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*Research Article*

# New Trends and Advancement in Next Generation Mobile Wireless Communication (6G): A Survey

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As the commercial implementations of 5G networks have been initiated in different regions of the world, the focus of the researchers is bending towards the next generation of wireless communication. This research study intends to investigate the requisites of the fast establishment of the theoretical and practical measures for sixth generation (6G) wireless communication. To this end, this paper first outlined the existing research works that have considered different aspects of 6G, and then based on this existing works, the future vision is established. Then, the 6G vision is based on four types of connectivity and is summarized as "Wherever you think, everything follows your heart." To fill the gap between the market requirements after one decade and the limited capabilities of 5G, different specifications of 6G that make it an appropriate replacement are discussed. Furthermore, different candidate technologies that can potentially realize the 6G communication are studied, followed by discussion on different challenges in the realization and possible research directions to cope with these challenges. By exploring the vision of future, its specification, and key candidate technologies, this paper attempts to summarize the general 6G framework. In addition, with mentioned challenges in realization of 6G, the aim of this paper is to guide the researcher and attract their interest to consider them.

## 1. Introduction

Though the deployment of fifth-generation (5G) wireless communication is in the early phase, i.e., the associated features should be more enhanced, it is also essential to uniformly set the communication requirements of the upcoming information society and initiate the theoretical and practical projects on future wireless system generation (henceforth mentioned as 6G). To this end, we intend to investigate the requisites for the establishment of the theoretical and practical works on 6G from three perspectives: (i) 10-year gap between successive generations [1]. More specifically, any generation takes a ten-year period to initiate the theoretical research till the practical deployment; that is, when any generation moves in the practical deployment phase, the next generation initiates theoretical research. Therefore, research on 6G is now in theoretical phase since research on 5G was initiated ten years back. To better understand, the time gap and technology evolution from 4G to 6G are presented in Table 1. (ii) For catfish effect, different from the previous generations, 5G primarily targets the IoT application related to industry. With the commercial implementation of 5G on a large-scale, there will be numerous members from vertical industry involved in the ecology of 5G. As compared to the status quo controlled by operators, the thorough contribution of developing enterprises will

Table 1: The evolution of cellular communications from 4G to 6G and their comparison with respect to different key features.

| Generation | 4G | 5G | 6G |
|---|---|---|---|
| Time range | 2010 to 2020 | 2020 to 2030 | 2030 to 2040 |
| Maximum achievable rate | 1 Gb/sec | 35.46 Gb/sec | 100 Gb/sec |
| Frequency | 6 GHz | 90 GHz | 10 THz |
| Standards | LTE, LTE-A, WiMAX | 5G NR, WWWW | Yet to be decide |
| Service | Video | 3D VR/AR | Tactile |
| Architecture | MIMO | Massive MIMO | Intelligent surface |
| Multiplexing | OFDMA | OFDMA | Smart OFDMA plus IM |
| Core network | Internet | IoT | Internet of Everything |

have a revolutionary e effect on the telecommunication industry which is generally termed as "catfish effect." (iii) For the IoT business model, the introduction of smartphones accelerated the usage of 3G services and prompted the 4G deployment demands; it is assumed that certain IoT business modes will encourage the 5G outbreak somewhere in the 5G period, thus boosting the need for the upcoming 6G networks. We must be prepared for the potential advent of the upcoming generation to lay an effective technical foundation. In short, it is the appropriate time to initiate the research on 6G. Recently, ever more individuals or organizations, including governments, industry, academia, and public [2–5], have initiated to implicate 5G/6G concepts. Federal Communications Commission in 2018 publicly expressed their expectation about 6G [5]. China and the United States (US) have already initiated research on 6G in 2018 [6]. Besides the US and China, the European Union, Japan, and Russia have also taken research initiatives towards 6G. It is obvious from the aforementioned points that there is a positive consent on initiating researches on 6G. To this end, the envision network for 6G is illustrated in Figure 1.

Major contribution points are as follows:

(i) Research initiatives for 6G

(ii) 6G vision

(iii) 6G specification

(iv) 6G technologies

(v) Challenges and future directions

## 2. Research Initiatives for 6G

The 6G vision along with some other key research advancements has been the focused areas of researchers in last few years [2, 7–11]. To this end, the authors in [7] have given the 6G vision and summarized its requirements. They have mainly focused on the battery life of mobile unit and different 6G service classes, rather than the latency and data rate. In [8], it is proposed that the research in beyond 5G (5GB) period must be based on the manufacturing capabilities of network devices to develop a feedback loop of research undertakings. In [2], different communication scenarios for 6G are forecasted, which contains flying networks, tactile internet, tele-operated driving, and the holographic calls.

The future trends and applications and enabling 6G technologies are summarized in [9, 10]. Particularly, blockchain technology-based network decentralization is considered to be a foundation for network management and delivering convincing performance in 6G. Furthermore, the human-centric service model is presented and considered as the key aspect in 6G. In [11], key 6G metrics are specified, and a detailed comparison of 5G and 6G is presented.

Some recent studies are focused on real-world implementation including air interfaces [12], data centers [13], and multiple access techniques [14] for 6G communications. 6G network networking patterns are discussed in [15–17], where cell-less architecture, three-dimensional superconnectivity, and decentralized resource allocation are highly anticipated to be present in 6G networks. In [18], vertical-specific solutions and massive machine-type communications (mMTCs) for 6G networks are discussed, and it is predicted that 6G could simplify the leading wall-breaking standard to entirely substitute the current standards and offer a combined way out by allowing continuous connectivity for all the requirements of vertical industries.

In 6G-related works, reconfigurable intelligent, and surfaces, artificial intelligence (AI) and terahertz communications are highly attractive concepts. They are considered as game changer technologies in the field of wireless communications. A detailed survey on 6G based on terahertz communications is presented in [19], which summarizes different 6G technological advancements, design aspects of the transmitter-receiver, and several use cases. AI-enabled 6G is supposed to offer lots of advanced features, including auto-configuration, context awareness, opportunistic set-up, and self-aggregation [20]. Moreover, AI-enabled 6G would explore radio signal potentials and allow cognitive radio to shift to intelligent radio [21]. Particularly, machine learning (ML) is a key for recognizing AI-enabled 6G from the algorithmic angle, which has been studied in [22, 23]. In [24, 25], reconfigurable intelligent surfaces are envisioned as the massive MIMO 2.0 in 6G. These materials can also combine index modulation to result in an increase of 6G spectral efficiency [26]. Besides the above discussed individual initiatives, multiple 6G projects are in progress globally, which target to first start and specify 6G followed by framework

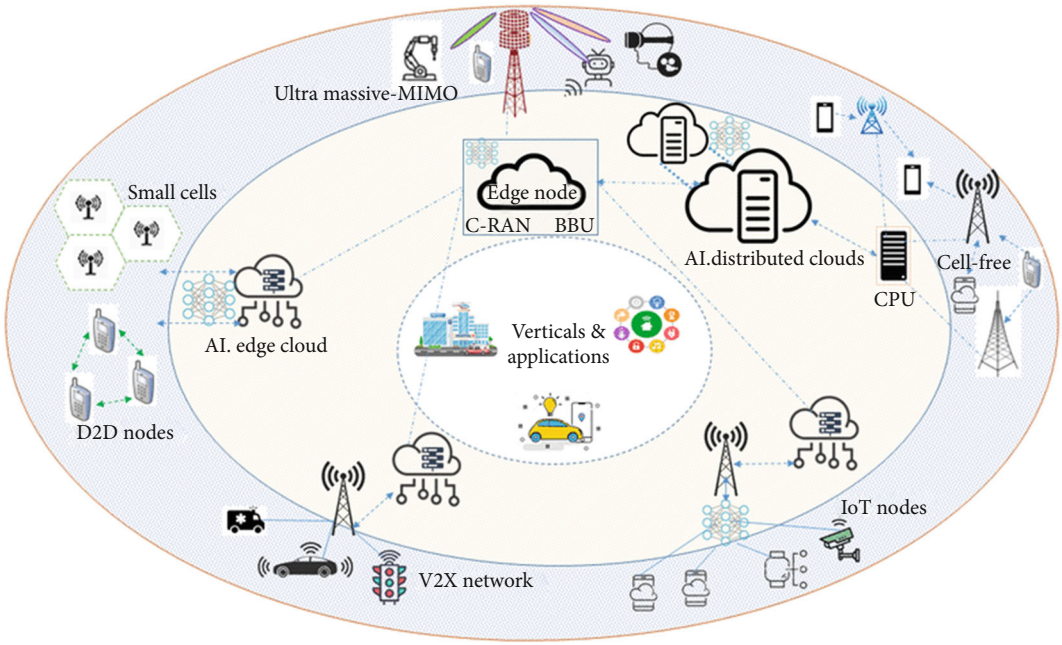


Figure 1: Illustration of the envisioned 6G architecture.

reshaping as well as setting wireless communication business model. To this end, 6Genesis Flagship Program was the first project followed by the Terabit Bidirectional Multiuser Optical Wireless System for 6G, which initiated in 2019. The first summit on 6G was held in March 2019 at Levi, Finland, and properly stimulated the launch of research race on 6G in academia. Many seminars and small-scale workshops were also arranged globally to discuss the 6G feasibility, for example, the Wi-UAV Globecom 2018, the Carleton 6G, and the Huawei 6G Workshops.

Beyond academia, future generations including 6G attract the attention of industrial and governments, organizations, and standardizing bodies. In August 2018, IEEE established Future Network program named "Enabling 5G and beyond" while ITU-T [27] established the Focus Group of ITU-T, namely, "Technologies for Network 2030" which aims at understanding the future network service requirements around 2030. Google triggered the Project Loon program which aims at offering consistent internet links to the 5 billion unconnected people. An EU's Terranova project-based research group is currently leading on the way to reliable 6G communication links having transmission capability of 400 G bits/sec in the terahertz band. LG Electronics also established a 6G research center in South Korea. In 2019, Samsung started its 6G research program while SK Telecom and Nokia and Ericsson collaborated for the same purpose. Towards the end of 2018, China declared the determination that in 2030s, they will lead the wireless communication market by increasing investment in 6G research. The US has opened the 95 GHz-3 THz spectrum for 6G research. Moreover, an EU-Japan program called as "Networking Research beyond 5G" which is supported by the funding of Horizon 2020 ICT-09-2017 studies the possibility of utilizing the terahertz band in the range 100 GHz to 450 GHz.

As 5G has already been implemented on experimental basis in many countries and researchers have taken research initiatives towards 6G, therefore, it is the need of the day that the available literature on 6G should be systematically assembled in the form of a survey. To this end, in this paper, we present a detailed and systematic survey on 6G communication where we presented a brief literature review on the available literature on 6G followed by the detail vision of 6G. Then, different specification and requirements of the 6G are studied followed by the details of potential 6G technologies. Finally, some future research directions are discussed. The flow and contents of these topics are provided in Figure 2.

The remaining of this paper is structured as follows. Section 3 discuss the 6G visions while Section 4 contains different specifications and requirements for 6G. In Section 5, different candidate technologies for 6G are discussed. Different challenges to which 6G is faced and some future research directions in 6G are discussed in Section 6. Section 7 contains the conclusion.

## 3. 6G Vision

In the early period of 5G, its vision is set as "everything is at your fingertips, and information is at your disposal" [28]. Keeping in view this vision, the 5G technical requirements, key technologies, and standards are recommended. Now, the next stage is to put 5G systems on large-scale commercial use. At this stage, it is also essential to set the vision for 6G, and its corresponding technological requirements and challenges are required to be specified in order to start research on 6G so as to follow the 10-year generation shift rule. But, 5G is so sensational and will completely attract the society in every aspect of life. If so, then what is there to be done in future? To this end, this section will first

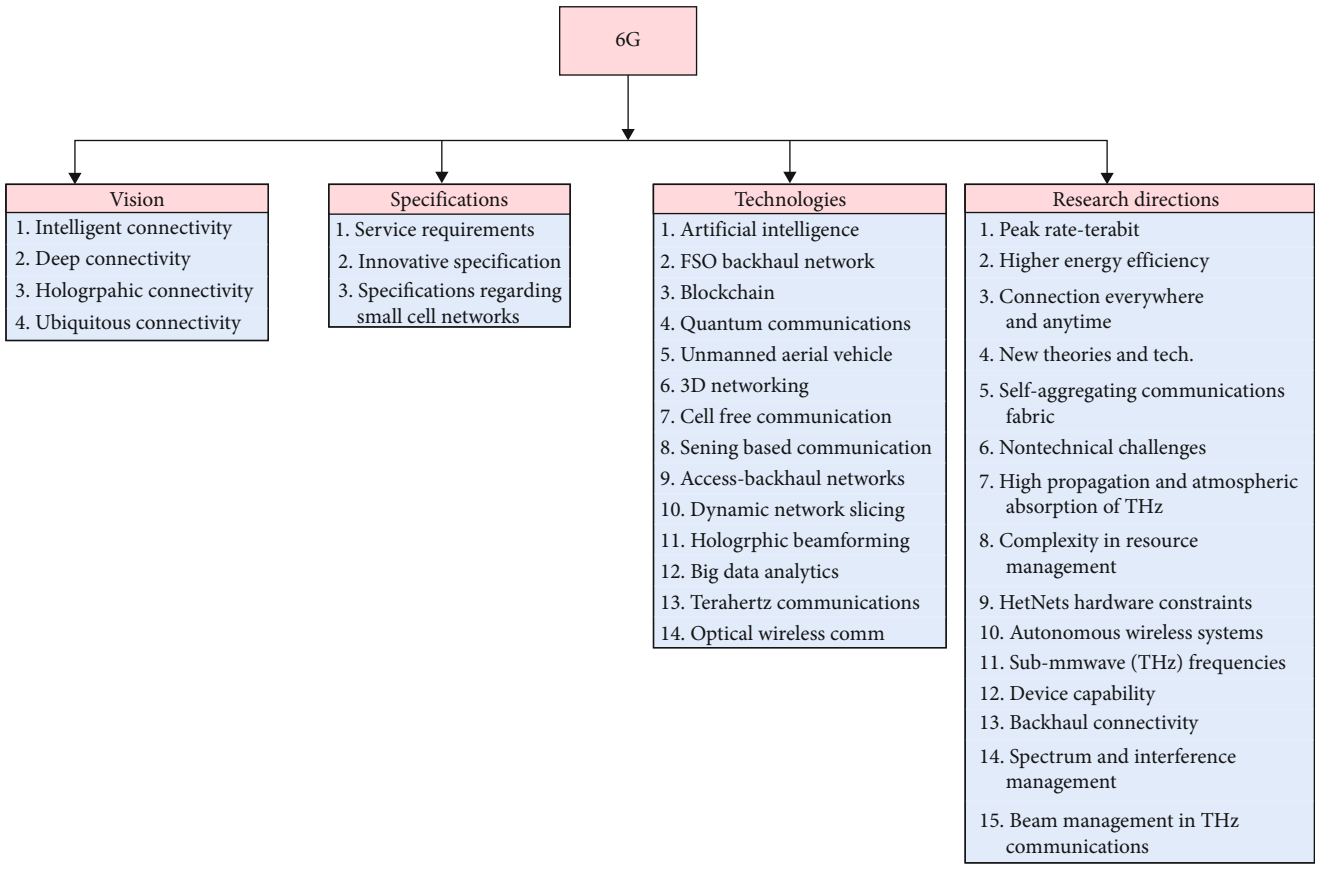


Figure 2: Skeleton of this paper.

provide the 6G vision establishment followed by analysis on the vision necessity, and then different technical requirements and issues in meeting this 6G vision will be discussed.

Currently, the main objective of 5G is to cover every aspect of human life and develop a user's centered information ecosystem. But, owing to immaturity of 5G standardization and associated technologies, still lots of deficiencies are there to overcome: the existing technologies are suitable to perform well in the limited space range, i.e., few kilometers above the surface of the land; while considering the IoT requirements, there is still a lot to do to achieve the real global IoT. Particularly, with the speedy growth of the human activities scope and advancement in various fields of technology, the demand for diverse information interaction is getting increase.

The 6G basic goal is to fulfil the information society requirements in 2030 ~; that is, the vision of 6G will be based on requirements that 5G is unable to fulfil and those services that 5G is unable to provide. Based on those requirements and services that 5G is unable to fulfil and provide, respectively, we believe that the vision of 6G should be categorized into the following four fundamental services: "Intelligent Connectivity," "Deep Connectivity," "Holographic Connectivity," and "Ubiquitous Connectivity." These different types of connectivity together set up the overall 6G vision. In contrast, the 5G vision puts emphasis on information exchange and IoT, while the communication range for connectivity is limited to 10 km space above the earth surface. Although 5G is underway to standardize the nonterrestrial network (NTN) technical characteristics, the technical systems and standard of cellular, and satellite networks involved in the architecture of NTN are still independent of each other, and special gateway equipment is needed for their connectivity and interaction [29]. Its efficiency and communication capability can hardly fulfil the future ubiquitous connectivity requirements. To fulfil the future connectivity requirements, 6G will require to support the space-air-ground-sea (SAGS) integration network. This network will require a unified technical system and standard protocol architecture to realize the ubiquitous connectivity of SAGS integration in true sense. Besides, instead of real-time performance, the main emphasize of the 5G mMTC is on the number of communication links [30, 31], while Ultra-Reliable Low Latency Communications (URLLC) focuses on real-time performance and reliability but does not emphasize on throughput and connections count, which leads to a decrease in the connection count and spectral efficiency. To overcome these shortcomings in 5G, the 6G vision includes reliability, massive connectivity, high throughput, and real-time performance. The wireless tactile networks can be presented as a typical scenario which is described below. Therefore, though some of the fundamental ideas which are included in 6G vision are already parts of the 5G, 6G vision is based on advanced objectives to fulfil the requirements and cope with the challenges of new scenarios in the future.

*3.1. Intelligent Connectivity.* Nowadays, artificial intelligence (AI) has gained the interest of researchers and become the most active research topic. Therefore, almost every field is moving towards the utilization of AI technology. The AI enabled wireless communication network has become a foreseeable trend [32–48]. In recent times, people have started to attempt the utilization of AI in 5G system [49, 50]; however, the enabling of AI in 5G systems is possible only as optimization of conventional networks based on AI, instead of a new one. AI-enabled 5G will change the dynamics of the networks. Even though the initial 5G architecture is more flexible (software definable), but AI has not been considered in it, therefore, it is still considered to be conventional network architecture. Secondly, even though the development of AI technology is speedy enough, and in many areas, it has proven its performance efficiencies; still it is in the experimental phase in most of the other fields. The enabling of AI in wireless communication technology is in its early research phase, and a long-term research planning is desirable before the actual technology grows up to maturity.

The growing tendency towards AI indicates the high probability of technology growth in the upcoming decade. In addition, believing that the upcoming 6G networks will be growingly massive and heterogeneous, and different application scenarios will become growingly dynamic; the active use of AI is expected to cope with these challenges. It is envisioned that the upcoming 6G will bring a revolution in the applications scope of conventional cellular systems and turn into the main Internet supporting all the operations in every industry and society. If the upcoming generation networks still utilize the current unified communication models to handle the very complex and diverse applications in 6G era, it will be faced with many severe challenges [51]. Therefore, we consider that building the AI-based 6G network will be an unavoidable move, and "Intelligent" will be its essential feature, resulting in "Intelligent connectivity."

The "Intelligent Connectivity" characteristic can be considered as an essential intellectualization of communication networks: intellectualization of connecting units (terminal devices) and intellectualization of network architecture and elements. In future, lots of issue will be faced in the realization of 6G networks: growingly massive and complex networks, massive densification of terminal devices, and complex business models. "Intelligent Connectivity" will simultaneously fulfil two demands: (1) all the connected network devices need to be intelligent and (2) the need of intelligent management for the growingly massive network.

*3.2. Deep Connectivity.* Conventional cellular systems (including 5G) are based on the vision of deep coverage, basically for the optimization of deep coverage of indoor access requirements. Deep coverage in indoor can be attain through macro base stations (BS) deployed in outdoor or wireless nodes deployed in indoor. 4G and prior cellular network generations were focused on people-cantered communication. In contrast, from 5G and onward, this focus has been shifted to the simultaneous and real-time communication of things, which is called Internet of Everything. Therefore, the architecture and implementation of 5G and onward generations require considering of deep coverage requirements for both the users as well as objects.

As the human productions and living space are increasing, the scenarios and categories of information exchange are turning growingly complex. From 5G and onward, the Internet of Everything will encourage the speedy growth of IoT communications, and it is expected that this growth will keep increasing in coming few years. Furthermore, the requirements for the Internet of Everything will drastically rise in the following four perspectives: (i) the deep expansion of the activity space of connecting objects, (ii) deeper perceptual interaction, (iii) deep data mining in physical world, and (iv) in-depth nerve interaction [52]. Thus, from deep coverage, the access requirements will change to "Deep connectivity," and its main features will include telepathy, AI, and deep sensing.

*3.3. Holographic Connectivity.* Virtual and augmented reality (AR/VR) is supposed to be among the most significant 5G requirements, specifically for high throughput applications. 5G will have the capability to allow the transformation of AR/VR of existing stationary wireless access into mobile wireless AR/VR. Once the utilization of AR/VR becomes convenient without location constraint, it will speed up the growth of AR/VR services, followed by speeding up the maturity and growth of AR/VR itself. After one decade, most of the media communication are generally imagined as planar multimedia, and holographic information interaction, high fidelity AR/VR-based communication, and holographical interaction will turn into realization. Holographic communication will be ubiquitous to allow people for making full advantage of the holographic interactive capability anywhere, which is the real purpose of "holographic connectivity." To achieve holographic connectivity, lots of challenges will be faced [53]. A number of articles have been focusing on the utilization of AI technology to cope with these challenges [54–56].

*3.4. Ubiquitous Connectivity.* Anywhere, anytime type of wireless access is the need of conventional cellular networks also. However, as per the communication needs of people, 5G will significantly expand the scope of space and information exchange types in IoT. The equipment activity range will significantly increase the geographic range of communication, comprising detectors installed in deep sea, human/unmanned aerial vehicle (UAV) in the medium and high altitude, intelligent remote-control equipment, autonomous robots in the harsh environment, and so on. Besides, human activity space is also increasing quickly due to the speedy improvements of technology in the areas of deep-sea exploration, astronautics, and the enhancement of survival ability in specific natural situations. For example, there may be high chances for people in 2030-2040, to approach the outer space. Consequently, the needs for satellite-ground communication and satellite-space craft's communication will be more common than that of conventional communication. The abovementioned communication scenarios will stimulate the needs for "anytime, anywhere" connections in 2030 ~ and beyond; that is, by achieving "Ubiquitous connectivity" in real sense, a vast world will turn into

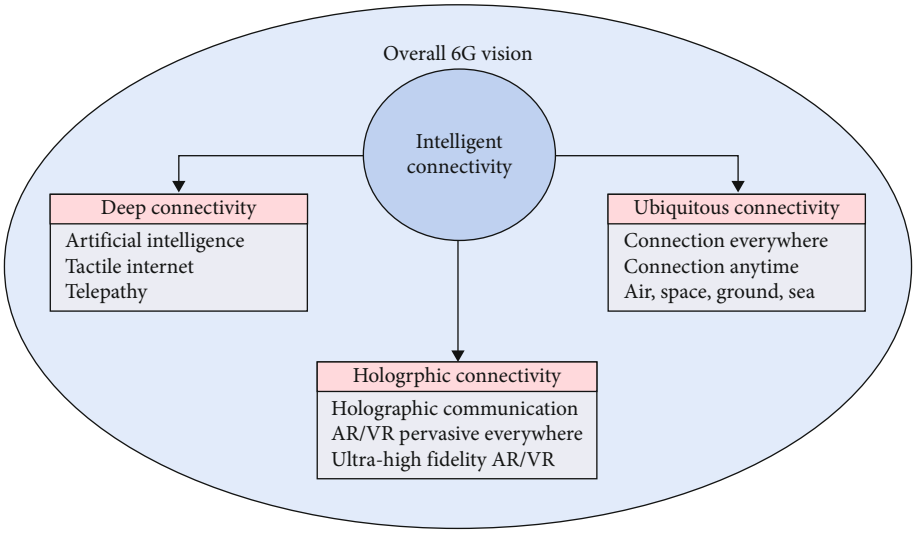


Figure 3: Sixth generation vision.

easily accessible place. The ubiquitous connectivity main feature is the integration of SAGS communication. In comparison with deep connectivity which focuses on the depth of the connected object, the focus of ubiquitous connectivity is on the breadth of the distributed area of the connected object [57].

Summarizing the above discussion on the four visions of upcoming 6G, intelligent connectivity performs as a nerve and brain of the 6G, while the remaining three features constitute the of 6G trunk as shown Figure 3. When these four features combine, the communication system will be more improved, the information will break through the time as well as space constraints, the distance between network devices will be minimized, the uninterrupted integration of human and everything will become reality, and finally the overall 6G vision will be realized.

## 4. 6G Specifications

It is highly expected that 5G will be unable to deal with the market requirements after one decade as it is faced with many challenges, for example, latency, throughput, deployment costs, energy efficiency, hardware complexity, and reliability. To fill the gap between the market requirements and the capabilities of 5G, 6G will be an appropriate choice. Based on the previously discussed 6 visions, the basic 6G goals are (a) latency minimization, (b) global connectivity, (c) massive connectivity, (d) enormously high data rates, (e) energy efficiency of network devices, (f) connection reliability, and (g) machine learning-based connected intelligence [58].

*4.1. Service Requirements.* The main services that 6G systems will provide contain mMTC, URLLC, IoT, tactile internet, AI-based communication, and Enhanced Mobile Broadband (eMBB). In addition, high network sum-rate, capacity, energy efficiency, and data security are also among the main services of 6G.

It is envisioned that the number of simultaneous wireless connections provided by 6G will be 1000 times more than that of 5G system. One of the main features of 5G named URLLC will also be part of the 6G. URLLC will provide less than 1 ms end-to-end delay [11]. In comparison with the area spectral efficiency, volume spectral efficiency is expected to better outcome in 6G [28]. In addition, 6G will support advanced improved technology which in turn will result in ultralong battery life. Furthermore, mobile units will not require to get charged alone.

*4.2. Different Innovative Specification*

*4.2.1. Satellite Integrated Network.* To realize worldwide connectivity, 6G is envisioned to combine satellite, airborne, and terrestrial networks. This way, the 6G vision of Connect Anywhere Anytime will be addressed [59].

*4.2.2. Connected Intelligence.* In comparison with the previous wireless network generations, 6G will support the shift from "connected things" to "connected intelligence" [21]. Consequently, AI will be utilized in every phase of the communication procedure. The ubiquitous utilization of AI will develop a new model of communication systems.

*4.2.3. Smooth Combination of Wireless-Information and Energy-Transfer (WIET).* 6G will also provide the wireless transfer of power to support wireless charging of battery units, for example, sensors and smartphones. It utilizes the same waves and fields as wireless communication systems. It will make the sensors and smartphones able to charge during communication through wireless power transfer. In addition, increasing the lifetime of wireless charging systems for batteries is also the potential capability of WIET [60]. Therefore, battery less devices are envisioned in 6G systems.

*4.2.4. Universal 3D Connectivity.* Controlling the functionalities of core networks through aerial vehicles and satellites will lead to the Universal Connectivity in 6G era [61].

*4.3. General Specifications regarding Small Cell Networks.* The concept of small cells in cellular systems is presented

to enhance the quality of received signals as a consequence of enhancement in the network spectral and energy efficiencies [62] and sum-rate [63–65]. Thus, small cell networks is an important consideration for 5 GB. Therefore, like 5G, 6G will also include this type of network model.

*4.3.1. Dense Heterogeneous Networks (HetNets).* Dense HetNets [66, 67] is another vital 6G feature. Multitier networks comprising different types of access points will enhance the network quality-of-service and decrease the cost [68].

*4.3.2. High-Capacity Backhaul.* The backhaul communication must be featured by high-capacity backhaul networks to allow a massive traffic. Free space optical (FSO) communication systems and high-speed optical fiber are potential solutions to this issue [69].

*4.3.3. Virtualization and Softwarization.* Virtualization and softwarization are two main features of 5G and beyond that are foundations for the design process to guarantee reconfigurability, flexibility, and programmability. Besides, they will make possible the sharing of same physical infrastructure among billions of network devices [70].

## 5. 6G Technologies

6G is the combination of several technologies, few of which are briefly discussed in the following.

*5.1. Artificial Intelligence (AI).* Among all the envisioned for 6G, AI is the most significant and advanced [14, 18, 20, 71, 72]. In 4G systems, AI was not included while the forthcoming 5G will support a limited use of AI. However, there will be full support for AI in 6G. The rapid developments in machine learning will result in efficient intelligent networks in 6G which will lead to achievement of real-time communication. Through different analytics, AI will be able to find the method for execution of complex target tasks [73]. Improving the energy efficiency, decreasing the communication and processing delays, time efficient network selection, and handover efficiency [74] will also be the salient features of AI. In addition, AI will play a vibrant part in intermachine, human-to-machine, and machine-to-human communications. Communication systems based on AI will be supported by meta-materials, intelligent networks, intelligent devices, machine learning, and self-sustaining wireless networks.

*5.2. FSO Backhaul Network.* Owing distant geographical situations, it is not always feasible to achieve fiber backhaul connectivity. FSO is a new trending technology to achieve efficient backhaul connectivity. The properties of FSO transmitter and receiver are comparable to that of optical fiber-based system. Hence, the data transfer of both, i.e., the FSO and optical fiber systems, are also comparable. Keeping this in view, in addition to the optical fiber networks, the FSO backhaul network is considered to be a capable technology for backhaul connectivity in 6G systems [75–77]. FSO can potentially support a long-range communication in more than 10,000 km range. Furthermore, it allows cellular BS connectivity as well as high-capacity backhaul connectivity everywhere such as underwater, outer space, sea, and isolated islands.

*5.3. Blockchain.* Another vital technology to handle the 6G massive traffic is blockchain [78–80]. Blockchains are a type of the distributed ledger technology which is a database spread over multiple processing units. Each processing unit keeps a duplicate version of the ledger. As it is controlled by peer-to-peer networks, so, there is no need of centralized server for its existence. The blockchain data is assembled and organized in blocks which are linked with each other and protected via cryptography. It is principally a suitable counterpart to the mMTC with enhanced security, scalability, and reliability [81]. Thus, it will offer many services, like traceability of data, self-regulating of IoT communications, and reliability of mMTC in 6G.

*5.4. Quantum Communications.* Unsupervised reinforcement learning is an efficient technique to achieve the envision goals of 6G. In contrast, the supervised learning technique will not be able to deal with the labeling of massive data produced in 6G. As labeling is not required in unsupervised learning, so, it can be utilized to develop complex networks. Furthermore, when reinforcement and unsupervised learnings are combined, it can lead to the possibility of network operation in a real autonomous way [82].

*5.5. Unmanned Aerial Vehicle (UAV).* UAVs or drone BSs are supposed to be significant components of the upcoming 6G. In various cases, efficient wireless connectivity will be achieved with the help of UAV technology. To this end, the BS units will be deployed in UAVs. There are certain features of a UAV which a fixed BS does not provide, for example, easy placement and strict line-of-sight. In case of emergency circumstances such as natural disasters, the implementation of conventional terrestrial infrastructure-based network will not be feasible economically and impossible sometimes to deliver any service in such an unstable environments. In contrast, the UAVs can conveniently cope with this kind of situations as it can fulfil the important 6G requirements that are mMTC, eMBB, and URLLC. In addition, UAVs can also provide several other services such as the fire detection, network connectivity enhancement, security, pollution monitoring, accident monitoring, and surveillance [83].

*5.6. 3D Networking.* The envisioned integration of different networks in 6G will allow users to communicate in vertical extension. In addition, UAVs will be utilized to realize the 3D BSs [84, 85]. The introduction of new dimensions with respect to altitude will turn the 3D connectivity substantially changed from the existing 2D networks.

*5.7. Communications without the Limitations of Cells.* The combination of heterogeneous technologies and multiple frequencies will be another potential method to achieve the envision goals of 6G because, this will allow the seamlessly internetwork mobility of the users without any physical change in the device configurations. The suitable network will be chosen spontaneously among the accessible

networks. Thus, the limitation of cell-based wireless communications is overcome. Currently, the user intercell mobility in dense networks results in frequent handovers which may cause an increase in handover failures, data losses, and handover delays. The cell-free model of 6G will deal with all these issues. This type of communication model can be attain by adopting multitier communication architecture and associated techniques and mMTC [86].

*5.8. Sensing-Based Communication.* An important move towards autonomous systems is the potential to uninterruptedly sense the frequent and random variations in environments and the information communication amid multiple device units [87]. In 6G, the strict integration of sensing with communication is proposed to achieve autonomous systems.

*5.9. Integration of Access-Backhaul Networks.* The 6G networks will be massively dense in terms of access networks. Every access network will be coupled with backhaul connectivity networks, such as FSO and optical fiber. To deal with this massive densification of access networks, strict integration of the access network with backhaul network is proposed in 6G [88].

*5.10. Dynamic Network Slicing (DNS).* DNS makes the network operators capable of dedicating virtual networks for the optimized distribution of services to different types of industries, machines, vehicles, and users. Among the potential 6G technologies, DNS is the most significant as it can manage the situation where a huge number of users is associated with a huge number of HetNets [89].

*5.11. Holographic Beamforming.* Beamforming is a common technique for signal processing where an antenna array is used for the directive transmission of radio signals. It is a group of smart and advanced antennas and has multiple benefits, such as improved network efficiency and low interference. Holographic beamforming (HBF) is an advanced technique to achieve beamforming and is substantially different from the MIMO [90, 91] systems as it utilizes software-defined antennas. It is supposed to be an efficient and effective technique in 6G to achieve the efficient communication in multiantenna communication network units.

*5.12. Big Data Analytics.* To investigate a range of large data sets also known as big data, Big Data Analytics technique is used. This technique reveals information, for example, customer inclinations, hidden patterns, and unknown correlations to guarantee the seamless data management. The big data is collected from a range of sources, such as social networks, videos, sensors, and images. It is supposed that this technology has the capability to deal with massive data in 6G systems [92].

*5.13. New Spectrum-Based Technologies.* Spectrum is a limited resource and foundation for any wireless communication. The rising wireless traffic needs the future wireless systems to increase their spectrum resources. For 6G, the terahertz spectrum and visible light spectrum are envisioned as two capable spectrums. The use of terahertz frequencies in wireless communication has been appreciated by Japan and many European and American countries. In addition, it has also gained strong interest of the ITU. Visible light-based technology is a modern a development which is a potential alternate for short-range wireless communication in 6G. In the following, these two technologies are briefly discussed.

*5.13.1. Terahertz Communications.* Spectral efficiency is among the most important objectives of every cellular generation and can be further improved by increasing the bandwidth. In 6G, spectral efficiency can be attained using THz communication technology. The RF band is now insufficient as it is not able to meet the growing 6G demands. To cover this deficiency in 6G, the THz band is an appropriate choice [93, 94] as it is envisioned as the future spectrum for data hungry applications. THz waves generally have frequency and wavelengths in 0.1-10 THz and 0.03-3 mm ranges, respectively [95]. As per recommendations of ITU-R, the band ranging from 275 GHz to 3 THz is supposed to be the suitable portion for cellular communications because this band is not specified for any other purpose globally, and it can provide high data rates. This proposed portion of THz band when added with the mmWave band ranging from 30 to 300 GHz and can improve the overall 6G cellular communication capacity. More specifically, this addition results in at least 11.11 times increase in the total band capacity. Of the THz band, the specified cellular band lies on the mmWave, while the band ranging from 300 GHz to 3 THz lies on the far infrared band. Furthermore, the band ranging from 300 GHz to 3 THz is located at the border of optical band and sharply next to the RF band, thus, resembles to the RF. The THz communication core features comprise ultralarge bandwidth and high path-loss [96].

*5.13.2. Optical Wireless Communications.* Optical Wireless Communications (OWC), which involves ultraviolet, visible, and infrared bands, is an expected replacement of the current RF technology. Among the three mentioned bands, the most useful is the visible band which is discussed in the following.

OWC system in 390 to 700 nanometer range is typically known as Visible Light Communications (VLC), which utilizes the potentials of LEDs to attain high data rates along with illumination. In contrast to the RF-based communication, VLC is more advantageous from the following four perspectives. Primarily, VLC allows the utilization of unassigned large THz bandwidth, which can be utilized without any bounds and authorization of spectrum regulators. In addition, VLC does not lead to electromagnetic (EM) radiation nor is it prone to interference from other EM radiation, so it is suitable to be utilized in different places, such as aircraft, hospitals, chemical plants, and gas stations which are usually sensitive to EM interference. Furthermore, the VLC network security is higher, because it utilizes the visible light as transmission medium, which is unable to penetrate the wall like obstructions, and the transmission remains restricted to the visual range of users only. Consequently, the transmitted information remains restricted to a building, which guarantees the information security from the outer

malicious interception. Finally, VLC allows the speedy establishment of wireless networks. In case of RF-based communication, the BS deployment and their maintenance costs are significantly high. The indoor VLC technology can utilize its indoor illumination source as the BS, to allow users to conveniently utilize the indoor wireless services. The common use cases of OWC include submarine communication (to cope with attenuation and EM interference), short-range communication, and optical hotspots (especially in indoor case) [97–100].

## 6. Challenges and Future Research Directions

Several technical problems need to be solved to successfully deploy 6G communication systems. A few of possible concerns are briefly discussed below.

*6.1. Peak Rate-Terabit.* In previously mobile communication era, the users were really concerned about peak rate, which is one of the key technical indicators that the first generation of wireless mobile communication systems have been pursuing since its inception. In fact, 6G further enhances the peak rate. According to an idea, 6G peak rate will increase up to Tera (bits/sec). Here, we quantitatively predict the peak rate in next decade up to 2030. Secondly, from 6G vision, two applications need significant increased peak rate, (1) intelligent applications and (2) big-data-based application, and analytics requires massive data transmission. Intelligence systems can be driven force for next generation communication technology. Also, high fidelity augmented/virtual reality (AR/VR) and holographic communication will be imminent applications carry by 6G, with the promise of providing higher data rate than existing wireless communication systems and also to provide high fidelity not only higher data required but with minimum latencies. It will increase throughput and minimize delay. Moreover, by AR/VR mean, we need communication anytime anywhere with high data rate, which would be another challenge for 6G.

*6.2. Higher Energy Efficiency.* Ultrascale mobile communication system becomes necessary part of world's energy utilization. It occupies considerable operating system costs with production of large carbon emissions. As proposed, future 6G technology will be capable to produce ultrahigh bandwidth, throughput, and with large number of wireless nodes, which results in extra challenges to energy consumption. Compared to spectrum efficiency and bandwidth, energy consumption is more serious issue as it will increase user cost. Therefore, we have to reduce this energy consumption as much as possible in per bit (J/bit). Further, the pervasive deployment of wireless sensors nodes along with human production and living space will trigger two important energy consumption issues; first pervasive deployed sensors will result in huge energy consumption, and second, the energy supply for largely placed sensors effectively would be a challenge. Also, the connected devices in 6G technology will bring mega data processing with power consumption of huge number of installed antennas for 6G technology operations. Due to these important energy consumption problems, Green communication can be suitable solution [101].

*6.3. Connection Everywhere and Anytime.* We are living in the world where technology changing second by second, which makes human life more advance and comfortable. With the rapid growth of information and communication technology, the space of human connections will be expanded where active area will have no boundary. In this 6G communicating, nodes like nodes in IoT will be spread over large area, which makes the communication unbounded. The future communication should be truly capable of providing efficient connection to Internet of Everything (covering deep sea, air, large geographic areas), multipurpose communication and computing (covering artificial intelligence, deep learning, SDN, Internet of Vehicles, big data, etc.). In short, the fundamental phenomenon of future technology should be that anyone can communication and connect to anything at any time efficiently [102].

*6.4. New Theories and Technologies.* In fact, to fully incorporate 6G technology, we need to push-up available spectrum resources for use and implement. Also, some basic theories need to be aligned with the need of future 6G technology. Further, refereeing to the 6G vision, we require break thoughts in several key areas, which will include improved channel coding and modulation schemes, millimeter wave solutions, Tera Hz communication, AI supported advance technology mechanism, etc.

*6.5. Self-Aggregating Communication Fabric.* The previously used technology standards like 3GPP or 4G claimed to integrate variety of technical standards, but after passage of time, these becomes self-enclosed standard systems. At first, the 3GPP standard tried to solve many challenges by itself, but with time passage, the integration of multiple devices and system becomes harder due to latest industrial and technology advancement. Therefore, to better provide interconnectivity of all things, 6G should be able to dynamically integrate different technology systems and networks, although 5G capable to integrate different networks but only combined or semistatic mode. Further, 6G needs to integrate different technologies with devices in a more efficient and intelligent way so dynamically and adaptively meet new complex and diverse technology standards and professional needs.

*6.6. Nontechnical Challenges.* For smooth transition of 6G, there are many nontechnical challenges along with the abovementioned technical challenges. In nontechnical challenges, we have to overcome different aspects like marketing factor, trade barriers, customer desires, rules, and regulations by the authorities. Compared to 5G, 6G will boost almost every aspect of socialism and life more adequately and will be closely integrated with other vertical industries. Also, the spectrum allocation and restrictions by authorities are also not-technical issues. For example, the use of terahertz spectrum in 6G requires different countries and region collaboration interim of coordinated allocation across the world to agree upon on a uniform band range as much as possible. Also, coordination with users in other spectrum

like meteorological radar or satellite communication will be more restricted in policies. As there should a central policy with consensus of different countries and region for the solution of orbit and satellite communication spectrum resources. Besides, compared with existing ground communication, satellite communication will face more issue in facing global roaming handover. Presently, different countries and commercial industry working to build coordinated satellite communication systems; however, to make this communication independently deployed system would be very complex and challenging. Further soon after the mobile communication emerged many vertical industries have different characteristics, it has to deal with user habits with huge differences. It would be great challenge to change user habits and inherent ways of things among diverse industries to adapt new rules and policies more quickly and efficiently.

The 6G vision is interesting along with numerous challenges from integrated key technologies in 6G. According to an idea, 6G will provide Tera bits/sec and be able to support 1000+ communicating nodes per person in 10 years (up to 2030) with smooth connectivity anytime anywhere. The future belongs to completely data-oriented society, which bring users and thing are connected universally as small technology hub and things going to have instantaneously in milliseconds in this universal connected world.

*6.7. High Propagation and Atmospheric Absorption of THz.* In fact, the high terahertz frequencies provide huge data rates. However, THz need to overcome the challenge of data transfer over long distances due to different atmospheric absorption and propagation-path loss [103]. This demands an updated design of transceiver for THz communicating systems. This transceiver would be able to operate on fully avail be high bandwidths and frequencies. Communication issues must be addressed properly. Health and safety measures using THz also be kept in mind, and problems emerged from it need to addressed.

*6.8. Complexity in Resource Management for 3D Networking.* With emergence of 3D networking, a new dimension added. Also, numerous malicious actions may legitimate the desired information and results in degrading the system performance. Therefore, new improved techniques for 6G resource management, optimization for handover-mobility, multiple access, and routing protocol are urgent priorities.

*6.9. Heterogeneous Hardware Constraints.* In 6G, a very large of numerous and heterogeneous communication including high frequency bands, different network topologies, service delivery, and many more will be involved. The existing hardware settings will be changed for access points and mobile terminals in 6G. Furthermore, MIMO techniques will be updated in transition from 5G to 6G; hence, it requires complex architecture. The routing protocols and algorithm will be more complex. Similarly, the hardware design is different for several communication systems. Also, the emerging needs to use AI, unsupervised, and reinforcement learning would be challenging in terms of complex hardware design and implementation, while integration of all these communicating and intelligent systems is also a big issue to solve.

*6.10. Autonomous Wireless Systems.* 6G industry will also able to provide services to automation systems such as intelligent transportation, unmanned vesicle, wireless drone, and Industry 4.0 using AI. To make intelligent autonomous wireless systems, we need convergence of subsystems, e.g., AI, machine learning, autonomous computing, and heterogeneous wireless systems [104]. Due to these integrations, overall system complexity and developing model become more complex. For example, to deploy fully intelligent vehicle system for unmanned vehicle would become more challenging for researchers and industry to overcome all aspect and complexity design of intelligent vehicle systems.

*6.11. Modelling of Sub-mmWave (THz) Frequencies.* Due to the propagation characteristics, the mmWave and sub-mmWave (THz) are dependent on atmospheric conditions: therefore, dispersive and absorptive effects are seen [105]. As atmospheric condition is changeable and hence unpredictable, the channel modelling of this band would be very complex, and it is quite possible that this band does match perfect channel modelling.

*6.12. Device Capability.* The 6G technology will support new features and device capabilities. However, it would be challenging to get 1 Tbps throughput, compatible AI, and integrated sensing features using the existing devices. Also, 5G devices need to be upgraded as they may not be fully compatible to 6G features. No doubt, it will increase the overall cost. As there are numerous devices connected to 5G technologies, so urgent need is to ensure the compatibility with 6G technology.

*6.13. High-Capacity Backhaul Connectivity.* The density of access networks will be increase in new 6G networks, as access networks diverse in nature and will cover large geographic area. Each of these access networks requires high data rate connection for diverse applications. The backhaul in 6G technology will be capable to provide high data rate connections between access networks and core network to support high data-driven applications at user end. One solution can be optical fiber and FSO for the high capacity backhaul system. However, how to improve the capacity of existing networks would be a challenge in 6G.

*6.14. Spectrum and Interference Management.* Managing 6G spectrum resources and interference problems is not easy and requires effective handling of spectrum sharing policies and updated spectrum management solutions. As effective spectrum handling is important for efficient resource utilization with high QoS. Researchers and industrial expert need to look issues such like how to manage and share spectrum in heterogeneous networks that synchronize the transmission at same frequencies. Also, they need to investigate the interference cancellation techniques, such as parallel interference cancellation and successive interference cancelation.

*6.15. Beam Management in THz Communications.* Beamforming using MIMO is promising candidate to provide high data-driven communications. However, its management in sub-mmWave or THz is very challenging due to wave propagation characteristics. Hence, effective beamforming management in terms of unfavorable propagation characteristics is a big issue to solve in MIMO [75]. While for smooth handover, it is important to select optimal beam efficiently in high mobility networks.

## 7. Conclusion

In this research paper, we have provided a detail and systematic survey on 6G wireless communication. This survey is carried out in such a way that initially, the literature on 6G and different practical research initiatives taken by different organizations are presented followed by the 6G vision, specifications, challenges, different candidate technologies, and future research directions. The vision of 6G is based on requirements that 5G is unable to fulfil and those services that 5G is unable to provide. To this end, the vision of 6G is categorized into four fundamental services: "Intelligent Connectivity," "Deep Connectivity," "Holographic Connectivity," and "Ubiquitous Connectivity." Based on discussed 6 visions, the achievable 6G goals are specified which are (a) latency minimization, (b) global connectivity, (c) massive connectivity, (d) enormously high data rates, (e) energy efficiency of network devices, (f) connection reliability, and (g) machine learning-based connected intelligence. To achieve these specified 6G goals, many potential technologies are proposed which include AI, FSO backhaul network, blockchain, UAVs, 3D networking, DNS, sensing-based communication, big data analytics, and some new spectrum-based technologies, e.g., terahertz spectrum and Optical Wireless Communications. To realize the vision of 6G and implementation of the potential candidate technologies to achieve the specified 6G goals, a lot of challenges will be faced which require intense research. These challenges include Peak Rate-Terabit, higher energy efficiency, connection everywhere and anytime, self-aggregating, high propagation and atmospheric absorption of THz, complexity in resource management for 3D networking, heterogeneous hardware constraints, autonomous wireless systems, modelling of sub-mmWave (THz) frequencies, and spectrum and interference management.

## Data Availability

This research is survey based; therefore, no dataset is used in this research.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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