sensor nodes are grouped together in clusters of different sizes. In each cluster, there is a master node that controls the flow of information. All other nodes forward their data to the master node, which aggregates all the data and sends it to the fog node. In this type of architecture, there is a reduction in cluster transmissions, improving the energy efficiency of the system. Figure 5 illustrates this architecture.

In the centralized architecture, there is also the existence of the master node, called Fog Cluster Head (FCH), and member nodes, called Fog Cluster Members (FCM). Master nodes and member nodes are selected according to the geolocation between the FCH and FCMs and through internal policies.

In a distributed architecture, there is no formation of clusters, and nodes can be selected according to their availability and also according to internal policies.

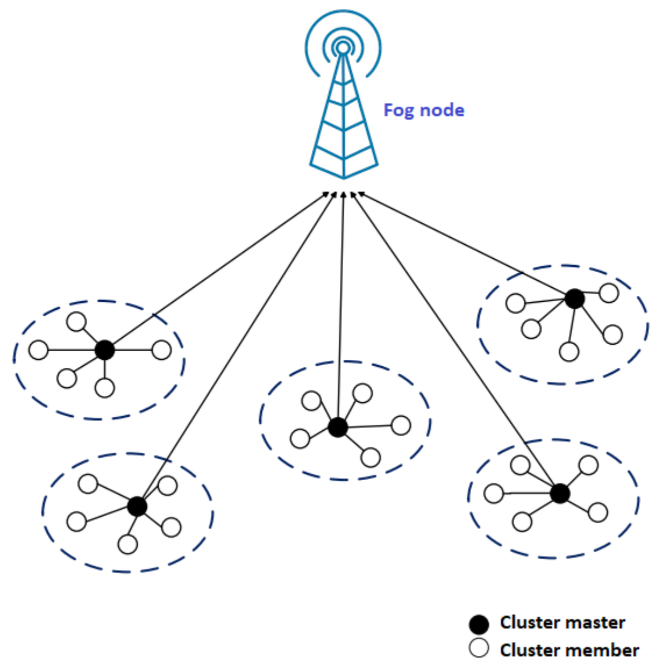

Fig. 5. Clustered Architecture to Fog Network [34]

G. Communication on Smart Surfaces

With the need to increase spectral and energy efficiency, increase data rates and higher frequencies, the use of massive MIMO, which is already a reality in fifth generation networks, will continue to exist in 6G. However, for sixth-generation networks, massive MIMO must work with smart surfaces that are matrices capable of controlling and amplifying wireless signals in targeted environments. These surfaces allow innovative forms of communication, as the use of radio frequency and holographic MIMO is possible [36].

H. Edge AI

In sixth-generation networks, the use of Artificial Intelligence will be imminent considering, for example, the possible creation of a Self-Sustaining Network (SSN) that can manage resources, control the network, and maintain, autonomously, the high KPIs of the network. These and other functions enabled in 6G through the use of AI will be complemented by the use of AI at the edge, by running AI and learning algorithms on devices to provide distributed autonomy [36].

VI. 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. The Industry 5.0 use case presents the requirements already mentioned in the previous use cases as a basic need. The challenge seen in Global Ubiquitous Connectivity has already begun to be addressed in 5G networks, however, to achieve truly ubiquitous global coverage, the insertion of both medium and low-orbit satellites into the 6G network architecture must occur. In the case of Pervasive Intelligence, the use of humanoid robots that come physically close to a human being will be one of the most promising scenarios. The use of computational resources offered by 6G will be a great opportunity for these robots to be more energy efficient. Finally, in the case of remote communications, the great expectation is that 6G will allow the digital era to be introduced into rural and remote populations. After examining these use cases, the requirements, also known as target indicators, were discussed, confirming the need for a revised, rather than entirely new, network architecture. This is particularly evident in the case of remote communications use, where infrastructure implementation will face significant challenges. This could lead to the emergence of a new pillar for 6G dedicated to guaranteeing minimum connectivity for remote and rural users. 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. An indicator that will also require a stable and consolidated network architecture is the data rate experienced by the user, as even with new applications and services, use cases will continue to demand increasingly higher rates so that the user experience is unique. Finally, energy consumption is one of the most important aspects observed since 5G, therefore, energy efficiency must be considered as a point of extreme attention when building sixth-generation networks. To this end, one of the technologies that is already expected to contribute to this end is Fog Computing, which can provide storage and computational services for 6G networks and allow edge devices to perform computing and storage operations closer to the edge. The 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.

References

[1] O. Francine Cássia, M. Gustavo Iervolino, S. João Victor Menino, N. Ramon Magalhães, ”Use Cases and 6G Architecture: New Needs and Challenges,”International Conference on Networks, Venice, Italy, 2023.

[2] ITU-R, “IMT traffic estimates for the years 2020 to 2030,” Report ITU-R M.2370-0, July 2015.

[3] L. Zhang, Y. Liang and D. Niyato, “6G Visions: Mobile ultrabroadband, super internet-of-things, and artificial intelligence,” China Communications, vol. 16, no. 8, 2019, pp. 1-14.

[4] J. Zhu, M. Zhao, S. Zhang and W. Zhou, ”Exploring the Road to 6G: ABC - Foundation for Intelligent Mobile Networks,” China Communications, vol. 17, no. 6, 2020, pp. 51-67.

[5] S. Zeb et al., “Industry 5.0 is Coming: A Survey on Intelligent NextG Wireless Networks as Technological Enablers,” Journal of Network and Computer Applications, vol. 200, 2022.

[6] N. H. Mahmood et al., “A Functional Architecture for 6G Special-Purpose Industrial IoT Networks,” IEEE Trans. Ind. Informatics, vol. 19, no. 3, 2023, pp. 2530-2540.

[7] P. Mitra et al., “Towards 6G Communications: Architecture, Challenges, and Future Directions,” 2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT), 2021.

[8] M Giordani, P. Michele, M. Marco, R. Sundeep and Z. Michele, “Towards 6G Networks: Use Cases and Technologies,” IEEE Communications Magazine, vol. 58, no. 3, 2020.

[9] L. Bariah et al., “A prospective look: Key enabling technologies, applications and open research topics in 6G networks,” IEEE Access, vol. 8, pp. 174792–174820, 2020.

[10] L. U. Khan et al., “Digital Twin Enabled 6G: Vision, Architecture Trends, and Future Directions,” IEEE Communications Magazine, vol. 60, no. 1, 2022.

[11] A. Rasheed, O. San and T. Kvamsdal, “Digital Twin Values, Challenges and Enablers from a Modeling Perspective,” IEEE Access, vol. 8, 2020.

[12] W. Tong and P. Zhu, “6G The Next Horizon,” Cambridge University Press, 2021.

[13] N. P. Kuruvatti, A. H. Mohammad, H. Bin, F. Amina and D. S. Hans, “Empowering 6G Communication Systems With Digital Twin Technology: A Comprehensive Survey,” IEEE Access, vol. 10, pp. 112158–112186, 2022.

[14] Z. Zhang et al., “6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies,” IEEE Vehicular Technology Magazine, vol. 14, pp. 28-41, 2019.

[15] M. Matinmikko-Blue et al., “White Paper on 6G Drivers and the UN SDGs,” arXiv:2004.14695 [cs, eess], Apr. 2020, arXiv: 2004.14695. [Online]. Available: http://arxiv.org/abs/2004.14695

[16] S. Chen, Y. Liang, S. Sun, S. Kang, W. Cheng and M. Peng, “Vision, Requirements, and Technology Trend of 6G: How to Tackle the Challenges of System Coverage, Capacity, User Data-Rate and Movement Speed,” IEEE Wireless Communications, vol. 27, no. 2, pp. 218–228, Apr. 2020.

[17] Z. Qu, G. Zhang, H. Cao and J. Xie, “LEO satellite constellation for Internet of Things,” IEEE Access, vol. 5, pp. 18391–18401, 2017.

[18] Y. Hu and V. O. K. Li, “Satellite-based Internet: A tutorial,” IEEE Commun. Mag., vol. 39, no. 3, pp. 154–162, Mar. 2001.

[19] K. B. Letaief et al., “The roadmap to 6G: AI empowered wireless networks,” IEEE Commun. Mag., vol. 57, no. 8, pp. 84–90, Aug. 2019.

[20] Boston Dynamics. Accessed: Jul. 29, 2023. [Online]. Available: https://www.bostondynamics.com/atlas

[21] ITU - International Telecommunication Union. The State of Broadband. Geneva: ITU, 2022.

[22] GSMA Intelligence. The Mobile Economy 2023.

[23] ITU - International Telecommunication Union. The Future of Virtual Health and Care.

[24] A. Chaoub, ”6G for Bridging the Digital Divide: Wireless Connectivity to Remote Areas,” IEEE Wireless Communications, vol. 29, no. 1, pp. 160-168, Feb. 2022.

[25] H. Saarnisaari et al., ”A 6G White Paper on Connectivity for Remote Areas,” ArXiv abs/2004.14699, 2020.
[26] A. Chaoub et al., ”Self-Organizing Networks in the 6G Era: State-of-the-Art, Opportunities, Challenges, and Future Trends,” 2021.
[27] Y. Zhang et al., ”A Survey on Integrated Access and Backhaul Networks”. 2021.
[28] E. Yaacoub, E. M. S. Alouini. ”A Key 6G Challenge and Opportunity - Connecting the Base of the Pyramid: A Survey on Rural Connectivity,” Proceedings of the IEEE, vol. 108, pp. 533-582, 2020.
[29] W. Jiang et al., “The Road Towards 6G: A Comprehensive Survey,” IEEE Open Journal of the Communications Society, vol. 2, pp. 334-366, 2021.
[30] Q. Zhang, W. Ma, Z. Feng and Z. Han., “Backhaul-Capacity Aware Interference Mitigation Framework in 6G Cellular Internet of Things,” IEEE Internet of Things Journal, vol. 8, pp. 10071-10084, 2021.
[31] L. Yan, C. Han and J. Yuan., “Hybrid Precoding for 6G Terahertz Communications Performance Evaluation and Open Problems,” 2nd 6G Wireless Summit, 2020.
[32] H. Tataria et al., “6G Wireless Systems: Vision, Requirements, challenges, Insights, and Opportunities,” Proceedings of the IEEE, 109.7, pp. 1166-1199, 2021.
[33] W. Jiang, B. Han, M. A. Habibi and H. D. Schotten, ”The Road Towards 6G: A Comprehensive Survey,” IEEE Open Journal of the Communications Society, vol. 2, pp. 334-366.
[34] U. M. Malik et al., ”Energy-efficient fog computing for 6G-enabled massive IoT: Recent trends and future opportunities,” IEEE Internet of Things Journal, vol. 9, no. 16, pp. 14572-14594, Aug. 2022.
[35] S. Luo et al., “Incentiveaware micro computing cluster formation for cooperative fog computing,” IEEE Transactions on Wireless Communications, vol. 19, no. 4, pp. 2643–2657, 2020.
[36] W. Saad and M. Chen, ”A vision of 6G wireless systems: Applications, trends, technologies, and open research problems,” IEEE Network, vol. 34, pp. 134-142, 2019.