Analysis of Requirements, Needs and Challenges Affecting the Development of the 6G Network

Adin Čanić [1], Zlatko Jerković [1], Elma Avdagić-Golub [1]

[1] *University of Sarajevo, Faculty of Traffic and Communications, Zmaja od Bosne 8, Sarajevo, Bosnia and Herzegovina*

***Abstract* – With the development and implementation of the 5G systems worldwide, the shortages and imperfections that limit the functions and services of 5G networks were made apparent. This generation should enable its users to access unseen services and applications and a better quality of service in comparison to its predecessors. However, aside from the apparent importance of 6G networks, the possibilities, use cases, applications, and services that this technology would provide are yet to be explored. Our intention with this paper is to research the papers and compare the differences in requirements, capabilities, services, and use cases between 5G and 6G.**

***Keywords* – 6G, services, requirements, capabilities, use cases.**

1. Introduction

The human need for faster data transfer always initiated the development and evolution of mobile networks.

DOI: 10.18421/SAR71-06
https://doi.org/10.18421/SAR71-06

Corresponding author: Elma Avdagić-Golub,
University of Sarajevo, Faculty of Traffic and Communications, Zmaja od Bosne 8, Sarajevo, Bosnia and Herzegovina
Email: elma.avdagic@fsk.unsa.ba

Received: 15 February 2024.
Revised: 18 March 2024.
Accepted: 23 March 2024.
Published: 27 March 2024.

This growth of requirements for network capacity is still here, and it will continue to grow as time passes by; appearances of new applications, services, and IoT and the importance that these can have on our daily lives and industries are influencing the development of mobile generations more and more. The fifth generation (5G) was represented as one that will be crucial in enabling and supporting IoT services [1]. Although some requirements were met, older technologies were improved, and some new ones emerged, the main goal, that of 5G networks as genuine bearers of IoT services, was not accomplished.

Table 1. List of abbreviations

Abbreviation	Definition
AI	Artificial Intelligence
eMBB	Enhanced mobile broad-band
ER	Extended reality
HTC	Holographic-type communication
IoE	Internet of everything
IoT	Internet of Things
ITU-R	The International Telecommunications Union Radiocommunications Sector
KPI	Key performance indicator
M2M	Machine-to-machine
MIMO	Multiple Input Multiple Output
mULC	Massive ultra-reliable low-latency communications
mMIMO	Massive multiple input multiple output
mMTC	Massive machine-type communications
QoE	Quality of experience
QoS	Quality of Service
ULBC	Ultra-reliable low-latency broadband communications
UMBB	Ubiquitous mobile broadband
URLLC	Ultra-reliable low-latency communications
V2X	Vehicle to everything
VPN	Virtual private networks
VR	Virtual reality

However, there are certain use cases (mMTC, eMBB, URLLC, explanations for abbreviations are given in Table 1.) [2] that were envisioned to have tightly connected use of IoT in the services that they offer, due to limitations that were a lot more apparent once these networks were implemented and commissioned, these objectives are yet to be achieved. We are witnessing the rapid growth of applications such as AI, VR, and IoE, which will generate huge volumes of data [3]. We are moving towards a society with automated control systems that are becoming increasingly popular in all fields (industry, healthcare, traffic, space sciences). For this to be achieved, millions of sensors have to be integrated into cities, vehicles, homes, industries, etc., for the development of "smart" life and automated systems [3]. For these requirements to be met and to solve the problems and difficulties that 5G faced, a new 6G mobile generation was proposed. At its core are the abilities needed to support the applications and technologies based around IoT [1]. Numerous papers are focused on services and applications enabled by 6G networks and the challenges that 6G networks face [1], [3], [4], [5], and [6]. Some papers focus on the correct functioning of 6G networks [7], [8], with a special emphasis on AI [9] and THz [10]. We believe that this paper will give a more detailed analysis and that it will better understand 6G networks. We reflected on the limitations of the 5G network; we analyzed services and use cases of 6G, requirements that need to be met, and compared them to those of 5G networks. In the end, we described a couple of technologies that will play a significant role in developing 6G systems and enable new applications and services to function properly.

2. 5G and the Challenges It Has Faced

The performance of 3G and 4G networks left certain demands and expectations unmet. But thanks to the progress of IoT, it is now possible to connect devices across sectors and industries worldwide. To enable efficient communication, the network has to surmount obstacles like interference and transmit signals in a way that permits all users to communicate without disruptions. 5G was anticipated to provide several functions and features, such as remote control, faster and more efficient data transfer, support for Virtual Private Networks, and Cloud computing.

5G networks have made an essential step towards developing an advanced network compared to their predecessors through emerging technologies.

• Massive MIMO (mMIMO): hundreds of antennas which serve dozens of user terminals within the same frame. The collection of phase-coherent signals from antennas on the base stations is fundamental for this technology.

• Spectrum sharing: Sharing bandwidth and spectrum is necessary to develop an advanced network. Spectrum sharing enables improved reliability. Spectrum is available in two forms: horizontal and vertical.

• Millimeter waves: emerged as a solution to problems of congestions and communication.

However, despite the development and technologies in the communications field, 5G networks continue to face challenges and requirements that they cannot deliver upon.

• Latency: the time needed for the package to travel through the network, from source to destination.

• Quality of Experience (QoE): metric of user understanding of the application and their enjoyment while using it. It is specific for the users, and it is based on applications. If it is too low, it indicates dissatisfaction. If it is too high, the application is probably using too many resources or has higher battery usage.

• Cost: The cost of developing 5G infrastructure and adaptations to existing cellular infrastructure is high. It gets even higher when the maintenance cost is included in the equation.

• Insufficient geographical coverage: Although 5G enables high connectivity in city areas, those inhabited in rural areas do not have this benefit. For now, a large number of areas that are positioned further apart from the cities cannot access cellular connections. The goal of 5G networks are cities, places with a more significant number of Populus and gradual spreading towards further areas.

3. 6G

In 2019 commercial 5G networks started implementing worldwide [5]. Suppose the tradition of a new generation appearing every ten years is to be followed. In that case, it is time to start exploring new technologies that will inherit 5G. When we talk about 6G networks, vital questions we need to answer are: "Do we need 6G? "or "Isn't 5G already enough?". A thorough comprehension of crucial enablers, patterns, and practical examples that sparked the evolution of 6G networks is essential to uncover solutions to these inquiries. The emergence of new generations is not solely due to the expansion of mobile data traffic, but also due to the proliferation of services and applications. We need to consider the continuous need for mobile communications to constantly improve the efficiency of networks by reducing costs, energy and spectral efficiency.

In correlation with the development of new technologies, communication networks can transform themselves into more efficient and robust systems that offer new and unseen services.

3.1. Growth of Mobile Traffic

We are witnessing a time when many innovative products, interactive services and intelligent applications are constantly developing and burdening existing 5G systems. Those systems can hardly answer the requests placed upon them, and predictions are that after 2030, it will become impossible. The situation has come about due to the increase in the usage of video content applications, improved resolution, machine-to-machine (M2M) communications, and cloud services. Global mobile traffic will continue to grow, reaching 5016 EB monthly in 2030. in comparison with 62 EB in 2020 [3]. The use of smartphones and tablets has increased drastically in the past ten years, and this trend is expected to continue, particularly in emerging nations. Wearable electronics and VR are also increasingly popular in the market. Users require higher bandwidth due to the popularity of applications such as YouTube, Netflix, and TikTok, as well as improvements in device resolution. Additionally, the growth of each individual user contributes to the increased demand for bandwidth. Traffic coming from mobile video services presents two-thirds of total mobile traffic [5].

3.2. Possibilities and Services of 6G Networks

To enable new services, 6G systems should overcome all of the challenges that 5G faced. Possibilities of 6G consist of the combination of past tends and new, emerging trends The potential for new applications is increasing as new technologies are developed and existing ones are improved.

• Holographic–Type Communication (HTC): the human tendency to interconnect with the highest accuracy possible and the highest level of reality, regardless of distance, will be one of the more significant challenges of 6G networks. In comparison with traditional 3D video services that are accessed with the usage of glasses, holograms have a more natural way of presenting an object in 3D space, with the fulfilment of all of the visual needs. With significant advancements in hologram technology (Microsoft HoloLens) [5], it is predicted that applications of these sorts could be available in the next decade. High-resolution holograms are able to offer a better experience overall. For example, with technology like this, distant members of companies can attend meetings, being projected in their hologram form; another opportunity for usage is the enabling of handling ultra-realistic objects using holograms, which is especially useful during training. However, critical requirements have to be satisfied for this technology to be used to its full extent. Those requirements are directed towards bandwidth (2-3 Tb/s). Besides the usual traits of two-dimensional videos (resolution, color, frame, quality), the quality of holograms will also include other data (angle, position, slope, etc.). For hologram communication to work efficiently, it requires high synchronization and low latency of less than a millisecond.

• Tactile Internet: demands extremely low latency (less than one millisecond). An opportunity arises for new applications in combination with high reliability, security and bandwidth. In combination with holographic communications and extended reality (ER) sensory data, it is possible to handle machines in places with dangerous chemical substances without being physically present. These services are, however, very latency-sensitive.

• Multi-sense: we use five senses to experience the world surrounding us. Digital communications of today rely on only two: eyesight and hearing. The inclusion of taste and smell can enhance the general experience and facilitate the creation of novel products in the fields of food, medicine, and gaming.

• Digital twin: used to create a virtual copy of some object. The aim is to create an accurate copy that includes various features and details associated with the original item. This replica is then utilized to produce multiple duplicates of the same object. Those copies possess a certain level of automatization and intelligence. Some earlier mentions of digital twins attracted much attention from different industries and producers. The complete adoption of this technology is anticipated to happen only after the establishment of 6G networks.

• Pervasive intelligence: With the growth of the popularity of smartphones and the appearance of new equipment like robots, VR headsets, smart cars, and drones, it is predicted that intelligent services will flourish. Intelligent tasks like these are relying on traditional computer technologies. 6G networks provide all-encompassing intelligence to address the challenges of storage, battery consumption, and privacy on mobile devices. The goal is simple: while providing the aforementioned services, networks use AI with resources from distributed computing, cloud computing, mobile edge, and edge devices [5]. Machine learning and interference mechanisms are also used.

For example, robots can take over a part load created as a result of simultaneous localization and mapping and redirect it to edge computer resources. This is done to improve movement accuracy and extend the battery life. Besides this, this kind of intelligence enables easier completion of time-sensitive tasks by introducing AI in those services.

• eHealth: The health sector is also expected to be revolutionized by the changes enabled when 6G is developed and implemented; firstly, by eliminating time and space barriers through distant operations and optimizing different health-related tasks and problems. However, these services face high costs and strict quality of service requirements (high connectivity and availability, very low latency, and mobility support) [6].

• Industry 4.0: The First Industrial Revolution is marked by the transition towards production driven by steam and water-powered machines. The implementation of this technology took a while, which led to the revolution lasting from 1760 to 1820 in both Europe and the United States. The Second Industrial Revolution, also known as the Technological Revolution, began in 1871 and it lasted until 1914. It resulted in the construction of enormous rail and telegraph networks that enabled faster transportation of people, ideas, and electricity. The Third Industrial Revolution, also known as The Digital Revolution, appeared at the end of the XX century, and it started with the development of the Z1 computer. The Fourth Industrial Revolution aims to automate industrial technologies and processes, and facilitate data exchange. This includes the Internet of Things (IoT), cloud computing, Artificial Intelligence (AI), and industrial Internet of Things. 6G networks will realize all of these ideas in their entirety. An essential part of said realization is surmounting the limitations between real and computer-generated industries that will allow Internet diagnostics, maintenance, operations, and direct machine communications [6]. Automatization comes with its own set of requirements that need to be fulfilled, such as reliability and synchronization of communications.

Autonomous transportation: evolution towards autonomous transportation offers safer travel and better traffic management.

To connect autonomous vehicles, very low latency and very high reliability are paramount for guaranteeing passenger safety even with high speeds (1000km/h) [6]. With existing technologies, however, these demands cannot be answered. A more significant number of sensors per vehicle also needs a more incredible speed of data exchange (2-3 Tb generated per hour of driving). Flying vehicles (e.g. drones) have potential in different scenarios (construction, emergency cases). Another exciting area of study is Vehicle-to-everything communication (V2X) [11].

3.3. Use Cases

5G systems were designed to fulfil several QoS requirements and to support applications and services that were not available till then. The ITU-R suggested Three use cases in 2015 to define these services (as shown in Figure 1). Those use cases were [5]:

- Enhanced mobile broadband (eMBB): in general, it defines applications used by human users for high data speeds in mobile services, data, and multimedia. The use case presented here could be utilized as a starting point for developing novel services that rely on intelligent gadgets such as smartphones, tablets, and wearable electronics. One essential aspect is covering an area as large as possible to provide better access and higher capacity.
- Ultra-reliable low latency communications (URLLC): focuses on human users. This opens the possibility of developing new applications and services that need constant connection for proper functioning (e.g. automatic vehicles, Smart Grif, Industry 4.0). These examples highly depend on reliability, availability, and low latency.
- Massive machine-type communications (mMTC): supports highly-condensed connectivity with many interconnected devices. This topic is primarily mentioned in IoT.

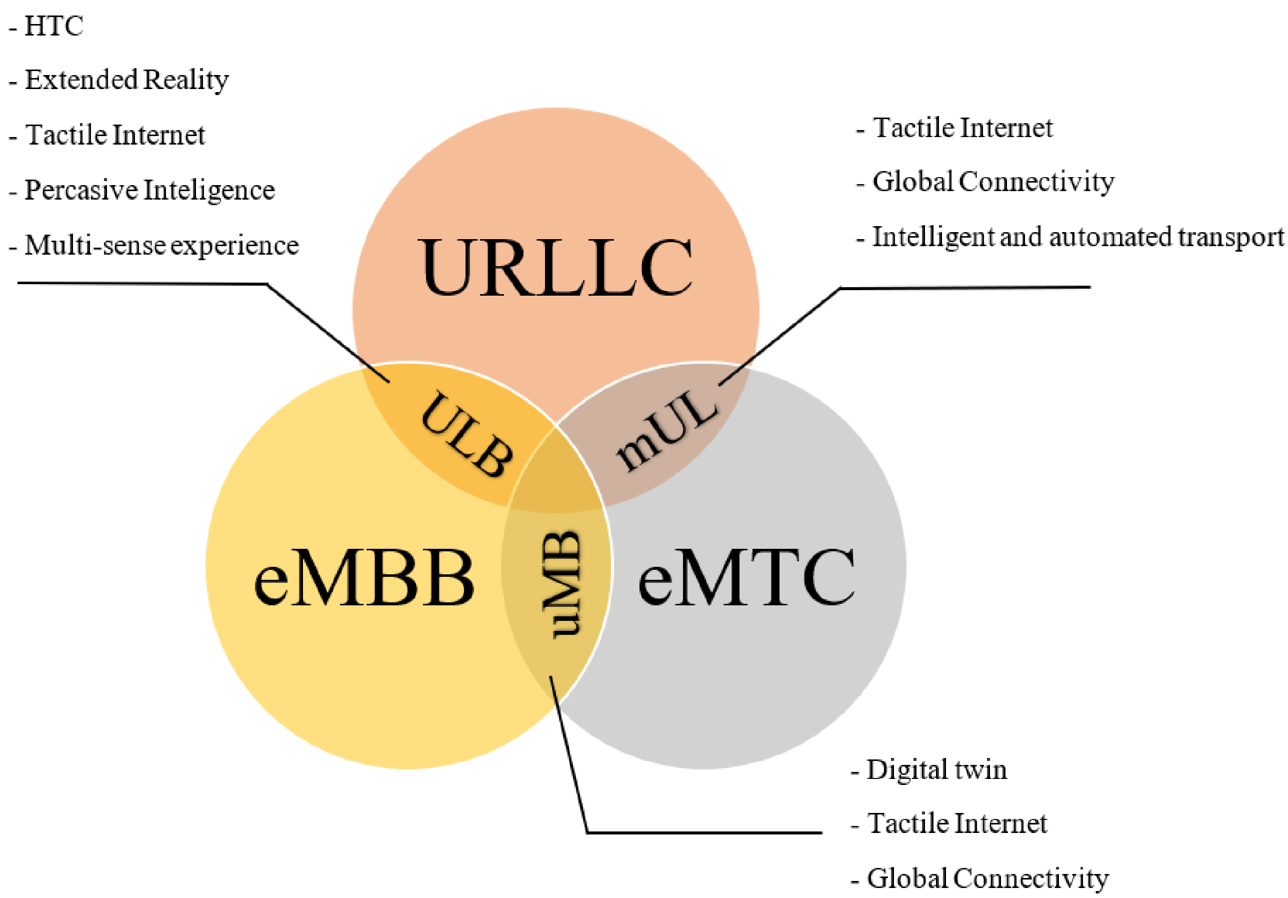

Figure 1. Besides the typical 5G use cases, three new were added, that are going to be used in 6G systems [5]

The aforementioned use cases are not enough to satisfy the needs of technical requirements of certain services introduced by 6G networks. A person who uses a VR headset to play interactive online games needs a high-speed internet connection with low latency to enjoy the experience. Similarly, autonomous vehicles or drones require a network with widespread coverage, high bandwidth, low latency, and high reliability for optimal performance. This is the reason for introducing three new use cases that should satisfy all of the mentioned requirements. Mobile broadband should be present and available globally in 6G systems, called ubiquitous MBB – uMBB) to meet the requirements of high-quality communications while in movement. Besides ubiquitousness, another improvement of this system is higher network capacity and faster transfer speeds. In addition to data transfer speed and users' data transfer speed, uMBB systems have other important KPIs such as mobility, coverage, and positioning.

Ultra-reliable low-latency broadband communications (ULBC) not only supports URLLC-based applications but also high-bandwidth applications such as HTC-based games. It is assumed that services like HTC, ER, and Tactile Internet will hugely benefit from systems like these. The third scenario for usage involves massive ultra-reliable low-latency communications, which combines the attributes of mMTC and URLLC. The utilization of numerous sensors and initiators in vertical industries is a crucial aspect when it comes to developing and executing services. Together, the use cases of 5G systems and three new use cases should fill the void that is currently present, and they can support any services and applications that originate from a combination of possibilities of these scenarios. KPIs needed during the development and implementation of these use cases are shown in Table 2.

Table 2. Key performance indicators that require special attention during the implementation of aforementioned services [5]

		KPI														
Generation	Usage Scenario	Peak data rate	User-experienced data rate	Latency	Mobility	Connection density	Energy efficiency	Peak spectral efficiency	Area traffic capacity	Reliability	Signal bandwidth	Positioning accuracy	Coverage	Timeliness	Security and privacy	CAPEX and OPEX
5G	eMBB	E	E	√	√		√	E	E		E		√		√	E
	URLLC			E			√			E	√	√	E	E	E	
	mMTC					E	E						√		√	
6G	uMBB	E	E	√	E		√	E	E	√	E	√	E		√	E
	mULC			E		E	E			E	√	√	E	E	E	
	ULBC	E	E	E	√		√	E	E	E	E	√	E	E	E	
Legened	√ : Generic/weak impact E:Specialized/critical impact															

3.4. Requirements of 6G Networks and Comparison with 5G

To support the abovementioned applications and services, 6G systems have to deliver high capacity, reliability, and efficiency. There are several indicators that represent the technical needs of 6G networks. Some of these indicators were previously used to assess 5G and remain applicable to 6G. There are also new indicators that have been added to measure new technical efficiency. The first eight KPIs were present in 5G networks.

• Peak data rate: presents the highest data transfer speed under ideal circumstances (all resources are directed toward one mobile station). One of the primary ways to distinguish between the various generations of mobile systems is through the use of this symbolic parameter. This has been a traditional method of differentiation. Due to the customers' needs and technological advancements like THz communication, these speeds are expected to reach 1Tbps, ten times more than 5G (20 Gbps) [11]. The user-experienced data rate is the fifth percentile point (5%) of the cumulative distributive function through users' bandwidth. In other words, this data rate is available to users anytime, anywhere, with the possibility of 95%.

It represents a more meaningful way of performance measuring, especially on the cell's edges. It also shows the design of the network (density, architecture, cell optimization). In 5G systems built around high-density urban scenarios, this parameter amounts to 100 Mbps for downlink and 50 Mbps for uplink. It is anticipated that the speeds in 6G networks will exceed 1 Gbps, which is ten times faster than the speeds offered by 5G networks.

• Latency: There are two types of latency, user latency and control latency. User latency represents latency that appears in the network from the moment data is sent to the moment it arrives at the destination. In 5G, the minimal requirements for user latency were 4 ms for eMBB and 1 ms for URLLC. It is said that in the future, these numbers will be 100 μs and even ten μs. The duration it takes to transmit data from the optimal battery state to the state of constant data transfer (active state) is known as control latency. In 5G technology, the minimum control latency should be 10ms, and this is expected to improve in 6G.

• Mobility: The maximum speed that a mobile station can provide while ensuring a satisfactory quality of experience is what this refers to. The highest mobility supported by 5G is 500 km/h to support the development of high-speed trains.

If we consider the usage of service during commercial flights, the highest mobility speed aimed for in the 6G is 1000 km/h [2].

• Network density: parameter used while evaluating mMTC. The maximum number of devices possible per square kilometer is 106, owing to the limited network resources. In 6G, it is proposed that this number will improve tenfold, 10^7 per km^2 [11].

• Energetic efficiency: important for realizing cost-efficient networks and reducing carbon emissions. For these reasons, it plays a vital role from the socio-economic perspective. Although energetic efficiency per bit improved drastically compared to earlier generations, during the early stages of the development of 5G, there were some complaints and problems due to the high energy usage. In 6G networks, this parameter will be improved 10-100 times.

Spectral efficiency plays a significant role in measuring the improvement of radio transmission technologies. The minimum requirements for 5G include a downlink speed of 30 bps/Hz and an uplink speed of 15 bps/Hz. In 6G, an improvement of three times is expected compared to 5G.

• Traffic capacity: the total quantity of mobile data traffic in an area, considering available bandwidth, spectral efficiency, and network density. In 5G, minimal traffic capacity is 10Mps for m^2; in 6G, this number will grow to 1 Gbps/m^2.

Together with the previously mentioned requirements, some new or expanded KPIs will be used to express new requirements of 6G networks more precisely. Reliability means transferring any quantity of data in a predetermined time interval with a significant likelihood of success. This parameter is used to evaluate URLLC use cases. In 5G systems, reliability is measured with the probability of $1\text{-}10^{-5}$ while transmitting a 32-bit package in 1 ms for channel quality on the edges of the urban macro area. In 6G, this parameter will be improved at least twofold ($1\text{-}10^{-7}$) [5].

• Signal throughput: maximal throughput of the aggregated system. The throughput of 5G networks is 100 MHz. The frequency in 6G will increase up to 1 GHz when operating on higher frequencies and could potentially go even higher with THz communications.

• Positioning accuracy: in 5G systems, positioning is better than 10 m. Requirements for better positioning accuracy are significant, especially in industries. With the usage of THz radio stations and their potential for precise positioning, 6G accuracy could reach the level of centimeters. In 5G networks, coverage usually implies the quality of the received signal within a base station. Losses, including path loss, shadowing, and antenna gain, refer to the channel losses between the terminal and the base station. They are used to measure the area in the service of one base station. In 6G networks, coverage should expand, taking into account ubiquitous coverage and the forming of 3D integrated networks with Earth and satellite networks.

• Promptness is a new parameter used in the evaluation of future networks. Some typical measurements are information freshness, query and synchronization freshness. Unlike latency, promptness analyses the freshness of data and services available to the end user.

Security and privacy are important for the evaluation of the security of the whole network to protect the infrastructure, data, devices, and users. The main security elements are confidentiality, which protects sensitive pieces of information from unauthorized access; integrity, which guarantees that information is not illegally changed; and authentication, which ensures that communicating entities represent themselves. On the other hand, privacy is becoming a huge priority to ease concerns and satisfy legal requirements.

3.5 Technologies that Enable the Development of 6G Networks

The underlying architecture of 5G networks serves as the foundation for the development of 6G networks. That way, they will inherit the benefits of 5G systems. Some new technologies will arise, and others will improve. Comparison of technical requirements of 5G and 6G networks are shown in Figure 2, and individual technologies are explained below.

• Artificial Intelligence (AI): on the list of all technologies used in 6G networks, AI is recognized as the most important. Intelligence represents a characteristic of autonomous networks and, as such, is critical to implement.

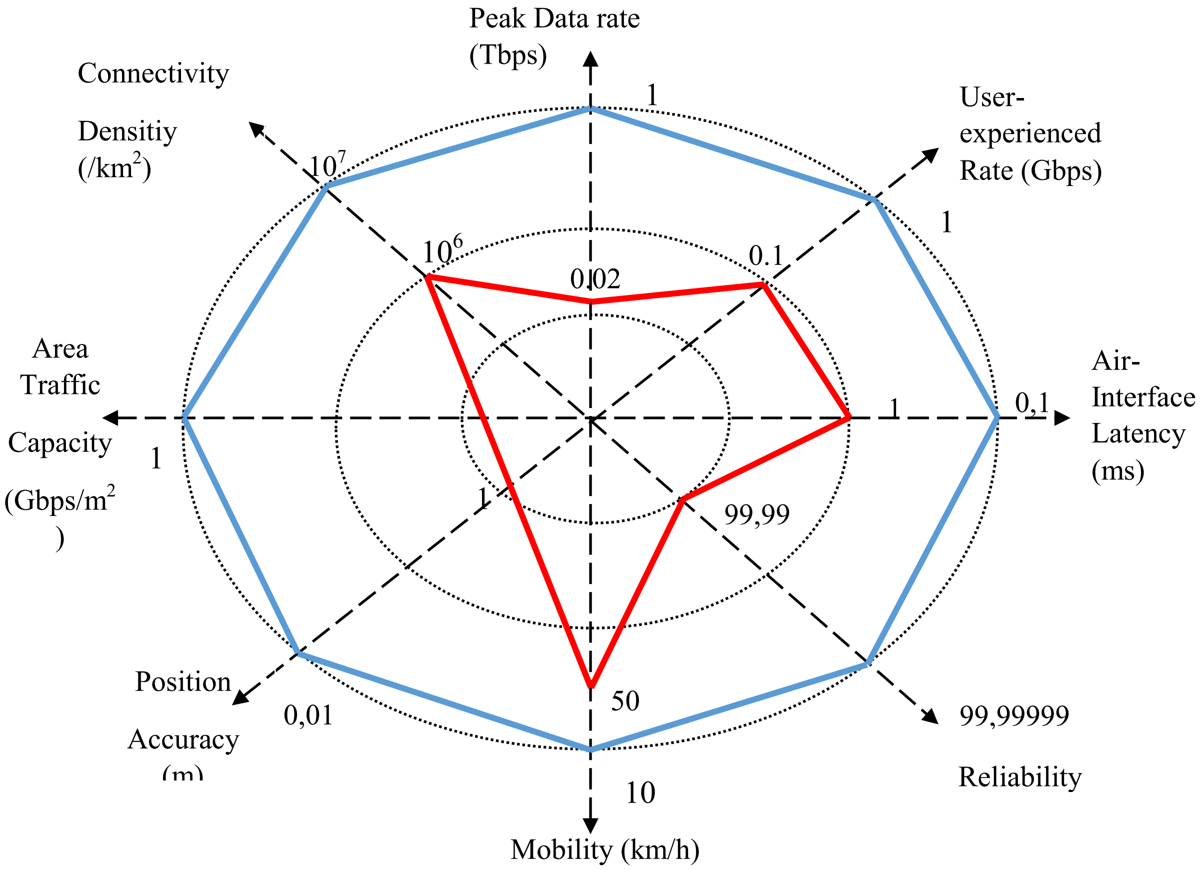

Figure 2. Comparasion of technical requirements of 5G and 6G networks. Red graph – 5G; blue graph – 6G [5]

In 4G networks, there are no records of usage of AI; in 5G networks, AI exists, but to a limited extent. 6G systems will completely support AI automatization.

Through the usage of AI, networks can use the full potential of a signal. Real-time communication networks become more efficient due to the advancements made in machine learning. Real-time data transfer can be made easier and more efficient through the implementation of AI in communications. Through the usage of a number of analytics, AI can select the best ways to complete complex tasks. Efficiency can be enhanced, while processing latency can be minimized with its use. Tasks that are typically time-consuming, such as handover and network selection, can be completed with it. The use of AI will be critical for M2M communications and will be backed by metamaterials, intelligent surfaces, networks, devices, self-sustaining wireless networks, and machine learning. Due to the reasons mentioned above, AI will support and help to reach these goals.

• Terahertz communications: spectral efficiency can improve through bandwidth enlargement. This can be done by bandwidth extension and using multiple-input multiple-output (MIMO) technologies [3]. In 5G networks, this was done by implementing high-frequency mm waves for faster data transfer and the possibility of new services.

However, besides the current abundance of spectral redundancy, mm waves will not be able to meet more extensive bandwidth requirements for another decade. Wireless technologies operating at higher frequencies, such as THz or optical frequencies, will have a crucial role to play in the 6G era. This will allow more bandwidth and greater data transfer capabilities. Similar to mm Waves, THz suffer from significant path loss, and it will be supported by directional antennas and LOS channels. With the presence of LOS, however, high frequencies will provide a much higher bandwidth level than earlier technologies. Enabling high performance in terms of bandwidth, latency, and reliability is possible for this reason. THz communications are resistant to atmospheric effects compared to mm Waves and optical systems. Due to these advantages, THz, together with already-known technologies, is becoming one of the leading solutions in communication systems. Although THz performs better than mm Waves, it also faces more significant technical problems, especially in the realm of hardware implementation (antennas, modulators THz communications pertain to the frequency range within 0.1 THz and 10 THz, wherein the wavelengths measure from 0.03-3mm. ITU-R suggests a band between 275 GHz and 3 THz for cellular communications [3].

By incorporating the THz band (275 GHz - 3 THz) into the current mm-wave band (30 - 300 GHz), the capacity of 6G networks will be increased. Currently, bands intended for these purposes are not being used anywhere in the world. For that reason, high-speed data transfer is possible.

4. Discussion

It is evident that the amount of research, development, and planning around 6G is increasing every day. Those researchers stem not only from academic circles but also from the private and government sectors. This interdisciplinary approach is necessary to expand the dialogue of future challenges and requirements. For those wishing to join this discussion, research areas are ever-increasing. In this paper, we touched upon services and applications; however, many questions remain unanswered (e.g. efficient implementation tactics for 6G worldwide and security of 6G networks from cyberattacks and hackers).

Based on the aforementioned applications and use cases, it is evident that requirements placed upon 6G are greater than those of 5G. Improving the peak data (ten times better than in 5G) and lowering the latency (1 μs) are especially important. Due to the new services and applications planned to be implemented in 6G, better mobility and network density will also be improved as well. Together with fundamental parameters, new ones will be added to present 6G networks more efficiently and with a lot more detail.

5. Conclusion

Our goal was to answer some of the questions, focusing on the services and applications that will appear together with the development of 6G networks by analyzing use cases and their corresponding applications. As a result of the combination of 5G use cases, three new were suggested. We looked back upon key performance indicators of 6G networks, compared them with 5G and defined new ones to measure the performances of networks, applications, and services more efficiently. Ultimately, we focused on the technologies that enable the development of 6G networks.

However, besides the technological challenges described in this paper, challenges that arise from the social aspect are becoming more and more evident. Opinions are divided, with some stating that ten years does not seem like enough time for the appearance of new mobile generations.

New technologies are developing ever-faster, and in correspondence with that, it is time that people speed up their efforts of harmonization in all communities worldwide. Currently, three billion people remain without Internet access. As a society, it is essential not to fall into the trap of developing new technologies solely due to economic benefits. We are all, as a collective, responsible for the well-being of planet Earth. How can we include those that were, until now, excluded from technological achievements? How can we secure enough jobs for future generations? How can we eradicate illiteracy? We believe that we can overcome these challenges by developing 6G networks as a network focused on humans, accessible, ubiquitous, fast, secure and reliable. For the aforementioned reasons, we believe that future wireless technologies will affect all aspects of our lives.

References:

[1]. Saad, W., Bennis, M., & Chen, M. (2019). A vision of 6G wireless systems: Applications, trends, technologies, and open research problems. *IEEE network*, *34*(3), 134-142. Doi: 10.1109/MNET.001.1900287

[2]. Lee, Y. L., Qin, D., Wang, L. C., & Sim, G. H. (2020). 6G massive radio access networks: Key applications, requirements and challenges. *IEEE Open Journal of Vehicular Technology*, *2*, 54-66. Doi: 10.1109/OJVT.2020.3044569

[3]. Chowdhury, M. Z., Shahjalal, M., Ahmed, S., & Jang, Y. M. (2020). 6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions. *IEEE Open Journal of the Communications Society*, *1*, 957-975. Doi: 10.1109/ojcoms.2020.3010270

[4]. De Alwis, C., Kalla, A., Pham, Q. V., Kumar, P., Dev, K., Hwang, W. J., & Liyanage, M. (2021). Survey on 6G frontiers: Trends, applications, requirements, technologies and future research. *IEEE Open Journal of the Communications Society*, *2*, 836-886. Doi: 10.1109/OJCOMS.2021.3071496

[5]. Jiang, W., Han, B., Habibi, M. A., & Schotten, H. D. (2021). The road towards 6G: A comprehensive survey. *IEEE Open Journal of the Communications Society*, *2*, 334-366. Doi: 10.1109/OJCOMS.2021.3057679

[6]. Giordani, M., Polese, M., Mezzavilla, M., Rangan, S., & Zorzi, M. (2020). Toward 6G networks: Use cases and technologies. *IEEE Communications Magazine*, *58*(3), 55-61. Doi: 10.1109/MCOM.001.1900411

[7]. Dogra, A., Jha, R. K., & Jain, S. (2020). A survey on beyond 5G network with the advent of 6G: Architecture and emerging technologies. *IEEE access*, *9*, 67512-67547. Doi: 10.1109/ACCESS.2020.3031234

[8]. Shakeel, P. M., Baskar, S., Fouad, H., Manogaran, G., Saravanan, V., & Xin, Q. (2021). Creating collision-free communication in IoT with 6G using multiple machine access learning collision avoidance protocol. *Mobile Networks and Applications*, *26*, 969-980.
Doi: 10.1007/s11036-020-01670-9

[9]. Letaief, K. B., Chen, W., Shi, Y., Zhang, J., & Zhang, Y. J. A. (2019). The roadmap to 6G: AI empowered wireless networks. *IEEE communications magazine*, *57*(8), 84-90.
Doi: 10.1109/MCOM.2019.1900271

[10]. Rappaport, T. S., Xing, Y., Kanhere, O., Ju, S., Madanayake, A., Mandal, S., ... & Trichopoulos, G. C. (2019). Wireless communications and applications above 100 GHz: Opportunities and challenges for 6G and beyond. *IEEE access*, *7*, 78729-78757.
Doi: 10.1109/ACCESS.2019.2921522

[11]. You, X., Wang, C. X., Huang, J., Gao, X., Zhang, Z., Wang, M., ... & Liang, Y. C. (2021). Towards 6G wireless communication networks: Vision, enabling technologies, and new paradigm shifts. *Science China Information Sciences*, *64*, 1-74.
Doi: 10.1007/s11432-020-2955-6