Comparing 5G and 6G Technologies

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***Abstract*—This article presents a succinct comparative analysis between 5G and the emerging 6G technologies, contextualized within the evolution from GSM to 5G. Beginning with a brief overview of GSM and its predecessors, we outline the foundational principles that have shaped wireless communication. We then delve into the distinctive features of 5G, including enhanced mobile broadband and ultra-reliable low latency communications, highlighting its transformative potential across various sectors. Building upon the advancements of 5G, our analysis extends to the anticipated features of 6G, such as terahertz frequencies and AI-driven networks, projecting the next frontier of connectivity. Through this comparative lens, we delineate the technological advancements and paradigm shifts that differentiate 6G from its predecessors and 5G, offering insights into the future of wireless communication. This article serves as a roadmap for stakeholders, researchers, and enthusiasts to navigate the continuum of wireless communication evolution, facilitating informed discourse and strategic decision-making in the telecommunications landscape.**

***Index Terms*—GSM, 5G, 6G, Wireless Communication**

I. Introduction

Today, mobile communication technologies are transforming every aspect of our lives. 5G mobile communication technology, with its high speed, low latency and wide connection capacity, has emerged as an important step towards meeting the needs of the digital age. However, as technological progress continues unabated, this time 6G communication technology is on the horizon. 6G goes beyond the possibilities offered by 5G, promising higher data rates, lower latency and wider connectivity. In this article, we will first introduce some basic concepts, then discuss the technologies used until 5G, their features and advantages. Then, the main features, advantages and possible application areas of 5G and 6G technologies will be compared and how the future mobile communication world will be shaped will be analyzed.

A. Basic Concepts

A cellular network is a type of wireless network built using several radio cells. Each cell is served by base stations. Unlike one antenna in a radio system, a base station both receives and sends signals, i.e. it consists of two antennas. Cellular networks have the advantages of better coverage, higher capacity and less power consumption than regular networks. The cellular network structure and a base station is shown in the Figure 1 and Figure 2, respectively.

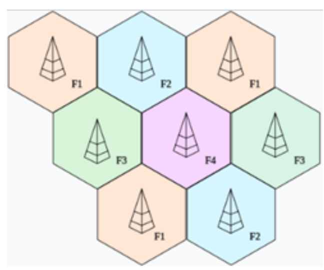

Fig. 1. Cellular network structure

Fig. 2. A base station

GSM (Global System for Mobile Communications) is a cell phone communication protocol. As the most widespread mobile phone standard, it is used by billions of people around the world. One of its most useful features is that it allows users to roam, i.e. make calls from different countries with the same line. All GSM standards use a cellular network and have the ability to switch between cells while roaming.

TDMA (Time Division Multiple Access) is a multiple access method that allows multiple users to share the same frequency channel. Each user is assigned time slots consisting of large units of time called frames. These frames are divided into multiple time slots and each time slot is assigned to a different user. The decision on which time slots the transmitter and receiver will communicate using this frequency is made by a centrally located router device. GSM uses TDMA technology for signal transmission.

CDMA (Code Division Multiple Access) is another multiple access method that allows multiple users to share the same frequency channel. In order for users to communicate with each other, it uses different coding in the same bandwidth, at the same time and on the same frequency. It allows multiple users to communicate using a single frequency without dividing the time. Each communication uses different, unique encodings. Before communication begins, the sender transmits a packet to the receiver containing the unique encoding format. Thus, the receiver knows how the incoming packets are encoded and can easily convert the received packets into their pre-transmission intelligible form. This reduces any possible collisions, waiting times and provides a certain level of security. Enables wireless communication for data transfers where high speeds are needed. Increases the available bandwidth.

The "G" in mobile phone systems stands for generation. Each generation is defined as a set of telephone network standards detailing the technological implementation of a particular mobile phone system. Mobile phone systems have the following generations: 1G, 2G, 3G, 4G, 5G, 6G.

B. Previous Generations

1) 0G (1940): 0G is known as zero generation mobile communications technology and is considered the forerunner of modern cellular network systems. This system was analog-based and was typically used by private user groups such as police, emergency services and commercial vehicle fleets, and was not available to the general public. Calls were manually connected by operators. 0G laid the foundations for mobile communications.

2) 1G (1980): 1G is known as the first generation of cellular technology. The maximum speed it supports is 2.4 kbps. Each cell covers a specific area using its own frequency band, so the same frequencies can be reused in different cells. It is the first cellular system to offer wireless telephony using analog voice signals and the first to commercially support voice-based analog communications. The key feature of 1G is that voice signals are transmitted using FM (Frequency Modulation) and AM (Amplitude Modulation) techniques. A single user occupies the entire channel for the duration of the call.

3) 2G (1991): 2G is known as second generation mobile communications technology. It was introduced commercially in Finland and opened the doors to the digital age in mobile communications. The maximum speed it supports is 64 kbps. One of the main innovations of 2G is the use of digital signals. This makes data transmission more secure and comfortable. Unlike the analog structure in 1G, 2G uses digital access techniques TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access). 2G makes more efficient use of the frequency spectrum and provides higher user capacity. 2G uses digital encryption, which significantly improves security. 2G supports voice calls as well as SMS and low-speed data transmission.

After 2G, 2.5G and 2.75G technologies were developed. In 2.5G, packet-switched domain is implemented in addition to the circuit-switched domain in 2G, and the maximum data rate increases to 144 kbps[1]. With these technologies, which serve as a bridge between 2G and 3G, the transfer speed of 2G has been increased. In addition, users were enabled to surf the web with their cell phones.

4) 3G (2001): 3G is known as the third generation mobile communication technology. When it became commercially available, it ushered in a new era in mobile communications. While the maximum supported speed was initially 2 Mbps, it was later able to reach higher speeds with developing technologies. 3G builds on the foundations of 2G but offers much higher data transmission speeds, an expanded range of services and improved mobile internet access. 3G networks operate over the UMTS (Universal Mobile Telecommunications System). UMTS provides high data transmission speeds using W-CDMA (Wideband Code Division Multiple Access) [2] technology and enables broadband data services. W-CDMA has the ability to serve multiple users simultaneously in the same frequency band by assigning a specific code to each user. The architecture of 3G is based on packet switched data transmission, making data transfer faster and more reliable.

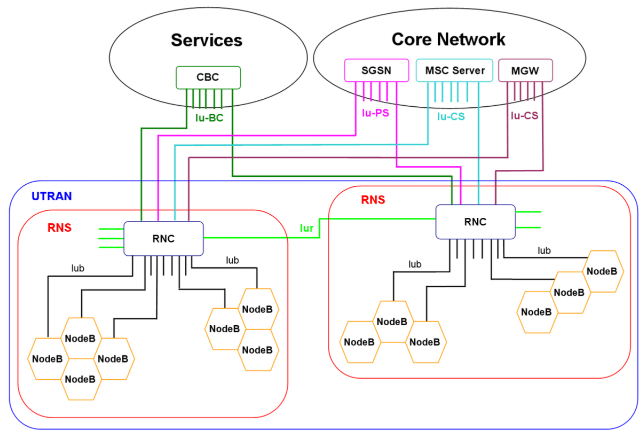

Fig. 3. 3G Architecture

Two other important components of 3G are HSPA (High Speed Packet Access)[3] and HSPA+ (Evolved High Speed Packet Access). HSPA significantly increases data transmission speeds, offering download speeds of up to 14.4 Mbps and upload speeds of up to 5.8 Mbps, while HSPA+ offers speeds of up to 42 Mbps and 22 Mbps respectively. This significantly improves mobile internet performance and user experience. The innovations offered by 3G include video calls, mobile television, multimedia messaging service (MMS), GPS-based services and high-speed internet browsing. Thus, 3G encouraged the development of mobile applications and led to the smartphone revolution.

5) 4G (2009): 4G is known as the fourth generation of mobile communications technology. The maximum speed it supports is 1 Gbps. The main difference from previous generations is that it provides much higher data transmission speeds, low latency and broadband internet access. 4G networks operate over the LTE (Long Term Evolution) standard. One of the main features of LTE is the use of OFDMA (Orthogonal Frequency Division Multiple Access) and MIMO (Multiple Input Multiple Output) technologies.

4G also uses E-UTRAN (Evolved Universal Terrestrial Radio Access Network) technology and IP-based architecture[4].

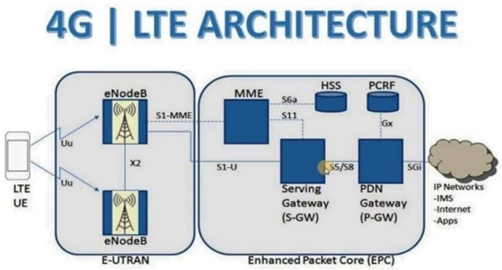

Fig. 4. 4G Architecture

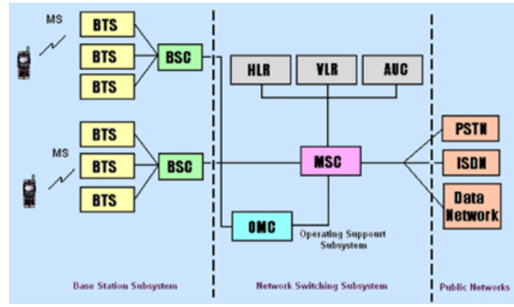

Fig. 5. GSM Architecture

IP-based architecture offers lower latency and more efficient data transmission, while simplifying network management and integration. E-UTRAN is 4G's radio access network and manages base stations (eNodeB) and radio resources. OFDMA divides a wide frequency band into narrowband subcarriers and assigns each subcarrier to different users, enabling multiple users to transmit data simultaneously in the same frequency band. Thus, this approach improves spectrum efficiency and expands network capacity. The main advantages of OFDMA include high spectrum efficiency, interference reduction, low latency and flexibility.

MIMO technology is a technology used in wireless communication systems to increase data transmission capacity and reliability. The basic principle of MIMO is to divide a wide frequency band into narrow-band subcarriers and assign these subcarriers to different users to enable multiple data streams in the same frequency band. This improves spectrum efficiency and expands network capacity.

The low latency and high speeds of 4G offer a variety of services that greatly improve the user experience. These include high-speed internet access, HD and 4K video streaming, video conferencing and cloud-based applications. In addition, 4G broadband and low latency connections facilitate the integration and management of Internet of Things (IoT) devices. 4G's all-IP-based architecture enhances the security of communications using more advanced encryption and authentication methods.

II. GSM Technology

GSM (Global System for Mobile Communications) is one of the most widely used standards for mobile communications worldwide. Developed by the European Telecommunications Standards Institute (ETSI) in the late 1980s, GSM is a digital cellular network system that enables voice and data communication between mobile devices [3].

A. GSM Architecture

The GSM architecture consists of four basic subsystems: BSS, NSS, OSS and MS.

1) MS - Mobile Station: Mobile station refers to mobile devices that enable users to use mobile communication services. It consists of two main components, ME and SIM.

- ME - Mobile Equipment: ME can be defined as cell phones or mobile devices. A mobile device is hardware that enables users to make phone calls, send SMS and utilize data services. The main features of a mobile device are radio interface, user interface, processor and memory and power supply.
- SIM - Subscriber Identity Module: The SIM card is a small personalized integrated circuit that can be inserted and removed from the mobile device. The SIM card provides secure storage of the International Mobile Subscriber Identity (IMSI) number and associated key. This information is used to identify subscribers using mobile communication devices and to verify network connections. SIM cards can also store a phone book.

2) BSS - Base Station Subsystem: The base station subsystem is responsible for radio communication between mobile devices and the network. It consists of two subcomponents, BTS and BSC.

- BTS - Base Transceiver Station: A base transceiver station is physical equipment that sends and receives radio signals. Each BTS operates to cover a specific area called a cell.
- BSC - Base Station Controller: The base station controller is responsible for controlling and managing multiple base transceiver stations (BTSs). It provides the connection between the MSC (Mobile Switching Center) in the NSS (Network Switching Subsystem) and the BTSs.

3) NSS - Network and Switching Subsystem: It is the subsystem responsible for the switching and management of calls in the GSM network. The NSS consists of subcomponents, each of which fulfills different functions.

- MSC - Mobile Services Switching Center: The MSC is the main component of the NSS. When a call is initiated, it establishes the connection to the target device when a call is made. It is responsible for the switching and routing of calls.
- HLR - Home Location Register: The HLR is a centralized database containing subscriber information and permanent addresses of users. The HLR keeps track of which VLR (Visitor Location Register) the user is registered in.
- VLR - Visitor Location Register: The VLR holds user information in the coverage area of the MSC where it is temporarily located. The VLR tracks temporary data and movements of users.

- AuC - Authentication Center: AuC contains security information that enables authentication of users. The AuC provides a secure connection between the SIM card and the network.
- EIR - Equipment Identity Register: EIR is a database containing the IMEI (International Mobile Equipment Identity) numbers of mobile devices. It checks whether devices are authorized and tracks stolen devices.

4) OSS - Operation and Support Subsystem: OSS is the system that provides operation, maintenance and management of the network. It performs functions such as network performance monitoring, fault management, configuration management and network optimization. OSS consists of two subcomponents, NMS and OMC.

- NMS - Network Management System: NMS monitors and manages the overall status of the network. It detects problems in the network and provides solutions.
- OMC - Operation and Maintenance Center: The OMC carries out the operation and maintenance activities of the network. The OMC manages the configuration of network elements, software updates and diagnostics.

B. GSM Features and Services

GSM provides voice and data communication digitally. Frequency Discrimination Multiple Access (FDMA) and Time Discrimination Multiple Access (TDMA) are used in this technology where subscriber information and security keys are stored on the SIM card. GSM also enables international roaming between different GSM operators.

Basic services include voice calls and SMS (short message service), while extra services include voice mail, call forwarding, call waiting and conference calls. Internet access and data transmission can also be provided through packet data services such as GPRS[4] and EDGE[5]. GSM provides many important features in terms of security. User authentication mechanisms, encryption algorithms, temporary IDs are used and operators can deactivate the SIM card if the mobile device is lost or stolen. All these features make GSM effective in enhancing the overall security of communications. As an advantage, GSM is intended to create a global standard and design a system that can be used from anywhere in the world. Thus, mobile devices can easily connect and communicate with each other regardless of location. It also ensured more efficient use of the frequencies used in cellular network systems. It has increased the sound quality by moving the communication, which was previously performed in analog, to digital. communication with high sound quality can be realized. While mobile devices could only transmit voice before, GSM has made it possible to transmit different data such as voice, video, pictures, SMS and internet access. It has also made communication more secure. This was achieved by using authorization and encryption mechanisms. Roaming agreements have made it available all over the world. The disadvantages of GSM are data rate limitations, capacity limitations and its obsolescence compared to emerging technologies.

To conclude, GSM has marked an important milestone in mobile communications, reaching a wide range of users and gaining global acceptance. With the continuous development of technology, GSM has been replaced by new generation mobile communication standards. Subsequent mobile communication standards such as 3G, 4G and 5G have significantly enhanced the user experience by offering advantages such as faster data transfer, low latency and wide coverage areas. These technologies have enabled the emergence of services, applications and devices that were not previously possible. Work on future technologies such as 6G shows the potential for mobile communications to go even further.

III. 5G, 6G and Their Comparisons

The rapid advancement of wireless communication has led to the widespread adoption of 5G, offering unprecedented speeds and low latency. 5G enables innovations across various sectors, including healthcare and transportation. As we harness 5G's potential, the focus is shifting to 6G, which promises even higher data rates, ultra-low latency, and integrated AI capabilities. This section explores the key features and advancements of both 5G and 6G. We will compare these generations to understand their differences and future implications. This comparison aims to provide insights into how 6G may shape the future of connectivity.

A. 5G (2010s)

5G refers to the fifth generation of wireless communication technology. Compared to 4G, it is faster, more error-free, less latency and more secure. The amount of data generated every day is increasing exponentially and at some point 3G and 4G network infrastructures become unable to handle it. At this point, 5G has become an important need in today's conditions.

1) The Architecture of 5G: The Reference Point Architecture at the top of Figure 6 shows the reference points defined between components in the 5G architecture. These reference points indicate the interfaces through which data in JSON format is transported. The Service-Based Architecture in the lower part of Figure 6 shows the bus and other control plane components that communicate over it.

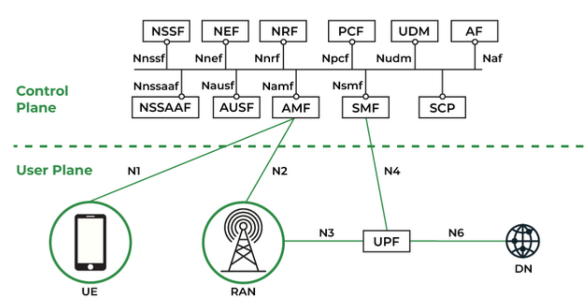

Fig. 6. 5G Architecure

The 5G network stack consists of several layers designed to handle the diverse requirements of modern communication. It includes the physical layer, which manages radio wave transmission; the data link layer for error detection and correction; the network layer for routing data; and higher layers that handle session management, application support, and security. These layers work together to deliver high-speed, low-latency, and reliable connectivity across various devices and applications.

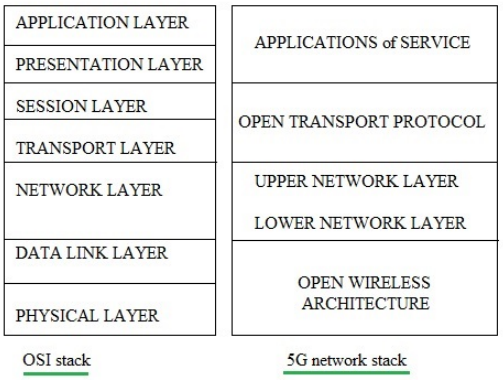

Fig. 7. OSI and 5G Network Stack

- Open Wireless Architecture: Corresponds to the Physical and Data Link layers in the OSI stack.
- Lower and Upper Network Layer: Due to the problems experienced in 5G due to the inadequacy of Ipv4 in some cases, the Network Layer is divided into 2 parts. The Upper part is used for the mobile terminal and the Lower part is used for the interface.
- Open Transport Protocol: Corresponds to the Session and Transport layers in the OSI stack. In 5G, it will be convenient for terminals to have a downloadable and installable transport layer. Thus, a new work for a specific wireless technology installed in base stations can be installed.
- Applications of Service: corresponds to the Application and Presentation layers in the OSI stack. It selects the best wireless connection for the given service.

2) Techonologies Used in 5G: 5G has a number of breakthrough innovations compared to previous generations. Thanks to these innovations, better quality communication becomes possible. In addition to communication, these innovations contribute to technological advances and pave the way for the invention of many different and advanced systems.

- Millimeter Wave: The 700 MHz to 2.6 GHz bandwidth, which is widely used in systems that need to be remotely controlled, is insufficient for these systems. As an answer to this problem, Milimeter Wave technology uses frequencies in the range of 30 to 300 GHz. In Millimeter Wave, the wavelength varies between 1 and 10 mm. These frequency bands are capable of carrying more information than the low frequency signals used in 4G LTE. It also provides high security. In addition to the advantages of Millimeter Wave technology, there are also disadvantages. These frequency waves have lower coverage and are easily blocked by obstacles such as buildings. Millimeter waves are absorbed by gases and moisture in the atmosphere, reducing their range and power. Millimeter Wave technology is both expensive and difficult to implement. Problems such as these have led to the development of Small Cell Nodes technology[6].

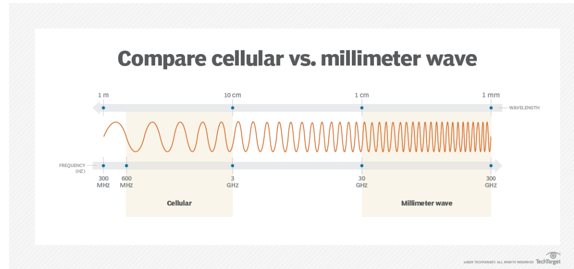

Fig. 8. Cellular vs Millimeter Wave Comparison

- Small Cells: Due to the disadvantages of millimeter wave transmission, the model of 5G infrastructure is different from 4G. Instead of the antenna masts that 4G brings with it, 5G networks will be produced in the formation of small cell nodes powered by base stations distributed throughout the city at regular intervals. Thus, an area will be utilized by dividing it into smaller areas. Small cells are divided into 3 types: pico cells, micro cells and femto cells. Femto cells have the lowest coverage and number of users. Microcells are the largest cells in terms of coverage and number of users. Small cell nodes increase energy savings in devices. They are also less costly to install.[6]

Fig. 9. Small Cells

- Massive MIMO: Massive MIMO is a technique in which a base station with a large number of antenna arrays provides independent data streams to a large number of user terminals, each with a single antenna, in the same time or frequency range[4]. By using more antennas, multiple data streams can be transmitted and received in parallel in the same frequency band. This significantly increases the system capacity. Massive MIMO utilizes the same frequency band more efficiently. It greatly increases efficiency by serving multiple users at the same time. The use of multiple antennas increases the strength of the signal and reduces the impact of interference. This results in more reliable and high quality communication. Massive MIMO consumes less energy to transmit the same amount of data. This saves energy, especially in large-scale networks. It can manage a large number of users simultaneously and efficiently. This is a great advantage, especially in crowded cities and areas with heavy data traffic.[7]

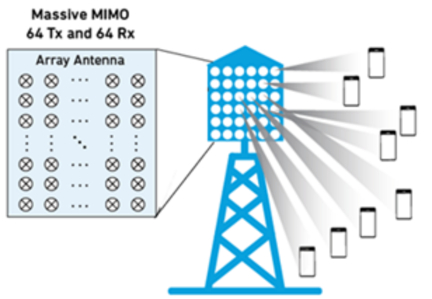

Fig. 10. Massive MIMO

- Beamforming: It is very difficult to transmit 5G data accurately and smoothly to and from the right places. Especially when interference occurs in millimeter waves. To overcome this problem, 5G base stations have started using Beamforming technology. In Beamforming technology, antennas change the distribution of the signal according to the devices that want to connect to the wireless network. In this way, the network coverage area moves according to the devices and changes shape according to its location. As a result of these processes, 5G provides a stronger and higher quality connection. The main purpose of beamforming is to increase the signal strength in a specific direction and at the same time reduce noise and interference in other directions. Its use is costly and complex.[8]

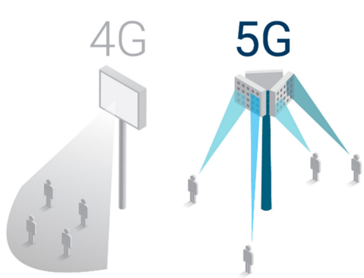

Fig. 11. Beamforming

3) Frequencies of 5G: Compared to LTE, 5G has three frequencies. These frequencies are called low-band, mid-band and high-band frequencies.

- Low Band Frequency: For LTE operators, low band is the number one band in terms of utilization. It has great coverage and good wall permeability. However, the maximum received speed at low band frequency is low compared to other frequencies.
- Mid Band Frequency: It is faster than Low Band Frequency and has less latency. However, it is not as permeable as low band. It is possible to see speeds up to 1Gbps.
- High Band Frequency: It is the most ideal frequency for 5G and provides high performance. It has low coverage and low building penetration. However, very high speeds can be achieved. It was previously used to transmit data from the main network to smaller sub-networks. But they have never been made available to users' devices. This is because miniaturized antennas were not previously available.

4) Advantages and Disadvantages of 5G: In terms of benefits, 5G speeds can reach gigabit levels, making operations such as downloading large files and streaming high-quality video much faster. Network latency depends on many factors, but in ideal conditions, 5G networks deliver 60 to 120 times lower latency than 4G. These latency speeds will make a range of applications, such as virtual reality, available today. 5G's scheme for sending data from Wi-Fi devices is better than the scheme used in 4G and 3G. As a result, the Block Error Rate, which is used to measure the frequency of errors in a network, turns out to be extremely low. In a 5G network, when the Block Error Rate rises to a certain level, the transmitter reduces the connection speed until the error rate drops, so that Block Error Rates are always close to zero. 5G networks offer very low latency, making them ideal for real-time applications. 5G allows many more devices to connect to the network at the same time. This is especially important with the growing number of Internet of Things devices. 5G supports smart city applications, improving the efficiency of traffic management, energy management and other municipal services. Automation of production processes and integration of robotic systems become more effective with 5G. 5G technology improves energy efficiency for specific tasks, which extends the battery life of devices. 5G has the ability to prioritize specific services, which ensures that critical applications always perform optimally.
Looking at the disadvantages, the development of 5G infrastructure or adaptations to existing cellular infrastructure incurs high costs. New base stations, fiber optic cables and other equipment must be installed. 5G can provide a really fast connection for urban areas, but people living in rural areas will not benefit fully from 5G connectivity. Since 5G operators will be targeting big cities, rural users will be the last to receive it. In addition, 5G requires more frequent base station installations, which will create problems, especially in residential areas in cities. It has been observed that the batteries of devices connected to 5G run out in a short time. For 5G to be used efficiently on devices, battery technology needs to advance. In addition, in addition to depleted batteries, devices using 5G experienced heating problems. The cost of 5G compatible devices will also increase. The complexity of 5G networks can lead to new types of cyberattacks and vulnerabilities. More data collection and processing may increase users' privacy concerns. There is a possibility of long-term health problems

due to increased base stations and Radio Frequency. The use of new 5G compatible devices may lead to faster disposal of old devices and an increase in electronic waste. Carbon footprint will also increase as energy consumption will increase.

5) 5G Development Process and Usage in the World: In 2008, NASA partnered with Geoff Brown and Machine-to-Machine Intelligence to develop 5G communication technology. By 2010, NTT Docomo in Japan began working on and experimenting with 5G. In 2011, initial studies emerged addressing millimeter waves as a crucial component for cellular 5G networks. In 2012, New York University established NYU WIRELESS, a multidisciplinary academic research center pioneering 5G wireless communication. The same year, the European Union initiated the ”Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society” project to define 5G, and the iJOIN EU project focused on ”small cell” technology. Also in 2012, NTT Docomo worked on a real-time 5G system simulator and conducted uplink field trials achieving 10 Gbps data rates. In 2013, Samsung announced the development of a 5G system, achieving 1.056 Gbit/s data transfer over 2 kilometers. India and Israel launched a joint 5G program, and Chinese companies, including Huawei, began 5G research. By 2014, Japan established the 5G Mobile Forum, and the European Commission allocated €700 million for 5G research. In 2015, Huawei created the first 5G test environment operating below 6 GHz. In 2016, the US released high-band spectrum for 5G, Chinese companies began technical trials, and the EU adopted an action plan for 5G services across all member states by the end of 2020. By 2017, 77 operators in 49 countries completed 5G trials. In 2018, several countries started limited 5G networks, with no 5G phones available yet. South Korea saw the first nationwide commercial 5G network deployment in 2019. By 2020, 5G became available in many major cities, and 5G phone production accelerated. In 2024, China announced a transition to 5.5G (5G Advanced). The maps of 5G coverage around the world is shown in the figures 12, 13, 14 and 15.

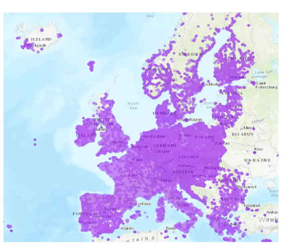

Fig. 12. 5G Coverage in Europe

Fig. 13. 5G Coverage in Turkey

5G is used in many developed countries and cities around the world. The first country to switch to 5G was the USA in 2018. Far Eastern countries were the countries that switched to 5G right after the USA. Although the installation is a little slower in Europe, 5G serves all cities in most countries. In

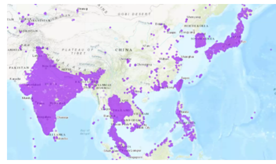

Fig. 14. 5G Coverage in Asia

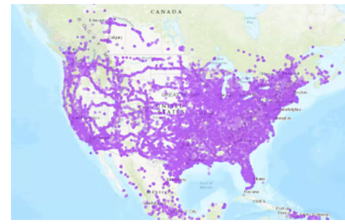

Fig. 15. 5G Coverage in USA

Turkey, 5G was made publicly available for the first time on July 29, 2022 at Istanbul Airport. As of 2024, there is no 5G use except in some pilot regions. Many researchers are taking an active role in the transition to 5G in Turkey. The transition to 5G as a country will be in 2026 according to state officials.

B. 6G (2030s)

6G is the 6th generation network technology that follows 5G technology, using higher frequencies than 5G networks and capable of providing significantly higher capacity and much lower latency. One of the goals of 6G is to support communication with a latency of one microsecond, which is 1,000 times faster than a millisecond throughput. With 6G, huge developments are expected in the field of technology. The computational infrastructure of 6G, working in conjunction with artificial intelligence, will be able to determine on its own the best location for information processing to take place, and will be capable of storing, processing and sharing data. It is estimated that 6G will be commercially available in 2030. 6G is being developed to address the ever-increasing radio access network and to utilize the terahertz spectrum to increase capacity and reduce latency.[9][10]

1) Technologies Will be Used in 6G: As the development of 6G technology progresses, it promises to incorporate advanced innovations that far surpass the capabilities of 5G. This section will explore the cutting-edge technologies underpinning 6G, including terahertz communication, artificial intelligence integration, and advanced network virtualization. These advancements aim to revolutionize connectivity, enabling unprecedented data speeds, ultra-low latency, and intelligent network management.

- Terahertz communications: With this technology, Terahertz frequencies ranging from 300 GHz to 3 THz are poised to become an integral part of 6G communications. These frequencies offer tremendous bandwidth, facilitating multi-gigabit per second data rates. THz communication opens the door to applications such as high-resolution holographic communication, ultra-fast download/upload and immersive virtual reality experiences. [11]
- AI-Driven Networking: With this technology, artificial intelligence and machine learning algorithms will play a central role in optimizing 6G networks. AI-powered network management, predictive analytics for dynamic resource allocation and intelligent routing protocols will improve network efficiency, reliability and security.

- Quantum Communications: With this technology, quantum communication protocols utilizing the principles of quantum mechanics promise unhackable and highly secure data transmission. Quantum key distribution and quantum teleportation protocols could revolutionize cybersecurity in 6G networks by protecting sensitive data against cyber threats. [12]
- Holographic communication technologies: Poised to redefine the way we interact and collaborate remotely. 6G networks will support real-time holographic telepresence, enabling realistic virtual meetings, interactive education and immersive gaming experiences.[13]

2) Usage areas of 6G: In healthcare, 6G networks will enable real-time remote surgeries by robotic surgeons, supported by ultra-low latency and high-definition video streaming. Health monitoring devices leveraging 6G connectivity will provide continuous patient data for proactive health management. 6G's ultra-low latency and high reliability are important for autonomous vehicles, enabling seamless communication between vehicles, infrastructure and cloud-based AI systems. This paves the way for safer and more efficient transportation systems. 6G networks will accelerate the development of smart cities by enabling interconnected Internet of Things devices, smart energy management systems and responsive urban infrastructure. From traffic optimization to environmental monitoring, 6G technology will improve sustainability and efficiency in urban environments. Immersive media experiences powered by 6G, such as augmented reality and virtual reality applications, will redefine entertainment and media consumption. High-quality streaming, interactive games and lifelike simulations will become ubiquitous.

3) Advantages and Disadvantages of 6G: As advantages, 6G has the potential to deliver speeds in excess of 1 Tbps per second. This means almost instant download, upload and streaming. Latency - the time it takes for data to travel between devices - is expected to reach unprecedented lows with 6G. This opens the door to real-time applications with minimal latency, such as remote surgery, autonomous vehicles and immersive virtual reality experiences. 6G networks are expected to manage significantly more connected devices than their predecessors. This meets the growing demand for connectivity in the Internet of Things era, where billions of devices will require seamless communication. 6G is expected to include advanced security features for data transmission and network infrastructure. This is critical as our dependence on connected devices increases and the need for robust cybersecurity becomes ever more important. 6G's unprecedented speed, low latency and increased capacity will pave the way for the development of entirely new applications and industries. Advances in areas such as artificial intelligence, robotics and personalized healthcare are becoming possible, powered by the capabilities of 6G.

As for the challenges that 6G is expected to bring, deploying the infrastructure required for 6G networks, including THz base stations and fiber optic backbones, poses significant logistical and investment challenges. Securing and allocating the spectrum required for 6G frequencies, including THz spectrum, requires international coordination and regulatory frameworks. As 6G networks handle large amounts of sensitive data, robust security measures, encryption standards and privacy protocols must be implemented to mitigate cybersecurity risks. The integration of AI into 6G networks requires ethical considerations regarding AI biases, data privacy and algorithm transparency to ensure responsible and fair technology deployment.

4) 6G Development Process in the World: After the widespread activation of 5G in most developed countries, efforts towards 6G have accelerated, with nations vying for leadership in this emerging technology. Although current 6G efforts are still in the research and planning stages and not yet ready for test environments, it is anticipated that experimental trials will commence by the late 2020s. Finland's University of Oulu is dedicated to a 6G research initiative called 6Genesis, which will run for approximately eight years and develop a vision for 2037. South Korea's Electronics and Telecommunications Research Institute is researching the Terahertz band for 6G, aiming to make it 100 times faster than 4G LTE and 5 times faster than 5G networks. China's Ministry of Industry and Information Technology is investing directly in the R-D process and closely monitoring it. Chinese manufacturer ZTE and China Unicom have agreed to collaborate on the development of 6G technologies, focusing on integrating satellite networks, IoT, and industrial IoT, and fostering technological innovation. The USA's Federal Communications Commission is expected to approve 6G frequencies ranging from 95 GHz to 3 THz for R-D purposes. The United Kingdom's University of Surrey plans to establish the 6G Innovation Centre, a global research hub focused on next-generation telecommunications engineering. Japan, by allocating a significant budget for 6G R-D, aims to secure a leading position in telecommunications and develop next-generation wireless communication technologies. Institutions like Germany's Fraunhofer Institute and France's Electronics and Information Technology Research Institute are conducting 6G research to contribute to the development of future wireless communication technologies.

When we look at the work in Turkey, there are projects carried out by many researchers. Prof. Dr. Hüseyin Arslan, one of the most well-known researchers, said at the 32nd Signal Processing and Communication Applications Congress: "We established an ecosystem in cooperation with ULAK Haberleşme AŞ, Vestel and many universities. With this ecosystem, we started 6G studies and we have already generated nearly 100 patents. Our goal is to be among the top 5-6 companies worldwide with 400-500 patents." However, there is no work done by the government.

C. Comparing the Technologies

5G and 6G technologies represent significant advancements in wireless communication, each building upon the capabilities of its predecessor while introducing new features. As in the data speeds and capacity, 5G offers impressive data speeds, with peak rates reaching up to 20 Gbps, and significantly enhances network capacity, allowing for more simultaneous connections and data-intensive applications. In contrast, 6G aims to push data speeds even further, potentially reaching up to 1 Tbps or higher, and seeks to expand network capacity to accommodate the increasing demand for data and support emerging technologies like holographic communication and immersive virtual reality.

5G technology brings ultra-low latency, reducing response times to as low as 1 millisecond, enabling real-time communication for applications like autonomous vehicles and remote surgery. In contrast, 6G aims to further reduce latency to the sub-millisecond level, approaching instantaneous communication, which is crucial for enabling seamless interaction between humans and machines and supporting applications that require instantaneous feedback. Moreover, 5G utilizes a wide range of frequency bands, including sub-6 GHz and mm-Wave frequencies. Sub-6 GHz offers better coverage and penetration, while mm-Wave delivers higher speeds over shorter distances. In contrast, 6G is expected to explore even higher frequency bands, including terahertz frequencies. These frequencies offer massive bandwidths and enable extremely high data rates but require innovative technologies to overcome propagation challenges.

5G integrates technologies like Massive MIMO (Multiple Input Multiple Output), beamforming, and network slicing to optimize network performance and efficiency. It enables a wide range of applications, including enhanced mobile broadband, IoT connectivity, augmented reality, and smart cities. In contrast, 6G is expected to integrate advanced technologies like AI-driven communication, intelligent network management, and quantum computing. These technologies will enable self-organizing networks, predictive maintenance, and enhanced security. 6G aims to revolutionize industries with applications like haptic communication, telepresence, advanced robotics, and decentralized AI, seeking to create immersive experiences and support emerging technologies that require unprecedented levels of connectivity and performance.

TABLE I
COMPARISON OF 5G AND 6G TECHNOLOGIES

Technology	Speed	Time delay	infrastructure
5G	1 Gbps – 10 Gbps	1-10ms	Present, not global
6G	10 Gbps - 100 Gbps*	¡1 ms	Not present yet

[a]Estimated values for 6G based on current projections.

In summary, while 5G represents a significant leap forward in wireless communication, 6G is poised to redefine connectivity with even faster speeds, lower latency, and revolutionary applications.

IV. CONCLUSION

In conclusion, the comparative analysis between 5G and 6G technologies within the context of GSM and its predecessors reveals a fascinating journey of technological evolution and innovation in wireless communication. From the foundational principles of GSM to the transformative capabilities of 5G, and the projected advancements of 6G, this exploration underscores the dynamic nature of connectivity. The distinctive features of 5G, such as enhanced mobile broadband and ultra-reliable low latency communications, have laid a robust foundation for the next evolutionary leap towards 6G, characterized by terahertz frequencies and AI-driven networks. As we navigate this continuum of evolution, it becomes evident that wireless communication is not merely evolving, but continuously redefining the boundaries of connectivity and catalyzing innovation across diverse sectors. This comparative analysis serves as a compass for stakeholders and researchers, guiding their understanding of the past, present, and future of wireless communication, and fostering informed discourse and strategic decision-making in the ever-evolving landscape of telecommunications.

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