An Overview of Key Technologies and Challenges of 6G

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Abstract. Significant increase has been witnessed in data usage and users over the years for communication. Development of technology is a necessity hence 5G (5th generation) system is about to launch commercially however over a few years even that won't be sufficient. 5G networks are being tested and released offering various noteworthy advanced technologies and are anticipated to move forward progressively in upcoming years. Keeping in light the ever-increasing demand, 6G will be the need of the hour. Researchers and scholars around the world instigated to turn their attention to what 6G might be in the next 10 years or more, and many initiatives are already taken in various countries to explore the possible 6G technologies. A major revolution has been attained in the design of communication networks through 5G networks for their capability of providing a single platform, allowing a diversity of different services, from enhanced mobile broadband communications to virtual reality and the internet of things (IoT). However, estimation of the increasing requirements for new facilities and envisaging the expansion of new technologies within a decade from now on, the fact is already imaginable to envision, that to gratify new needs of society. This article aims to extend the vision of 5G soon and contemplates about the ambitious technologies which will lead to the implementation of 6G networks.

Keywords: 6th generation technology (6G) · Artificial intelligence · Terahertz communication · Visible light communication · Intelligent reflecting surfaces · Radio stripes

1 Introduction

As the modern technological world becomes smarter, intelligent, and pervasive, the stream of data becomes more imperative. The last two decades have perceived never-ending progress in the global mobile data traffic [1, 2], and the changes in the field of telecommunication will remain happening for many years. The need for data traffic has increased significantly since the evolvement of communication technologies and assumed to exceed Petabytes by 2021. From 1G to 5G, each of these generations has many innovations as shown in Fig. 1.

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There are many limitations in 5th generation mobile communication technology although it is still in implementation process [3, 4], such as high data traffic, latency, security, energy efficiency, frequency bands for which researchers have already started to work on 6th generation (6G) system which will have various innovations and technologies which 5G and its preceding technologies lack. As networks will need to share more amount of data with high speed, machine type communication will get progress connecting not just people, but vehicles, devices, and sensors. There is no uncertainty that due to the concept of pervasive artificial intelligence (AI), 6G is becoming a hot topic in the scientific world. The rise of the massive usability of AI will be the main reason for the enfranchising of 6G.

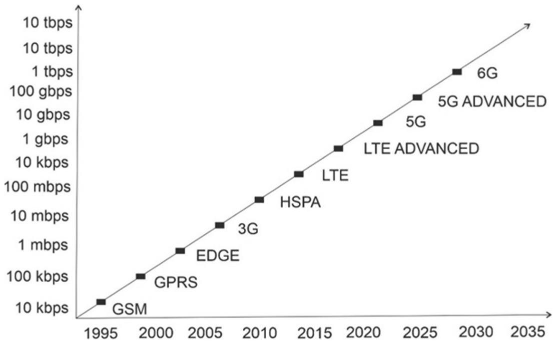

Fig. 1. Wireless roadmap to 2035

From data mining to network arrangement, AI will be present at all surfaces. To fulfill the requirements of users that are increasing rapidly each year along with their need for high data throughput with secure communication. 6G is expected to gain attention near 2030 and it will become the major requirement of users. Table 1 shows how the requirements and characteristics may become key performance indicators in 6G against 5G.

Table 1. Comparison of key characteristics of 5G and 6G

Characteristics	5G	6G
Data Rate UL	10 Gbps	1 Tbps
Data Rate DL	20 Gbps	1–10 Tbps
Latency Rate	1 ms	<0.1 ms
Spectral Efficiency (SE)	30 Bps	100 Bps
Visible Light Communication (VLC)	No	Yes
Pervasive AI	No	Yes
Real-Time Buffering	Not available	Available
THz Communication	No	Yes
Cell-Free Networks	Conceivable	Yes
Satellite Integration	No	Yes
Intelligent Reflecting Surfaces (IRS)	Conceivable	Yes
Uniform User Experience	50 Mbps	10 Gbps

In this paper, we will discuss various key technologies and challenges for 6G. We will try to determine the innovative aspects of the 6G technological development and explore the profound literature framework to get the answer about technological areas of 6G. The first section of this paper provides an overview of key technologies assumed to be used in 6th generation technology (6G). The second section provides the challenges and problems to deal with the limitations of 6G.

2 Key Technologies

There is no lack of conviction that 6G will look much better than 5G, but to achieve the goals for 6G some major leap forwards are required. There are various key technologies of 6G which we expect can fulfill the requirements for the improvement of the system. These key technologies include

2.1 Virtual Reality

Virtual reality or Artificial intelligence will be the main reason for the development of 6th generation communication technology. Since the advancement of IoT (Internet of Things), mobile communication technologies are becoming more and more important for better usage of technological devices. From self-driving cars to air traffic, every technology needs higher data throughput with low latency. Though 5G networks already offering downloading speed of up to 600 MB to 10 GB and have the potential to get significantly faster as compared to previous 4th generation technology which offers much less speed than 5G. But 6G will offer even much faster speed, the current estimate is that they could approach 1 TB per second. To achieve the goal of complete usage of artificial intelligence, researchers and scientists are already looking for 6G which will become a key enabling force behind an entirely new generation of applications for machine intelligence. Semantic communication and machine learning will have some major roles in AI for 6G [5, 6]. Based on Shannon's classical information theory, Semantic communication can tremendously improve the efficiency of communication by enabling semantic interference. Machine learning by enabling self-organization strategies can greatly enhance the communication system in 6G on the network level. Also in the process of deployment of AI, intelligent agents trained in the cloud using machine learning algorithms on Big Data will be deployed in the real world in the next decades which can unravel multiple optimization problems. Like 5G, 6G will not use the traditional algorithms of AI. To utilize the true power of AI, collaborative AI will be the key [7], which will revolutionize the world.

2.2 Terahertz (THz) Communication

Terahertz is a unit of frequency which is defined as one trillion (1012) cycles per second or 1012 Hz. Terahertz technology has the capability for employment in future wireless systems in a short-range. Terahertz communication is rising as the imminent technology to facilitate Terabits per second link (Tbps) with various spotlight features such as high throughput and trivial latency [8, 9]. Photonic technologies are being used for the generation of terahertz waves. Terahertz waves lie between the microwave band and infrared band in the electromagnetic spectrum as shown in Fig. 2. Terahertz (THz) frequency range (0.1 THz–3 THz) is the last span in the whole electromagnetic wave spectrum and is described as a THz GAP in the world of science.

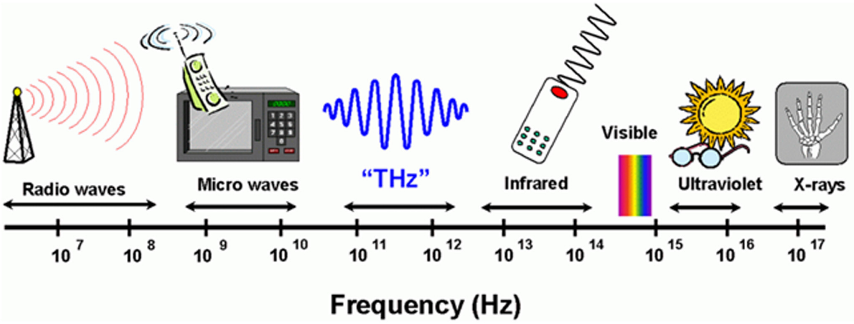

Fig. 2. Electromagnetic spectrum

Several issues limit the practicality of networks using lower frequency bands. To counter these limitations, terahertz communication technology can provide up to the Tbps link to fulfill the communication demand such as high throughput and low latency. THz is appropriate for developing a wireless telecommunication system that can provide a very high speed of 100 Gb/s. The efficacy of Terahertz technology is propitious for high-speed information transmission between electronic devices; creating wireless local area networks (WLANs) and wireless personal area networks (WPANs). Due to the limitation of transmission distance the THz wireless communications can be widely used for indoor application scenarios. The deployment of terahertz systems needs a strong understanding and precise modeling of channel conditions between the receiver (RX) and transmitter (TX). There are many key technologies for the realization of THz wireless systems including THz solid-state superheterodyne receiver, THz modulators, THz channel model, THz channel estimation, THz beamforming, and THz beam tracking. There are two different kinds of THz communication systems; Solid-state THz wireless communication system and spatial direct modulation THz communication system. The major difference in both of these systems is solid-state system is based on the frequency mixing mechanism, and the spatial direct modulation system is based on the baseband signals which are directly modulated into the radio frequency [10]. As we explore more about Terahertz (THz) communications, we find more technical challenges in the implementation of this communication system. Though THz provides huge bandwidth, the band deteriorates from high atmospheric losses. In THz band, antennas become smaller so to invoke communication we have to use high-gain directional antennas over distances surpassing a few meters. The concept of Ultra-Massive MIMO is formulated which depends on embracing ultra-dense frequency-tunable plasmonic nano-antenna arrays that are utilized which increases distance and also achieving higher data rates at THz frequencies [11].

2.3 Visible Light Communication

Visible light communication (VLC) can become a major technology for 6th generation wireless communication systems. VLC has great potential for progress over the next decade, bridging the existing efficiency gap between VLC and 5G technology that has already proved the experience of Gbps and will reach the Tbps with 6G technology. One potential alternative strategy for future 6G networks is to utilize the visible spectrum for visible light communication to have optical fiber-like output.

VLC is the type of communication in which data is sent wireless through the air with modulation of light waves from the visible spectrum with a range of 380 nm to 750 nm wavelengths [12]. This technology revolves around the principle of intensity modulation of solid-state infrastructure provided by light-emitting diodes (LEDs). One key advantage of VLC is providing an additional spectrum of approximately 300 THz of bandwidth which is much larger than traditional radio-frequency based access networks. VLC is one of the promising technology due to its features of non-licensed channels, high bandwidth, and low power consumption [13]. While the implementation of VLC technology, omnidirectional features can be achieved by using numerous transmitting elements [14].

2.4 Radio Stripes

Network densification was one of the major ideas for the deployment of massive MIMO 5G communication. Many large scale antennas were deployed on base stations distributed in many cells. Although there were many advantages of cellular massive MIMO networks like improved beamforming and facilitating more users in the large area through coordination between access points (APs) in small cells still it has some limitations in signal strength in beamforming and inter-cell interference which needs to be addressed. For this purpose, the new concept of cell-free massive MIMO is already in discussion in the world of wireless communication. Just like traditional MIMO networks, communication in cell-free massive MIMO will happen through coordinated multipoint. Deployment of this cell-free massive MIMO will happen with a congruous cost-effective framework Radio Stripes System (Fig. 3).

In February 2019, Ericsson proposed a radio stripes system. They presented that we can achieve great performance through distributed MIMO but it is inoperable to deploy it due to its high cost. To ease the deployment, we need to employ a radio stripe system. In the radio stripe system, the antennas and APUs are integrated inside a single cable [15]. Deployment of antenna elements with radio stripes system will not just make it easy to deploy large-scale antennas but it will also provide robust performance. At the Mobile World Congress (MWC) event in Barcelona, Ericsson suggested that radio stripes system will give pervasive effectuation and connectivity. From public transport to stations to shopping malls, deployment of radio stripes system is not just easy due to invisibility and cost-efficiency but also provides magnificent performance. This change

Fig. 3. Ericsson's radio stripe

of distributed antenna systems over a stripe is a great step towards future technologies and will play an important role in the deployment of 6G mobile systems.

2.5 Quantum Networks Communication

When the Quantum networks and quantum internet will be fully implemented on a wide scale the communication will be revolutionized, people will not only encounter the faster speed also the secure communication compared to the current system. The high data rate and security are the features that will play an important role in the usage of quantum communication in 6G technology [16]. Researchers employed the principle of entanglement, which tangled photons to transferal information among two nodes, where half of the photons are owned by the sender, while the receiver owns the other half. Photons are manipulated to communicate, causing an instant change in conforming photons. Entanglement, however, is the object of decoupling and the theorem of no cloning. Entangled particles become disentangled due to their strong interaction with the surrounding environment. No cloning theorem states that unknown quantum states cannot be copied.

Additionally, each node of a quantum network comprises of Quantum processors relying on qubits as a replacement of conventional bits. Qubits can also be defined as superposition and may occur in multi-state, which allows them to accomplish numerous calculations at one time whereas, the conventional bits are restrained to only 0 and 1 restricting them to one calculation at one time. While one quantum processor alters its photons state, the tangled photons in the equivalent quantum processor also alter, allowing them to transfer essential qubits. One of the advantages is, this is an unhackable communication system, any attempt of snoop or – the information will disengage the system. The information will be altered and notify that the hacking assault occurred. Though existing applications are inadequate but have been employed magnificently in quantum key distribution. Because the tangled photons instantly transmit information, this makes it faster than the conventional system.

To overcome the difficulty of long-distance communication academia has employed quantum repeaters. These repeaters are placed among the sender and receiver. The motive of these repeaters is to store the tangled photons by the sender and receiver. If accomplished entanglement swap with Bell state measurements, the photons of both receiver and sender can be tangled over a long distance. Although researchers have developed resourceful methods to suppress the problems still a handful of quantum repeaters are required even in primary quantum networks.

2.6 Large Intelligent Surface (IRS)

Large Intelligent Surface (LIS), also known as Intelligent Reflecting Surface (IRS) is considered as a prominent energy-efficient technology for the 6G communication system which can get unprecedented Massive MIMO output gains. 5G networks used Massive MIMO system for the communication system to get improved spectral and energy efficiency where base stations are equipped with a very large number of antenna arrays, thereby scaling up the conventional MIMO systems by many orders of magnitude. The difference which the IRS makes is that IRS contains low-cost passive reflecting elements [17], which are low-cost and consume less energy that can reconfigure the controlled propagation environment. The resulting IRS can be readily integrated into walls, ceilings, and facades of buildings. It has the potential to reduce energy consumption significantly.

Figure 4 shows communications using Intelligent Reflecting Surface (IRS) where the base station is out of the line of sight from the user equipment (UEs) due to tree. Each reflecting element induces a certain phase shift on the incident electromagnetic wave which will make the propagation channel more favorable for users. In 6G networks, IRS will play a fundamental role and will satisfy the various quality of services (QoS).

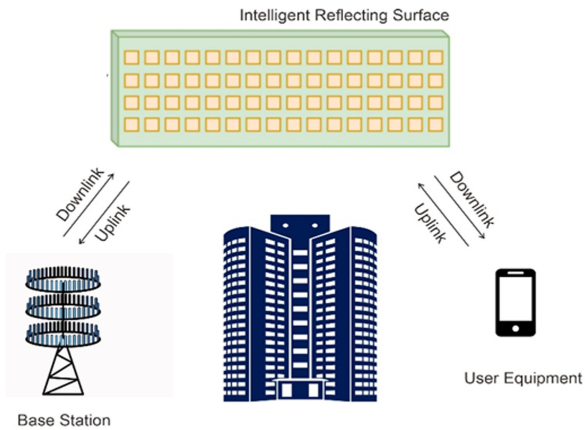

Fig. 4. IRS assisted communication system

3 Technological Challenges

There are many advantages of 6G over 5G and previous networks which will make way for its implementation but at the same time, there will be many hurdles that require special attention. Some of these hurdles are already being considered and addressed in 5G but no decisive answer was found.

3.1 Advanced Access Network

6G will provide very high data rates but an adequate growth of the backhaul capacity will be required [18, 19]. The deployment of VLC and THz communication systems will further increase the density of access points. These access points are geographically distributed and pervasive. For various types of applications and users, each of these access points will support very high data rate connections for communication. To avoid the creation of bottleneck, the backhaul networks in 6G have to manage the immense amount of data for communication between the access points and the centralized network to provide high data rate services to users. To cope with this challenge, there may be many solutions like quantum communications and exploring capacity of 6G access technologies for solutions of self-backhauling where radio stations provide both access and backhaul services. When the access and the backhaul share the same wireless channel with time, frequency, and space. The major benefit will be the easy deployment of dense network in a more integrated manner by counting on many control and data channels defined for providing access to the user equipment (UEs) as shown in Fig. 5.

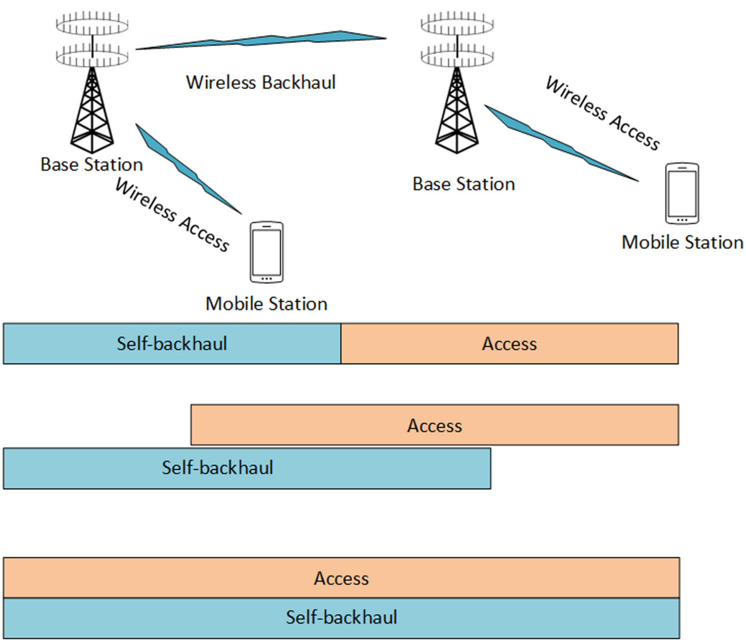

Fig. 5. Advanced backhaul architecture

3.2 Terahertz (THz) Frequencies

Recent development indicates that frequencies in the THz range and above will be considered for 6G. Many terahertz (THz) free bands will be available to satisfy the requirement of high data rates with increased bandwidth. 5G introduces mm-Wave with wider bandwidths for higher data rates but due to lack of propagation modeling and channel understanding, the 5G spectrum may not exceed 140 GHz. However, 6G will utilize spectrum beyond 140 GHz but still, there will be many challenges including the range of communication and size of antennas that needs to be addressed in the future. The propagation properties of mmWave and sub-mmWave (THz) are susceptible to environmental conditions; thus, the results are absorbent and dispersive [20]. The atmospheric situation is often complex, and therefore very unstable. Hence this band's channel modeling is relatively complex, and there is no ideal channel model in this band. In the recent development, Rohde and Schwarz presented the system at the EuMW2019 workshop held in Paris on mm-Wave and THz frequencies. The target of the workshop was on frequencies above 100 GHz, where the primary focus was on D-band (150 GHz) and H-band (300 GHz). The research resulted in a system that allows signal generation and signals analysis at 300 GHz and 2 GHz bandwidth. Fundamental research is on carrier frequencies above 300 GHz as it will be appropriate for THz communication.

3.3 Devices Capacity

As artificial intelligence will be the key factor of 6G communications. Like every other generation, 6G will also be defined by user equipment capability and requires very high computational power to run the algorithms of AI. UEs will need more power and to make them more efficient will be a major challenge for companies working on building UEs. Notables companies launched 5G enabled devices but the working of these devices is still under observation. Conventional devices are not energy efficient and they produce excessive heat that needs to be improved and devices will be designed with new materials and design to fulfill the requirements of emerging systems of the future.

3.4 Mobile Edge Computing

Edge computing is a technology which is proposed before 4G and remains as a challenge in its implementation. The concept of MEC enables cloud computing and IT services at the edge of the network for ease of users. Mobile edge computing MEC is used for the reduction of latency to the applications and services as well as much more bandwidth consumption saving [21], but there are some major challenges in implementing MEC from which some are addressed even in 5G but it further needs to be addressed in the research of 6G. Some of these challenges are mobile data and computation offloading, policy control, session management function (SMF), user plane function (UPF), edge cloud infrastructure, and convergence with network function virtualization (NFV). A layered architecture based on the NFV concept, WI Cloud can be used [22], for providing network function and compute resources which will change the conventional elements of network and cloud computing (Fig. 6).

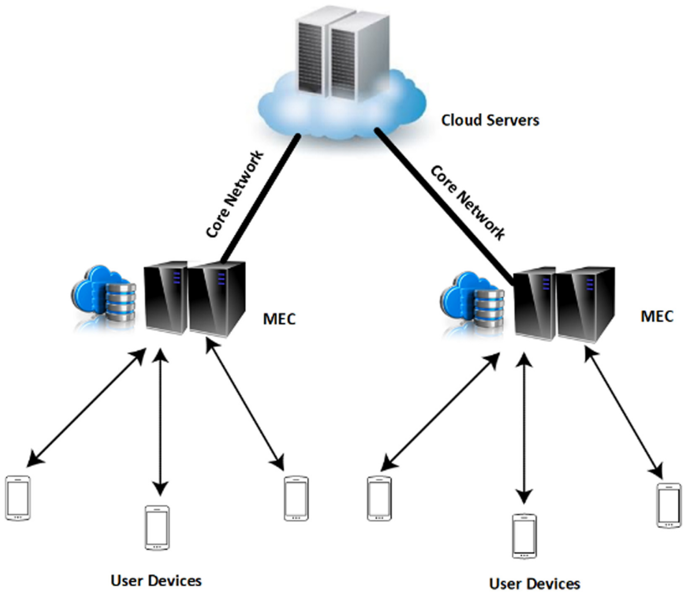

Fig. 6. Mobile edge computing architecture

3.5 Tactual Communication

Upcoming usage of holographic communication is to convert virtual views close to people's reality, behavior, environments, etc. Exchanging physical contact remotely via a real-time Internet connection is advantageous. The anticipated facilities involve telecommunications, the automated cooperative reader, and interpersonal communications that will enable random control to be applied across communication networks. To meet these strict requirements, the effective design of the communication framework between the rows must be carried out. For example, new physical layer diagrams (PHY) must be developed to enhance transfer and motivated protocol for the design of signaling systems, congestion of waveforms, etc. Wireless communication systems cannot meet that standard and it needs wireless fiber communication systems [23, 24].

3.6 Security

Security is a key issue for 6G wireless networks, especially when employing the Terrestrial Space Integrated Network (STIN) technology. In 6G other modes of security, such as advanced network security, should be considered collectively in addition to traditional physical layer security. Hence, new security solutions worth more extensive research, depending on low complexity and having high safety standards. To this extent, other physical layer security approaches proposed for 5G can be applied to 6G systems, like Low-Density Parity Check (LDPC)-based protected massive MIMO; protected mm-Wave techniques might also be sufficient for UM-MIMO and THz band applications. For integrated network security, diverse security domains need to have a suitable management objective for various functions. A centralized distribution control system is a good framework for STIN that takes diverse management into accounts and certificate less communication keys. These physical and network layer protection approaches will combine this comprehensive protection approach with efficient administration and operation, which effectively preserves sensitive information and anonymity on 6G networks [25].

4 Conclusion

In this paper, we surveyed key technologies that will help in the future to work more efficiently on 6G. 6G will provide a very high data rate and capacity, all around there will be no drop in quality of data throughput regardless of the number of user equipment (UEs) connected to the network during the same time. We have analyzed different technologies regarding the development of 6G standards and discussed how Terahertz (THz) communication can become a major difference between previous generations and the 6th generation communication system and how by using all of these technologies, the requirements of AI applications will be fulfilled. Due to innovation and an increase in demand for artificial intelligence, THz communication along with Radio Stripes and quantum networks will be able to fulfill the requirement of high data rates and security for applications. We also presented some major challenges for 6G, such as the range of communication and size of antennas in THz frequencies of THz communication system and the capability of devices to ascribe with new technologies.

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