THE EMERGING TECHNOLOGIES, USE CASES, PROSPECTS, AND CHALLENGES OF 6G WIRELESS SYSTEMS

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Abstract: The insatiable need for a higher volume of data transmission at the highest possible transmission speed is increasingly driving wireless communication researchers to innovate technologies that could handle low latency and high-speed communications of such data. While the 5G wireless system is yet to be fully adopted in many countries especially developing countries, in anticipatory mode, effort is ongoing to move to the next generation of wireless system; the 6G network. This paper discussed the emerging technologies that would require the features of 6G networks and also focused on the use cases, the challenges, and possible solutions of 6G networks. This paper concluded that the weakness of 6G in handling the issue of space roaming and hand-offs among satellites of different networks would lead to the emergence of the 7G network which would finalize the satellite hand-offs and roaming for future global connectivity.

IndexTerms - **Wireless communication, low latency communication, 6G network, emerging technologies.**

INTRODUCTION

The trend of the usage of the Internet has always been on the increase from inception as shown in Figure 1. The figure shows mobile data traffic growth as obtained from International Telecommunication Union (ITU) World Telecommunication/ICT Indicators Database spanning from 1990 to 2020. The figure shows that the adoption of internet technology became significant in the mid-1990s where less than 5% of the world's population is using the internet. Since then, there has been an increase in the usage. By the year 2010, about 30% of the world's population has joined the Internet community while in the year 2021; the percentage of the world's population using the Internet has increased to over 60%. This trend in Internet usage illustrates the growing demand for higher data rate.

Series : Individuals using the Internet (% of population)
Source: World Development Indicators
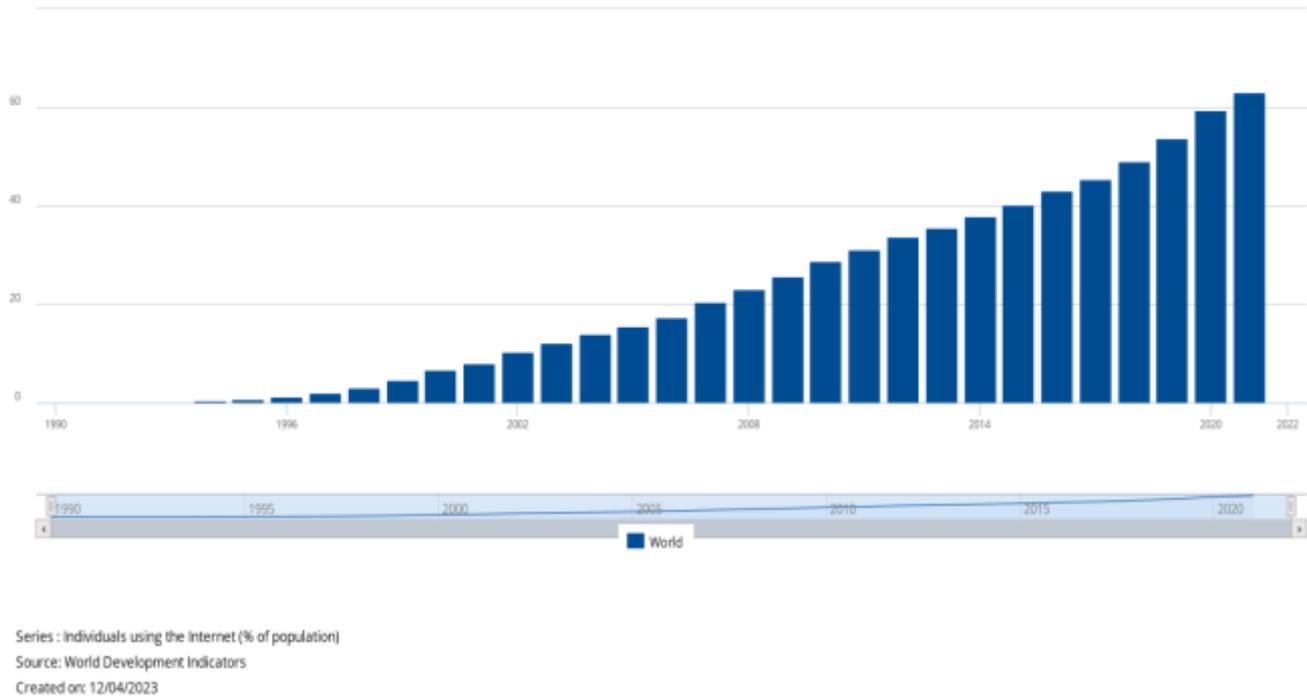Created on: 12/04/2023
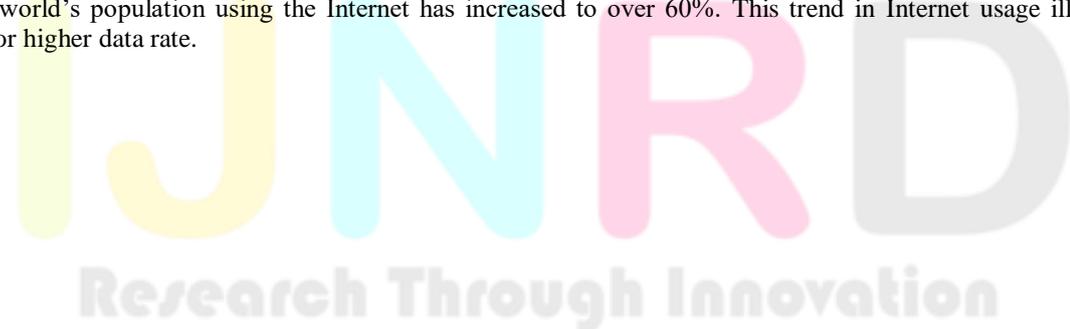
Figure 1: Individuals using the Internet (% of the population)-The World

It is in the light of this that wireless communication technologies keep evolving from one generation to another. To meet the demand for spectrum, new technologies to efficiently utilize the limited radio frequency are being developed [1]. The evolution of wireless mobile communication as shown in Figure 2 saw the addition of one generational mobile networking system from its inception in 1980 [2], [3] . Between the years 1980 and 1990, the first generation of wireless technology which uses Frequency Division Multiple Access (FDMA) for analog voice communication with a data speed between 2.4 kb/s and 14.4 kb/s primarily for voice communication was in use. The following decade, 1990 to 2000 saw the birth of the second generation of wireless systems which replaced the first generation. The second generation of wireless systems is a digital cellular system that uses Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). This second wireless generation is based on Global Mobile Communications System (GSM) which has a data rate between 14.4 kb/s and 64 kb/s and carries both the Voice and the Short Message Service (SMS) [3].

Figure 2: Generation of Wireless Systems

The years between 2000 and 2010 witnessed the era of the third-generation wireless system. This generation of wireless systems based on techniques such as Time Division Duplex, and CDMA2000 was for both voice and data. The data speed between 3.1 Mb/s and 14.7 Mb/s was achieved. When accessing advanced applications such as web browsing, TV streaming, or video streaming 3G systems quality of service degrades significantly [4].

The years between 2010 and 2020 saw the introduction of fourth generation of wireless systems. This technology of wireless systems operates frequency, time and orthogonal frequency division duplex. Data transmission speed is between 100 Mb/s and 1 Gb/s. Video operation is the main application of 4G networks. The 5G network introduced in the 2020s allows simultaneous connections of increasing devices and delivers high-quality services to all [4]. The 5G network supports high-definition video streaming and has the prospective to combine spectra and the ability to achieve faster data throughput of 1 Gb/s and above.

EMERGING TECHNOLOGIES

Every wireless network introduced opens the door for improvement on the existing network and new features and applications to be added. Notably, 5G comes with artificial intelligence, smart cities, and automation technologies, but they were partially integrated into the 5G network. The introduction of the 6G network system will see the full integration of these technologies into the system giving higher data rates, low latency, higher reliability, and efficient system transmission [5], [6]. Some technologies envisioned to be employed in the 6G network system are diagrammatically represented in Figure 3 below and briefly discussed.
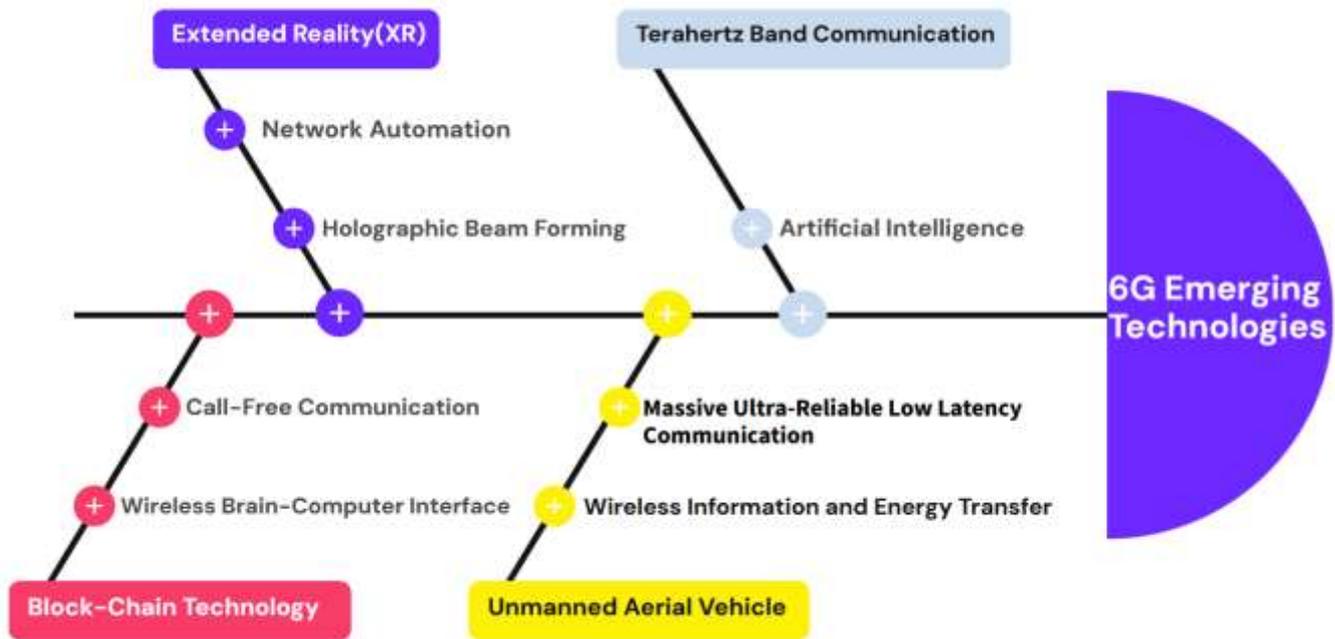

Figure 3: 6G Emerging Technologies

2.1 TERAHERTZ BAND COMMUNICATION.

The terahertz band frequencies, ranging from approximately 0.1THz to 10THz will play an essential role in the 6G network system [4] This frequency band will provide more bandwidth, capacities, ultra-high data rates, and secure transmission. 6G will be the first network system to usher in and support Tbps for faster communication technology.

2.2 Artificial Intelligence.

Unlike previous network work generations, 4G lacked artificial intelligence; while 5G only partially integrated it [4]. The 6G network system will fully support artificial intelligence to automate processes. It will include network handover, selection, and resource allocation to improve performance in delay-sensitive applications [[5].

2.3 CELL-FREE COMMUNICATION

There would be the integration of different technologies and multiple frequencies to allow the seamless switching between networks of user equipment (UE) without manually configuring their device when the user moves from one coverage area to another [2] The 6G network system will support this cell-free communication technology.

2.4 BLOCK-CHAIN TECHNOLOGY

Block-chain technology comprises blocks of data arranged and secured using cryptography. The technology will be used in the 6G network system to manage, organize and secure big data, as well as manage the extensive connectivity in the 6G network system [2] Block-chain technology will also be employed in spectrum sharing between the users and resolving the issues of large spectrum requirements in the 6G [7]. The technology will ensure security, low cost, and efficient spectrum utilization.

2.5 NETWORK AUTOMATION

The 6G will support complete automation of the network communication system. Communication between robot to robot, robot the server, and direct link and communication between them will be made possible with the automation technology supported by the 6G. The automation technology will also include automatic systems, automatic devices, and automatic process control [8]

2.6 UNMANNED AERIAL VEHICLES (UAV)

The 6G wireless communications UAV will provide a high data transfer instead of the conventional fixed base stations [9].

2.7 WIRELESS INFORMATION AND ENERGY TRANSFER (WIET)

Wireless information and energy transfer technology will be used in the 6G wireless network system to provide suitable power to the batteries of devices such as smartphones and sensors. The WIET will allow the production and growth of battery-less intelligent devices [5].

2.8 WIRELESS BRAIN-COMPUTER INTERFACE

With the current increase in wearable devices, these fundamentally use the brain-computer interface technology to communicate between the brain and the external discrete devices by evaluating the brain signals and decoding them [5]. This technology will be supported by the 6G wireless system and will support more applications such as five-sense information transfer.

2.9 EXTENDED REALITY (XR)

Extended reality technology comprises three realities, viz. Virtual Reality (VR), Augmented Reality (AR), and Hybrid or Mixed Reality (MR). Virtual reality creates an imaginary world by generating sounds and images using a headset experience. Augmented realities use specific devices such as mobile phones and add them to the real world. The mixed reality combines both AR and VR to create a compound environment. The 6G wireless network system will be valuable for this technology [5], [6], [10].

2.10 HOLOGRAPHIC BEAM FORMING

The 6G network system will use beam-forming technology in deploying the antennas. The beam forming uses a narrow beam with a high gain for transmitting and receiving signals. It offers better coverage and throughput, higher signal-to-interference, and noise ratio. These antennas are cheaper, lighter, smaller, and consume less power than traditional antennas. Using this holographic beam forming in the 6G technology has resolved the challenges of cost, power, weight, and size associated with the traditional communication system [6], [10]

2.11 Massive Ultra-Reliable Low Latency Communication (URLLC)

ULTRA-RELIABLE LOW LATENCY COMMUNICATION (URLLC) IS SIGNIFICANT IN MODERN APPLICATIONS SUCH AS AUTOMATION, REMOTE HEALTHCARE, SMART HOMES, AND SELF-DRIVING. THESE APPLICATIONS INVOLVE ULTRA-HIGH RELIABILITY, HIGH AVAILABILITY, AND LOW LATENCY RESPONSE TIME. THUS, THIS URLLC FORMS A PART OF THE 5G NETWORK KEY ENABLERS AND USE CASES IN ITS CLASSICAL FORM. THE 6G NETWORK WILL USE THE 5G ULTRA-RELIABLE LOW LATENCY COMMUNICATION (URLLC) AND MASSIVE MACHINE-TYPE COMMUNICATION TO MEET THE REQUIREMENTS OF THE MASSIVE NODES FOR CYBER-PHYSICAL SYSTEM-ENABLED INTELLIGENT FACTORIES AND SMART GRIDS IN THE FUTURE ON THE 6G NETWORK SYSTEM [7], [11].

2.12 Reconfigurable Intelligent Surfaces

This technology apply the use of smart surfaces that can dynamically control electromagnetic waves to optimize signal strength and coverage by directing signals towards users thereby enhancing communication pathways in complex environments [8]. Reconfigurable Intelligent Surfaces boost wireless communication by enhancing performance, efficiency, and adaptability. They promise to be crucial in future networks, even with some technical challenges ahead.

2.13 Quantum Communication

Quantum communication, which leverages quantum mechanics, promises unmatched security and ultra-fast data transfer. Despite challenges, it is set to revolutionize fields like cryptography and network infrastructure.

This 6G technology will explore and exploit the principle of quantum mechanics to provide ultra-secure communication channels for data transmission through quantum key distribution (QKD) and other quantum encryption techniques, thereby protecting data from potential eavesdropping and hacking [5]

2.14 Integrated Sensing and Communication (ISaC)

The 6G technology will integrate communication and sensing technologies into a single technology, allowing networks to detect, and interpret the physical environment. This would support applications such as the smart cities, autonomous vehicles, healthcare and industrial automation [11]. It will also provide real-time data and improve the decision-making process.

2.15 Advanced Edge Computing

The 6G network will integrate edge computing with artificial intelligence, which would usher in processing capabilities closer to the end users. By distributing computational tasks to the edge of the network, latency can be drastically reduced with optimized bandwidth usage which is vital for real-time applications [9].

2.16 Visible Light Communication

This technology uses light-emitting diodes (LEDs) for high-speed data transmission. 6G network will use this technology for with complement with the traditional radio frequency transmission communication to improve bandwidth and security where RF interference is a problem [9]

2.17 Space-Air Ground Integrated Networks (Sagin)

Space-Air-Ground Integrated Networks establish an intricate network infrastructure that links space, air, and ground domains, enabling seamless communication and data exchange. By leveraging the synergies between different segments, SAGIN improves operational efficiency, resilience, and effectiveness across diverse sectors, fueling technological advancements and capability enhancements [4]. This idea includes combining satellite, aerial, and terrestrial networks to furnish unlined connectivity across different environments, from municipalities to distant rural areas.

6G USE-CASES

The study of 5G wireless network system use cases envisioned to present a wide range of innovative and intelligent services served as a background for use cases for the 6G network system. The 5G wireless network system has three main classes of use cases introduced, the 5G enhanced mobile broadband (eMBB), [9], [12] the ultra-reliable low latency communication (uRLLC), and the massive machine type communication (mMTC). These were thought to provide various services but could not cater to the growing application needs.

These applications have interrupted the performance trade-off in the throughput, latency, coverage, energy efficiency, and reliability of the network system [13]. Hence, the need to redefine and improve the new use cases for these emerging applications gives rise to the 6G network system use case. The 6G use cases are illustrated in Figure 4 and discussed below.
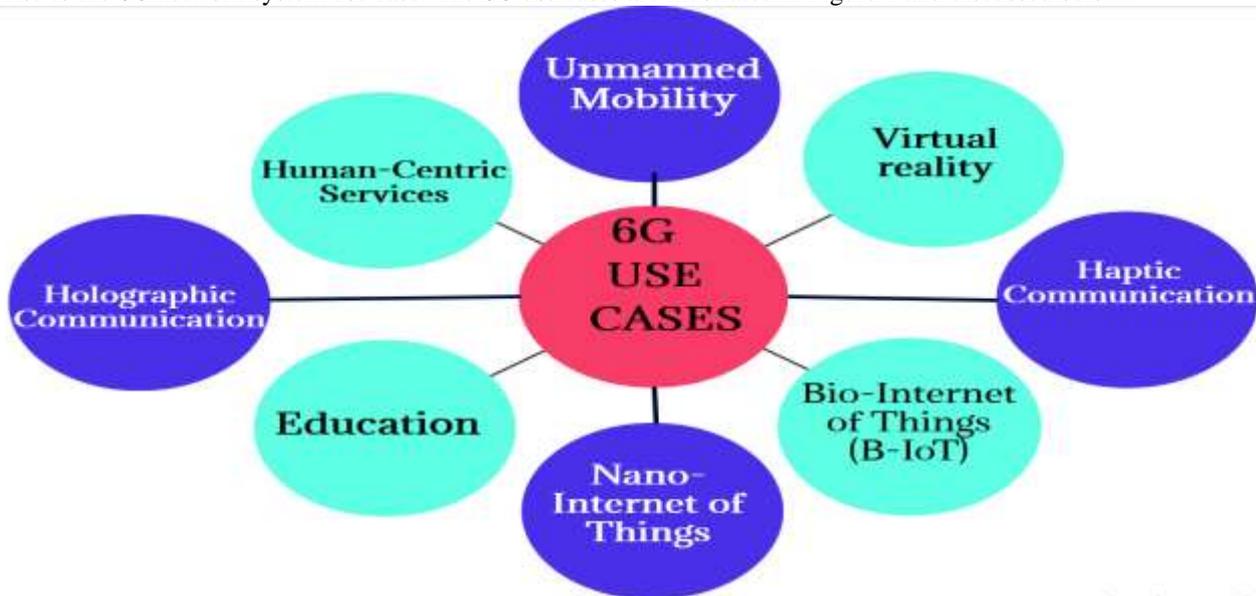

Figure 4: 6G Use Cases

3.1 HAPTIC COMMUNICATION

Haptic communication is touch or non-verbal communication that sends messages between both parties. The 6G wireless system will enable a sense of touch from a remote place, and this real-time experience will require a considerable design of the 6G network system [14].

3.2 UNMANNED MOBILITY

UNMANNED MOBILITY AS A USE CASE WILL FULLY EMPLOY AN AUTONOMOUS CONNECTED SYSTEM OF MOVEMENT OF VEHICLES. THEY PROVIDE THE SERVICES OF SAFE AND INTELLIGENT DRIVING, REMOTE MANAGEMENT, INFOTAINMENT, AS WELL AS INTELLIGENT OR ENHANCED TRAFFIC MANAGEMENT. 6G NETWORK WILL MAKE THIS POSSIBLE [14], [15]. 6G WIRELESS SYSTEMS WOULD BE ESSENTIAL FOR SELF-DRIVING CARS. THEY WOULD NEED TO BE ABLE TO COMMUNICATE WITH EACH OTHER AND WITH THE SURROUNDING INFRASTRUCTURE TO OPERATE SAFELY.

3.3 HUMAN-CENTRIC SERVICES

The 5G network system provides us with many functions and applications that are machine, and human-eccentric, ranging from basic augmented and virtual reality, to high-definition video streaming, internet protocols, television, Etc. [13]. There is a need to provide applications that are more human-eccentric service use cases to represent new user-centric metrics. Following this basis, secrecy, high security, and privacy will be fundamental attributes of the 6G network system [14]. User service satisfaction will also be supported as an essential metric in the 6G network communication system to enhance user satisfaction.

3.4 HOLOGRAPHIC COMMUNICATION

This use case employs the communication of real-time capturing, transporting, encoding, and rendering of 3D representations, anchored in space, of remote persons shown as stereo scope images or as 3D video in extended reality which requires higher accuracy and data rates and will be supported in the 6G network communication [10], [16].

3.5 Bio-Internet of Things (B-IoT)

Bio-Internet of Things is the interconnection between the Internet and bio devices using the Internet of Things. Bio-Internet of Things as a use case integrates innovative healthcare services, bioengineering, and all health-related issues, management, and resolution using the Internet of Things. B-IoT is enabled in the 6G network communication system [8]. 6G wireless systems would allow surgeons to operate on patients remotely. This would be especially beneficial for patients who live in rural areas or who have access to limited medical care.

3.6 NANO-INTERNET

Nano-internet of Things is the interconnection of nano-devices into the Internet of Things network. The Internet of Things can be employed in a smart factory to monitor activities in a factory, such as gas emissions, water quality, humidity, Etc. Nano Internet of Things uses molecular communication, which could not be enabled or supported by 5G due to the high band needed for its operation. Nano-networks use terahertz for better performance which falls within the 6G network frequency band. Though in its infancy, essential requirements must be well defined [4], [8].

3.7 Education

6G wireless systems would allow for more interactive and engaging educational experiences. They would also allow students to learn from experts from all over the world.

3.8   Tactile Internet

The Tactile Internet represents a state-of-the-art network system enabling smooth, rapid, and reliable communication among humans, machines, and devices. It incorporates touch-based feedback and minimal latency, ideal for tasks demanding precise control like remote surgery, virtual reality, and industrial automation [16]. In the upcoming 6G network, it will revolutionize remote surgery, allowing surgeons to perform procedures with precision from distant locations. Additionally, it will enable remote operation of machinery in hazardous environments, improving safety and efficiency. Furthermore, it will facilitate the control of robots for applications in high-risk workplaces.

3.9   Smart Cities and Infrastructure

Smart cities and infrastructure utilize digital technologies to upgrade urban areas, enhancing their efficiency, sustainability, and livability [7]. These improvements rely on data-driven solutions in transportation, energy, waste management, and governance to address urban challenges and promote city development [12]. The forthcoming 6G network is poised to leverage its capabilities for IoT applications, aiding in traffic management, energy distribution, and optimizing urban living standards.

3.10   Advanced AI Integration

Advanced AI integration involves embedding highly sophisticated artificial intelligence systems into different areas of technology, industry, and our daily routines. This integration empowers AI to analyze data, make decisions, and handle tasks independently, resulting in enhanced efficiency, innovation, and problem-solving across various fields [8]. With the advent of 6G technology boasting high data throughput and low latency, AI systems can function effectively, enabling real-time decision-making in applications like edge computing, autonomous vehicles, predictive maintenance in industries, and intelligent personal assistants [10].

3.11   Precision Agriculture

Precision agriculture utilizes cutting-edge technologies like GPS, drones, sensors, and data analytics to enhance farming methods. By gathering and studying data on soil, weather, and crop health, farmers can make well-informed choices to boost productivity, conserve resources, and lessen environmental harm [10]. The upcoming 6G technology is poised to support the implementation of comprehensive networks in agriculture, delivering real-time updates on soil health, crop conditions, and weather patterns.

3.12   Space-Terrestrial Integration

Space-terrestrial integration means working closely between satellites in space and systems on the ground. By pooling resources and data from both areas, this collaboration improves communication, navigation, and information sharing. It's valuable for sectors like telecommunications, navigation, weather monitoring, and disaster response [10].

6G technology aims to merge space and ground networks smoothly, ensuring strong connectivity for space missions, satellite communications, and potentially even missions to Mars. This advancement will aid scientific research and commercial ventures in space.

3.13   Enhanced Security and Surveillance

Enhanced security and surveillance entail using cutting-edge technologies like AI, drones, and biometrics to strengthen safety protocols and monitor activities in different settings. By deploying these tools, organizations can enhance their ability to detect threats, respond promptly, and overall, ensure better security for assets and people [10], [15].

6G technology will bolster advanced security and surveillance systems with features like high-definition cameras and real-time data analysis. This advancement holds the potential to enhance public safety by enabling improved monitoring and swift response to incidents.

3.14   Environmental Monitoring and Management

Environmental monitoring and management involve using advanced methods and technologies to understand and regulate the natural environment. By utilizing tools like sensors, satellite imagery, and data analysis, organizations can keep track of environmental conditions, identify changes, and take action to preserve ecosystems and reduce pollution [13], [15].

In the context of the 6G network, comprehensive monitoring of air and water quality, wildlife tracking, and climate conditions will be facilitated through a dense network of sensors and satellite data. This network will also improve communication and coordination during natural disasters by enabling real-time data sharing and predictive analytic, leading to quicker and more effective responses [6], [13]. Additionally, precision farming techniques will be enhanced using IoT sensors, drones, and AI to optimize crop yields, monitor soil health, and manage water usage efficiently.

3.15   Entertainment and Media

Integrating 6G into entertainment and media means using cutting-edge network features to create more immersive experiences, deliver content efficiently, and enable interactive communication. With super-fast connections and minimal delays, 6G allows smooth streaming of high-quality media, augmented and virtual reality adventures, and instant collaboration between users [8]. This improves how we enjoy entertainment, play games, and create content, sparking innovation in the entertainment sector.

CHALLENGES AND PROSPECTS

SEVERAL TECHNICAL ISSUES MUST BE ADDRESSED AND RESOLVED TO IMPLEMENT AND DEPLOY 6G WIRELESS COMMUNICATION SUCCESSFULLY. A FEW OF THESE POSSIBLE CONCERNS ARE DIAGRAMMATICALLY REPRESENTED IN FIGURE 5 AND DISCUSSED BELOW.

Figure 5: 6G Challenges and prospects

4.1 TERAHERTZ BAND

The terahertz frequency provides high data rates, but it is subjected to the issues of data loss transfer over relatively long distances due to high propagation loss and atmospheric absorption characterized by the high frequency [17]. The data loss issue over a high path length needs resolution. A new transceiver architecture should be designed to operate in the high-frequency band, supporting considerable bandwidth, high power, high sensitivity, and low noise.

4.2 DEVICE CAPABILITIES

Currently, devices are not compatible with all wireless communication technologies. Now companies are working on devices supporting the 5G network system. The same devices should support the 6G network and all other previous network generations [17]. Devices supporting the 6G network system are expected to support the Tbps data rate and the high operating bands. Device-to-device communication, artificial intelligence, and extended reality should be incorporated into the system's capabilities. Wireless energy transfer methods and different charging methods should be considered, as these are costly and challenging [18].

4.3 TRANSCEIVER AND ANTENNA DESIGNS

The 6G antenna design will be more challenging than the 5G. The 6G has a highly designed operating frequency in terahertz that helps spectrum and resource sharing [9], [17]. The transceivers are expected to be designed to help the antenna design technology with the required size and nano-meter to micrometer components to satisfy the holographic beam forming requirement [5].

4.4 NETWORK SECURITY

6G will have many network communications and devices connected to it. Smart devices are used in automation, artificial intelligence, extended reality, smart cities, and satellites. There would be a need to increase and improve the security architecture as the 5G security system will not be sufficient for the 6G [19], [20]. Excellent innovative cryptography security techniques should be considered comprising physical layer security and integrated network security techniques with low cost, low complexity, and high security.

HEALTH HAZARD AND ENVIRONMENTAL SUSTAINABILITY OF THE 6G WIRELESS NETWORK

The 6G wireless network is expected to employ the use of aerials of high-frequency bands in terahertz to radiate its signals to various geographical areas where they will be deployed. These terahertz band antennas with a frequency range of about 0.1THz to 10THz though have the advantages of providing high data rates, more bandwidths, efficient capacity, and a secure transmission [21], [22]. But it has an adverse effect of frequency dispersion and electromagnetic radiation.

Study research on biological effects of terahertz radiation shows that it has a negative effect to human health due to high frequency and power transmission. This effect is usually dependent on the duration of the exposure to the radiation, and the distance to the antenna [22]. In the 6G network, the adverse effect of the terahertz radiation will present an unsafe environment for the residents as well as the end users. To this end, a sustainable and hazard-free environment should be highly concerned and critically addressed. A sustainable approach of 6Rs- Reduce, reuse, recycle, recover, re-manufacture and redesign should be adopted. Where the reduction gives guidelines for the reduction in radiation, waste, energy consumption and other health hazard emissions from the system. The end-user's needs should be the focal point of development [19], [22]

6G AND BEYOND

The 6G internet system is based on the union of the latest radio system and fibre optic technology, and it integrates the 5G system and the satellite network. The satellite network system includes the telecommunication satellite, navigation satellite network, and earth imaging satellite. The telecommunication satellite functions on voice, data, video broadcasting, and the internet; the navigational satellite network works on a global positional system (GPS); and the imaging satellite network is for weather and environmental information updates [18].

The 6G wireless network system is expected to integrate these satellites to achieve global coverage. Four different countries have developed the global coverage system of these satellites. The USA develops the global position system (GPS), the COMPASS system by China, the Galileo system by the European Union, and the GLONASS system by Russia [18], [20]. In 6G, space roaming and hand-offs will be an issue as these satellites are of different networks. For global coverage to be achievable, the consolidation of these satellites must occur, and for unification to occur, hand-offs and roaming must be possible. Is this possible? This question might drive the research beyond 6G to 7G [14]. The task of the 7G network is to unite the satellite by solving the issues of space roaming and hand-offs.

CONCLUSION

This paper has presented the trend of wireless communication systems up to the fifth generation to achieve low-latency communication. However, the reason that technologies such as artificial intelligence, smart cities, and automation technologies could only be partially integrated into the 5G system has led to the introducing of the 6G network system which is believed to give higher data rates. The emerging technologies and use cases alongside prospects and challenges of the 6G network system were presented. A problem of the 6G network that was identified is the issue of space roaming and hand-offs among satellites of different networks.

In looking beyond 6G, the seventh-generation network system (7G) will function like the 6G for global coverage integration and define the satellite functions for mobile communication. The 7G will be the most advanced generation network system in mobile communication [18]. There would be some issues like the usage of international mobile phones during mobility from one country to another. The satellite is also mobile at a constant speed in a specific orbit; the standards and protocols for cellular-to-satellite systems and satellite-to-satellite communication systems will pose more research into the next generation, which could be named 7.5G [18]. Finally, this paper concluded that the search and quest for higher data rates with ultra-low latency, and reliability by network users would be met by the 6G wireless communication system and that the 7G would finalize the satellite hand-offs and roaming for future global connectivity.

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