ISSN 2278-3091
Volume 10, No.5, September - October 2021
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse211052021.pdf
https://doi.org/10.30534/ijatcse/2021/211052021

A Survey on Future Generation Wireless Communications-6G: Requirements, Technologies, Challenges and Applications

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Received Date : August 06, 2021 Accepted Date : September 16, 2021 Published Date : October 06, 2021

ABSTRACT

Within the last few decades, wireless connectivity has experienced an exponential growth. With far more features than 4G communications, next-generation (5G) will soon be available worldwide. In the year 2027 to 2030, the sixth-generation (6G) wireless system, fully supported by artificial intelligence, will become the dominant paradigm for wireless communication. Beyond 5G, the main factors to consider are higher system capacity, greater data rates, reduced latency, enhanced security, and improved quality of service (QoS) compared to current 5G systems. In this paper, we describe the strategy for future 6G wireless networks, emerging technologies and the architecture within which they will operate. This paper focuses on key performance indicators, applications, new services, and key technologies that could enable 6G networks. By presenting a new perspective on future research directions, this article will make a significant contribution to future research directions.

Key words: 5G, 6G, Cyber security, Privacy preservation, wireless Communication, data rate, massive connectivity, virtual reality, terahertz(THz), Tactile Internet, Free-space optics (FSO), Backhaul, Fronthaul.

1. INTRODUCTION

We must begin to research 6G networks even though 5G technology has not yet fully arrived. World's top communications experts have drafted together the first ever 6G whitepaper at the world's first 6G summit in Finland in March 2019 with the world's top communications experts. In an unofficial way, this was the move that officially launched 6G as a field of research. There have been a growing number of government and nongovernmental organizations that have announced their intentions to take part in 6G research. Governments around the world are investing in techniques and technologies that could be applied to 6G networks [2]. The Academy of Finland has also launched a foundational research project named "6 Genesis", which aims to pinpoint the best ways to develop 6G networks.

In the 6G network, there have been no standards or specifications set in stone, just many possible applications. There are people who argue that 6G networks shouldn't simply be faster versions of 5G networks, but rather an overall improvement of the 5G technology. With regards to coverage, despite the limitations of the 5G network, it should not be confined to the ground. Undersea surfaces should be fully covered. Artificial intelligence (AI) will also be much more advanced in the 6G network. Many researchers believe that the 6G network should be both AI-driven and AI-enabled, which means that AI is its key characteristic [3].

The 5G networks won't be able to provide a service that is fully automated with everything available as a service and truly immersive [5]. Even though the 5G communication system will offer many benefits over the current systems, it won't be able to meet the needs of future intelligent and automated concepts ten years from now [6]. In comparison to 4G communications, the 5G network will offer new features and provide better quality of service [7]–[10]. There are new elements of 5G technology, such as additional frequency bands, new spectrum management techniques, and the integration of licensed and unlicensed bands [6].

There are also vulnerabilities in 6G applications. A connected robotics and autonomous system typically relies on artificial intelligence and video coding to transmit data, where malicious behavior, encryption and data transmission may pose a challenge. A number of multisensory XR applications use molecular communication technologies, THz technology and quantum technologies, which make them susceptible to access control attacks, malicious behavior, and data transmission vulnerabilities. Brain computer interactions, like multi-sensory XR applications, implement similar techniques but have their own unique security barriers. Blockchain and distributed ledger technologies are relatively safe as the last applications of the 6G network; however they may still be vulnerable to malicious activities [11].

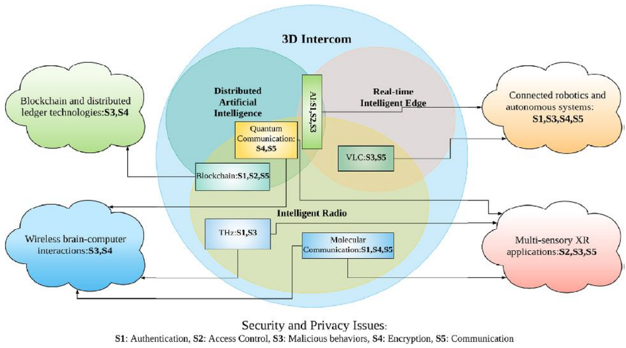

Figure.1. 6G network: Security and privacy issues

Following is a summary of the rest of the paper. Section 2 focuses on the growing trend of mobile communication. Section 3 contains Enabling Technologies of 6G, a summary of the major challenges and research directions leading to 6G is provided in Section 4, the requirement and trends regarding 6G are presented in Section 5 and finally, the paper concludes in Section 6.

2. MOBILE COMMUNICATIONS: EVOLUTION AND TRENDS

In this section, we highlight the evolution of wireless security and privacy from 1G to 5G.

1G : In the 1980s, 1G was introduced for voice communications. Wireless standards are not established for this technology, which transmits information via analog signals. There are many disadvantages to such an approach, including hard handovers, a lack of security and privacy, and low transmission efficiency. Phone conversations and data transmissions cannot be made private or secure because phone services are not encrypted. Voice data within a call can very often be low-quality as analogue signals degrade over time and space. This network utilized circuit switching. A cellular network was analog [49]. These networks were not secure.

2G: In the early 1990s, GSM (Global System for Mobile Communication) technologies were introduced. Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) are digital modulation techniques used in 2G networks, which can carry both voice and short message services. Using the system, users could now send and receive digital voice and data across the network. To ensure greater security and privacy in telephone calls, 2G also used Signaling and Data Confidentiality and Mobile Station Authentication. In the transition from 1G to 2G, many of the fundamental services that we use today were introduced, like SMS, internal roaming, conference calls, call hold, and billing based on usage, such as long distance charges and billing in real-time. 2.5G is a broadband data transfer and internet network that was developed between 2000 and 2003 based on a change in technologies. GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM) were included in the standards. Data transmission rates are flexible with GPRS, and it provides a continuous connection with the network. As a result, service providers are able to charge users for the data sent rather than their connection time.

3G: A 3G network was launched in 2000 for communications and internet access at a speed of at least 2 Mbps. Although the speed would not allow advanced services like web browsing, TV streaming, or video streaming, this speed could support advanced services not possible in the 1G or 2G networks [12]. On the basis of 2G technologies, the 3G system provides security. A 2G network must both include GSM and other elements, as well as robust security measures. The security weaknesses of the 2G are reduced with the 3G, provides a basic introduction to authenticating in two directions and the Authentication and Key Agreement (AKA). In 3.5G, faster data rates than 3G are achieved by using technologies like HSUPA, HSDPA, and EVDO. The technology in this generation allowed for high-quality video applications. Consequently, the data rates were higher than the prior generation [49].

4G: The fourth generation was launched in 2010 and is a completely IP based system. By offering high-speed, high-quality, and high-capacity services, VoIP, multimedia, and internet over IP costs can be lowered with improved security. IP based networks offer the advantage of seamless handover from previous generations of infrastructure, such as GSM, UMTS and CDMA2000, to the newer technologies. This technology introduced packet switching as well as an all IP network in the LTE standard. As LTE is not circuit switched, but instead uses the RAN architecture, there are significant infrastructure changes that carriers will need to integrate in order to supply quality of service.

5G: With 5G networks just around the corner, we can enjoy improved reliability, more comprehensive systems, and more secure architectures [13]. In 5G networks, the main innovation is to allow the simultaneous connection of an increasing number of devices and to deliver high-quality services to all devices. Additionally, the network will support other devices, including SDN-enabled IoT equipment, smart phones will not be the only devices supported [14],[15].

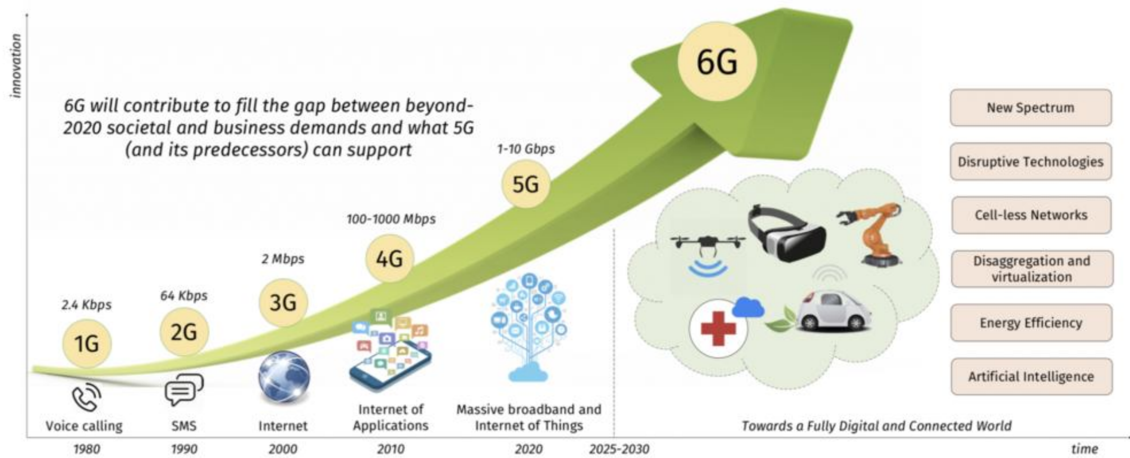

Figure 2. Evolution of Mobile Networks: From 1G to 6G

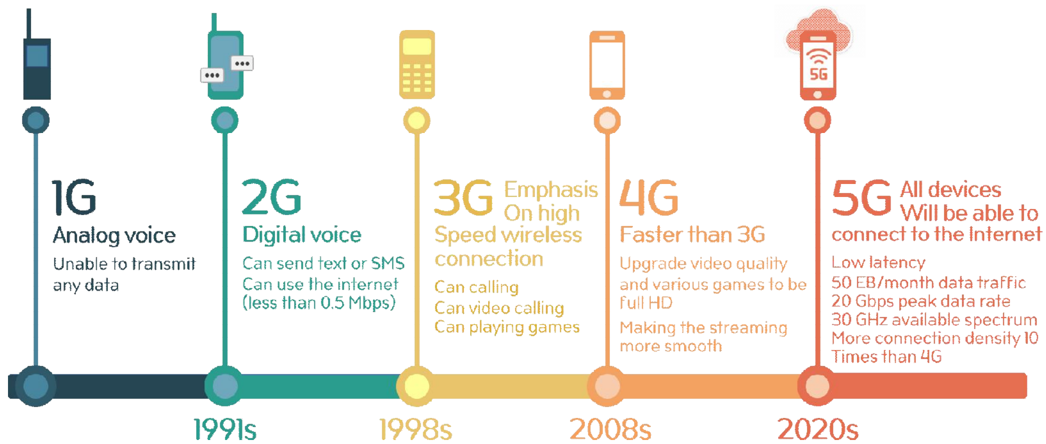

Figure 3. Generations of mobile communications

3. ENABLING TECHNOLOGIES OF 6G

6G networks inherit the benefits achieved in 5G based on their historical evolution in mobile networks [16]. 6G technologies will add some new capabilities and improve certain 5G methods. Hence, many technologies will be employed for the 6G network.

Artificial Intelligence: 6G autonomous networks are characterized by intelligence. In order to succeed in 6G communication systems, Artificial Intelligence through is a crucial and newly introduced technology [17]-[21]. For 4G communication systems, artificial intelligence was not used. A small portion of or very little AI is going to be supported by upcoming 5G communication systems. However, AI technologies will support 6G's automation. In addition to enabling the transformation from cognitive to intelligent radio, 6G with AI will exploit the full potential of radio signals [22]. Intelligent networks will be crucial for 6G communications in real time as a result of machine learning. Data transport will be simplified and improved through AI integration in communication.

Terahertz Communications: The bandwidth can be increased to improve spectral efficiency. A wider bandwidth and the application of modern Massive Multiple Input Multiple Output (MIMO) technologies can be used in order to do this. New applications are enabled by the introduction of mmWave frequencies in 5G. In order to meet even higher demand, 6G plans to extend the frequency band to THz. There is no more RF spectrum in which to meet the strong demands of 6G, since it has reached its maximum capacity. Sixth generation communication will heavily rely on the THz band [23],[24]. Communications at high data rates are expected to take place in the THz band. The THz frequency range is also referred to as submillimeter radiation. It usually refers to a frequency range between 0.1 terahertz and 10 terahertz, with the corresponding wavelength in the 0.03 mm-3 mm range [25]. The forming of super-narrow beams can reduce the agglomerated interference components and severe propagation loss experienced by the mmWave and THz bands. We will use highly directional pencil beam antennas for communication in the THz band to overcome the high atmospheric attenuation.

Optical Wireless Technology: The OWC architecture is envisioned for both RF-based and wireless communications for all possible device-to-device networks; these networks can also connect to network-to-network and network-to-backhaul networks. In 4G communication systems, OWC technologies are used. To meet the needs of 6G communications, the technology is expected to be utilized more widely. Some of the most well-known OWC technologies are light fidelity, visible light communication (VLC), and optical camera communication. Several applications involving these technologies, including V2X communications, indoor mobile robot positioning, VR , and underwater OWC, are expected to be implemented.

FSO Fronthaul/Backhaul Network: Backhaul network connectivity by optical fiber is not always feasible due to remote geographical locations and complexities. It may also be uneconomical to install optical fiber links for small cell networks. 5GB communication systems can benefit from the FSO fronthaul/backhaul network [26]-[29]. A FSO system is similar to an optical fiber network in terms of its transmitter and receiver characteristics. Therefore, the FSO system was capable of transferring data at a level comparable to an optical fiber system. In summary, FSO serves as an excellent backhaul and fronthaul connectivity technology for 6G, along with optical fiber networks.

Massive MIMO and Intelligent Reflecting Surfaces: uHSLLC, mMTC, and uHDD services will be supported more easily with massive MIMO technology in the 6G network. MIMO is one fundamental technique for improving spectral efficiency [30],[31]. Spectral efficiency is also developed when the MIMO method is used. Consequently, massive MIMO will improve spectral efficiency and energy efficiency, as well as higher data rates and frequencies for 5G and 6G systems [32]. We expect wireless 6G systems to switch from massive MIMO to integrated radio services in order to offer wide surfaces for wireless communication and heterogeneous devices, as compared to 5G. It is a recently developed technology that has enormous potential when it comes to green, energy-efficient communication. To locate a legitimate user, massive MIMO provides the highest level of beam-guiding accuracy. Due to this, information can be sent to unintended locations (such as Eve). In contrast to traditional MIMO, massive MIMO presents a number of challenges [49].

Quantum Communications: 6G networks offer the potential for unsupervised reinforcement learning. Large volumes of data generated in 6G will not be labeled with supervised learning. Labeling is not necessary for unsupervised learning. Thus, this technique is capable of generating representations of complex networks autonomously. A truly autonomous network can be operated through the combination of reinforcement learning and unsupervised learning [5]. Initially, quantum computing and quantum machine learning were considered to be a core enabler of 6G networks.

Blockchain: For future communication systems, blockchains are essential technologies for managing large amounts of data [33]. It is a distributed ledger technology that is used to create blockchains. There are many computing devices or nodes in a distributed ledger, which is a database. Identical copies of the ledger are replicated and saved by every node. Blockchains are managed by peer-to-peer networks. A centralized authority or a server is not necessary for its existence. A blockchain consists of blocks of data that are arranged together. Cryptography is used to secure the connections between the blocks. With its improved security, privacy, interoperability, reliability, and scalability, the blockchain is a perfect complement to the massive IoT [34].

Unmanned Aerial Vehicles: In 6G wireless communications, UAVs or drones are essential. UAVs are used to deliver high-speed wireless connectivity in many cases. Cellular connectivity is provided by BS entities in UAVs. Unlike fixed BS infrastructures, UAVs have certain characteristics characteristic of mobile systems, such as easy deployment, direct line-of-sight communications, and degrees of freedom with controlled mobility [37]. During emergencies, such as natural disasters, the implementation of terrestrial communication infrastructures is not economically feasible, and sometimes it is not possible to provide any service in volatile environments. This is an easy task for UAVs. UAVs will change the way wireless communications are conducted in the future. With this technology, fundamental wireless network requirements can be accomplished, such as mMTC, uHDD, and mHSLLC [38].

3D Networking: Users in the vertical extension of the 6G system will be able to communicate using both ground and airborne networks. Satellites and UAVs are used to send 3D BSs on low orbit [35],[36]. Three-dimensional networks differ greatly from conventional two-dimensional networks because altitude, and degree of freedom, is added. With 6G heterogeneous networks, coverage will be three-dimensional. Through the decentralized 6G networks, which integrate terrestrial, UAV, and satellite technologies, we can truly realize seamless global access and comprehensive coverage even in oceans and mountains.

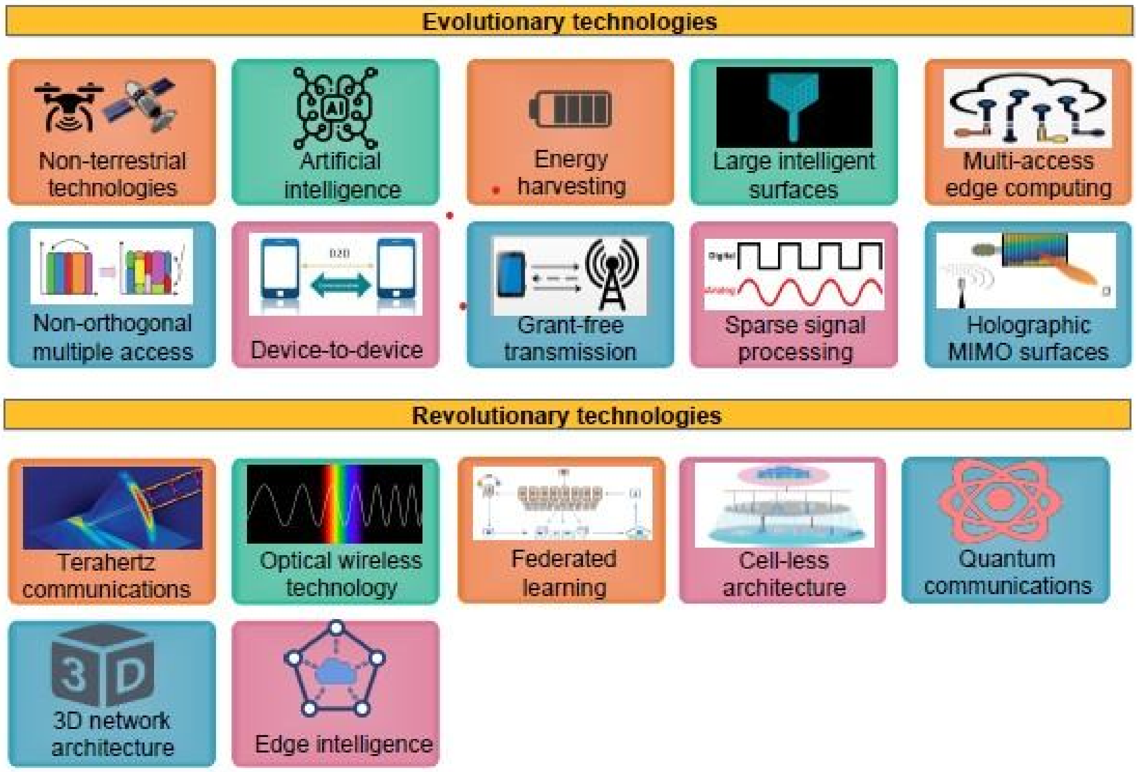

Figure.4. Evolutionary and Revolutionary Technologies

Cell-Free Communications: In order for a 6G system to function, multiple frequencies and different technologies must be tightly integrated. By doing this, users can seamlessly switch from one network to another, without having to change their device configuration [6]. Traditionally, cellular and orthogonal communications were synonymous, but 6G will introduce the concept of cell-free and non-orthogonal communications. From the available communication technologies, the best network is automatically selected. Cellular communication will become obsolete with this technology.

Integration of Wireless Information and Energy Transfer (WIET): A key 6G technology will be the use of WIET in communication. Similarly to wireless communication systems, WIET uses waves and fields. During communication, wireless power transfer is used to charge sensors and smart phones. WIET allows wireless charging systems to operate for longer periods of time [39]. Therefore, 6G connections will support devices without batteries.

Integration of Access-Backhaul Networks: 6G networks will have huge density of access points. In addition to access networks, there are backhaul connections like optical fibers and FSOs. It is not uncommon to have an access network and a backhaul network that work together.

Big Data Analytics: Big data analytics involves analyzing large sets of data and analyzing them in a complex way. Using this process, data management can be enhanced by uncovering hidden patterns, undiscovered correlations, and customer inclinations. Video, social media, images, and sensors are examples of big data sources. 6G systems widely use this technology to handle large amounts of data.

4. A FUTURE RESEARCH DIRECTIONS AND REVIEW OF CHALLENGES

For the deployment of 6G communication systems to be successful, a number of technical issues must be addressed. The following are some possible concerns.

High Propagation and Atmospheric Absorption of THz: Data rates are high due to the high THz frequencies. Despite this, data transmission over relatively long distances in THz bands presents a significant challenge because of high propagation loss and low atmospheric absorption [11]. Transceiver architecture needs to be redesigned for the THz communication systems. To ensure the maximum use of widely available bandwidth, the transceiver must run at high frequencies. THz communication faces another challenge with the antennas of distinct THz bands having minimal gain and effective area. Moreover, health and safety issues associated with THz band communications must be addressed.

Complexity in Resource Management for 3D Networking: In 3D networking, vertical networking was possible. Thus, a new dimension was added. The interference of multiple adversaries may also have an adverse affect on the performance of the entire system. In order to optimize resource management for mobile access, routing protocols, and multiple access, new techniques must be developed. An updated network design is needed for scheduling.

Heterogeneous Hardware Constraints: Several kind of heterogeneous communication systems will be involved in 6G, including different frequency bands, communication topologies, and service delivery methods. Furthermore, there will be significant differences in the hardware settings between access points and mobile terminals. A more complex architecture will be required to upgrade massive MIMO from 5G to 6G. Also, communication protocols and algorithms will be complicated. A communication will also cover AI and machine learning.

Autonomous Wireless Systems: Using 6G technology, autonomous vehicles, UAVs, and Industry 4.0 systems based on AI will be fully supported. In order to build autonomous wireless systems, we have to come together multiple heterogeneous subsystems. There are several types of autonomous systems such as autonomous cloud, interoperable processes, and system of systems, machine learning, and heterogeneous wireless systems [40]. Therefore, it becomes very challenging to develop the overall system.

Modeling of Sub-mmWave (THz) Frequencies: As atmospheric conditions affect mmWave and submmWave (THz) propagation, absorption and dispersion effects are observed [42]. The climate is highly unpredictable because it changes so often. This band has a fairly complex channel model, since there is no perfect channel model for this band.

Device Capability: Several new features will be available in the 6G system. The new features should be compatible with devices like smartphones. Especially challenging is supporting Tbps throughput, AI, augmented reality, and integrating sensing with communication features using individual devices. Many of the 6G features may not be available on 5G devices, and devices with 6G capabilities will cost more as well. Billions of devices are expected to be connected to 5G. The compatibility of 5G devices with 6G is critical when communication infrastructure switches from 5G to 6G. Users will benefit from this compatibility because they'll save money and it makes it easier.

High-Capacity Backhaul Connectivity: There will be a high density of access networks in 6G. In addition, the geographical distribution and the variety of these access networks are remarkable. There will be diverse access networks for different types of users, each with fast data rates. Connecting the access networks and the core network, 6G backhaul networks must handle enormous data volumes. Any improvement in the capacity of these networks will be challenging to meet 6G's exponentially growing data demands, as optical fiber and FSO networks are possible solutions for high-speed backhaul connectivity.

Spectrum and Interference Management: It is very important to manage spectrum resources efficiently, including spectrum sharing strategies and innovative spectrum management techniques, given the scarcity of spectrum resources and interference issues. For optimum resource utilization and QoS maximization, it is necessary to manage the spectrum efficiently.

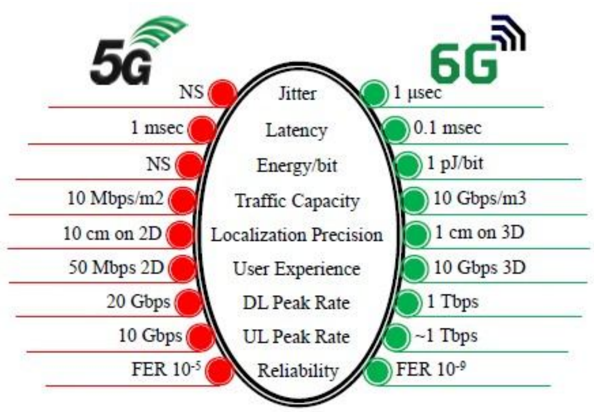

Figure 5. The requirements of 5G and 6G.

Beam Management in THz Communications: It is possible to achieve higher data rates through beamforming using large MIMO systems. The propagation characteristics of sub-mmWave, i.e., the THz band, make beam management in this band challenging. Massive MIMO systems will thus find it challenging to manage beams against unfavorable propagation characteristics [23]. In high-speed vehicular systems, choosing the optimal beam efficiently is also important for seamless handover.

Physical-Layer Security: Many of the 6G applications that are concerned with empowering humanity relies on human-centric communications [41]. The key features of 6G networks should be security, secrecy, and privacy. The security features of 5G networks are still under question, including decentralization, transparency, data interoperability, and privacy issues. Current regulations and processes of privacy and security of 6G networks are not effective enough for maintaining their physical security.

Planning of Economic Prospect: In addition to economic prospects, 6G communications must also be deployed. There will be an increase in infrastructure costs associated with 6G implementation. However, the cost of transforming a 5G system into a 6G system can be reduced with proper planning. In order to make 6G cost-effective, it is essential to study the possibility of infrastructure, data, and spectrum sharing.

5. TENDERS AND REQUIREMENTS FOR 6G

Broad frequency bands: Due to the requirements of the envisioned use-cases of 6G, it is evident that the frequencies allotted to NR may not be capable of supporting the required QoS and QoE. Accordingly, higher frequencies are predicted for future networks, including 73GHz, 140GHz, 1THz, and 3THz.

Opportunistic data-rate: An extremely high and opportunistic peak data rate is necessary to support emerging applications, such as immersive multimedia [44].

Opportunistic latency: Latency and delay between ends of a 6G channel must be less than one millisecond. The QoS of XR services must be improved by reducing latency to near zero [45]. Moreover, telepresence must have latency less than sub-millisecond [43].

mMTC: 6G will have to support many connected devices. Because of the complexity of the network and the sheer number of devices connected, the current trend, for example, human-centric solutions, won't be effective. For such a large number of devices, a new trend, machine-centric, is needed. 6G use cases demand fast connectivity, high reliability, and low latency communications, in addition to high data rates and low latency. 6G networks must, in order to achieve this objective, meet strict requirements like high availability, very short latency, and reliability.

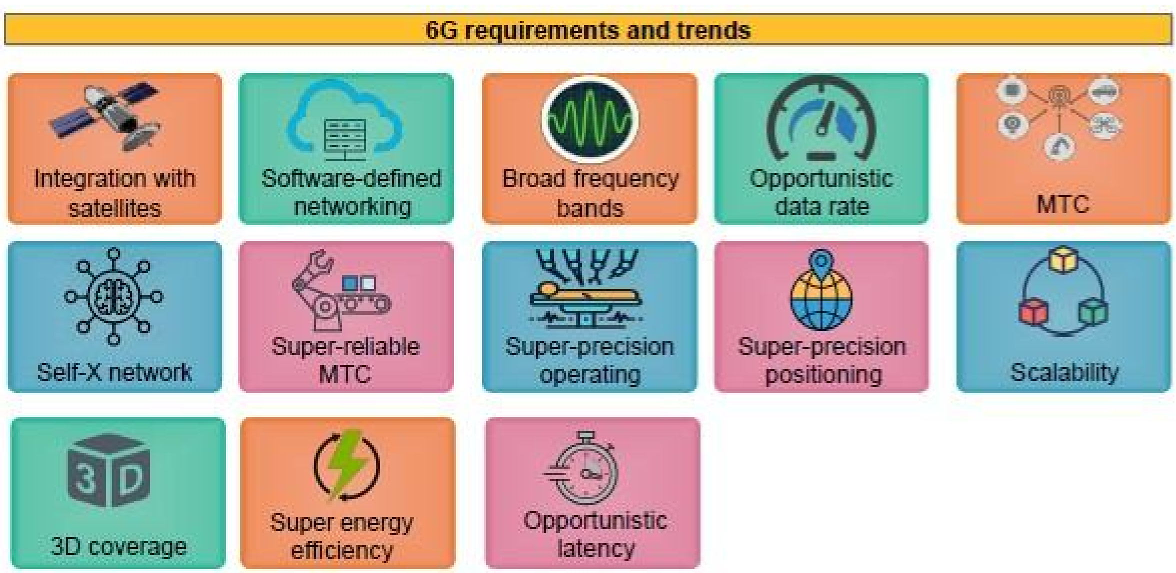

Figure.6. Requirements and Trends of 6G

Super-precision operating: It is evident that the traditional statistical multiplexing techniques do not function adequately for supporting future applications and services that require high precision. Intelligent transportation systems and tele-surgery are a few examples. This kind of service or application requires very precise and high-level performance, such as guaranteed delivery time. There are numerous functions that must be utilized to accomplish this, such as user-network interfaces, reservation signalling, new forwarding paradigms, management for network configuration, and internal and self-monitoring operations.

Self-X network: A 6G network must be more flexible and robust compared to previous generations. Humans are incapable of controlling the flexibility and robustness of these kinds of networks. Machine learning (ML) methods are therefore essential for managing such complex networks. By implementing ML techniques, network autonomy can be supported as well as insights into the environment in which they operate can be captured. The ML algorithms will enable the 6G network to be self-learning, self-configuring, self-optimizing, self-healing, self-organizing, self-aggregating, and self-protecting.

Super-precision positioning: Signal strength and travel time determine a position using Global Positioning System (GPS). These services, when measured in meters, have a sub-par precision according to the errors that they encounter [46]. Precision positioning with sub-millimeter accuracy will be necessary for future services. Among them are the services of telesurgery and tactile Internet.

Scalability: The Internet of Things will connect billions of devices including sensors, actuators, smartphones, tablets, wearables, home appliances, vehicles, and many more to the Internet [47]. These connected devices generate a large amount of data. An appropriate method of extracting the hidden knowledge is machine learning. In ML-enabled devices, the data is analyzed and hidden knowledge is extracted, thus resolving the raw data transmission issue, resulting in increased network efficiency.

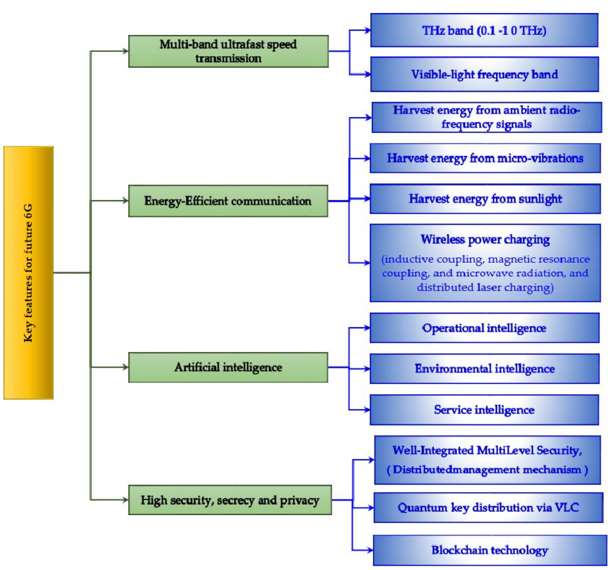

Figure.7. Key features for future 6G

Supper energy efficiency: Devices that operate on 6G frequencies consume much more energy than those that operate on 5G frequencies. The issue of energy efficiency in 6G is being addressed by energy harvesting, as an example.

Connectivity in 3D coverage: A 3D holographic display will be available to 6G users when they use 6G applications [48]. These services can be achieved with two sorts of devices: terrestrial and aerial.

Integration with satellites: In order to provide global coverage, 6G will use satellite communication technologies. In order to provide localization services, broadcasts, and the Internet, satellite-based telecommunications, satellite-based imagery, and satellite-based navigation will be integrated into 6G.

SDN: Dynamic and programmatically efficient configuration of networks is essential to 6G network management. With NFV, network instruments can be consolidated onto servers in data centers, distributed networks, or even on end-user premises.

6. CONCLUSION

6G networks have become the forefront of many researchers' agendas since 5G network research and deployment is close to an end. In comparison to previous generations, 6G will bring network services to a new level. Communications systems continue to evolve and gain exciting new features with each generation. The continued growth in the wireless communication market will not be fully met by 5G by 2030. Therefore, 6G needs to be implemented. A brief of security and privacy issues related to 6G networks is presented in this paper. First, we reviewed the steps from 1G to 5G. This paper examines 6G communication applications and technologies. Further, we discussed the challenges and directions for 6G research.

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