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An imperative role of 6G communication with perspective of industry 4.0: Challenges and research directions

Yamini Ghildiyal [a], Rajesh Singh [a,c], Ahmed Alkhayyat [b], Anita Gehlot [a,c], Praveen Malik [d], Rohit Sharma [e,*], Shaik Vaseem Akram [a], Lulwah M. Alkwai [f]

[a] Uttaranchal Institute of Technology, Uttaranchal University, India
[b] College of Technical Engineering, The Islamic University, Najaf, Iraq
[c] Department of Project Management, Universidad Internacional Iberoamericana, Campeche 24560, Mexico
[d] School of Electronics and Electrical Engineering, Lovely Professional University, Jalandhar, Punjab, India
[e] Department of Electronics & Communication Engineering, SRM Institute of Science and Technology, NCR Campus, Delhi- NCR Campus, Ghaziabad, UP, India
[f] College of Computer Science and Engineering, University of Ha'il, Ha'il, Saudi Arabia

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ABSTRACT

The united nations have set a target of meeting sustainability by 2030 in terms of social, economic, and environmental. Digitalization has proven to be a significant approach to meeting the goal of sustainability. Along with digitalization and Industry 4.0, it was also stated that 6G communication is beneficial for lowering carbon emissions, effective management of natural resources, etc. Based on this motivation, this is the first study to attempt to present the significance of 6G communication from the perspective of Industry 4.0. The fundamental technologies of 6G wireless communications at the physical layer are emphasized, and also discussed enabling technologies of Industry 4.0 for 6G communication in detail. The recommendations and challenges are discussed for future directions. 6G for low earth orbit (LEO) communication and data center operations for 6G network nodes, and 6G network with aerial computing are the recommendation presented in the study. The novelty of study is, it integrates and discussed the sustainability aspect, the vision of the 6G network with fundamental technologies, and Industry 4.0 in detailed. The recommendations and challenges presented in the study motivate the researchers to carry out the study for future research in implementing 6G communication for achieving sustainability with industry 4.0.

Introduction

Currently, the world is moving towards smart and digitalization in order to achieve sustainability by 2030. Wireless and mobile communication has a major role in the establishment of resilient and digital infrastructure, where the fast transmission of information with security and reliability. Mobile communications can help to achieve the united nations' sustainable SDGs by providing the necessary infrastructure and accessibility to digital services that encourage development, efficiency, and sustainable development. Apart from technology, Mobile communication has an evident ability to contribute directly to the UN SDGs by acknowledging digital inclusion and sociocultural empowerment [1].

SDG 9 aims to build resilient infrastructure, promote sustainable industrialization, and foster innovation. In order to build resilient infrastructure with industry 4.0 technologies, they need advanced wireless communication technologies. Wireless mobile communication is undergoing its most rapid growth in history from 1G to 5G (Fig. 1). It started with 1G mobile communication which was an analog mobile phone system developed in the U.S. and Nordic mobile telephone developed in Europe [2]. This is the first offered calling service in 1980. After that 1G cellular system was replaced by a digital mobile phone system, 2G.2G is a time-division multiple access (TDMA) based wireless communication system that provides more capacity than the 1G system and uses GSM architecture which provides services to around one billion users and many other features. After that when 3G was introduced, it was a great evolution in mobile communication technology. 3G system was based on Code division multiple access(CDMA-2000), Time division synchronous code division multiple access (TD-SCDMA) & wideband code division multiple access (WCDMA).

These are the 3G standard technologies for cellular networks. CDMA-2000 Supports data ranging from 114 Mbps to 2 Mbps. WCDMA is a 3G

* Corresponding author.
E-mail addresses: rajeshsingh@uttaranchaluniversity.ac.in (R. Singh), anita.ri@uttaranchaluniversity.ac.in (A. Gehlot), rohitapece@gmail.com (R. Sharma).

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Nomenclature

AI	Artificial Intelligence
BDMA	Beam Division Multiple Access
CaeC	Contextually Agile Embb Communications
CDMA	Code Division Multiple Access
CPS	Cyber-Physical Systems
COC	Computational Oriented Communication
DT	Digital Twin
EDuRLLC	Event Defined Ultra-Reliable and Low Latency Communication
eMBB	Enhanced Mobile Broadband
EHF	Exceptionally High Frequency
FBM	Filter Bank Multi-Carrier
ICI	Inter Carrier Interference
IEC	Intelligent Edge Computing
IoE	Internet Of Everything
IoT	Internet of Things
IoNT	Internet of Nano Things
ISI	Inter Symbol Interference
LEO	Low Earth Orbit
LiDAR	Light Detection and Ranging
LTE	Long Term Evolution
ML	Machine Learning
mMTC	Massive Machine Type Communication
MIMO	Multiple Input Multiple Outputs
NTN	Non-Terrestrial Networks
OFDM	Orthogonal Frequency-Division Multiplexing
OWC	Optical Wireless Communication Technologies
QoS	Quality Of Service
QoPE	Quality-Of-Physical-Experience
RF	Radiofrequency
RFID	Radio-Frequency Identification
SDG	Sustainable Development Goals
SuRLLC	Secure Ultra-Reliable Low-Latency Communications
TDMA	Time-Division Multiple Acces
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
UAV	Unmanned Aerial Vehicles
UCDC	Unconventional Data Communications
UFMC	Universal Filtered Multi Carrier
uRLLC	Ultra-Reliable and Low Latency Communication
WCDMA	Wideband Code Division Multiple Access

standard for wireless that supports both data and voice at data rates of up to 384 Kbps. TD-SCDMA is a time division duplex, that was developed in China. Long Term Evolution (LTE) networks were launched in 2009, December [3], which are known as 4G wireless communication. The 4G network, is based on orthogonal frequency-division multiplexing (OFDM) and multiple input multiple outputs(MIMO) techniques [4]. In

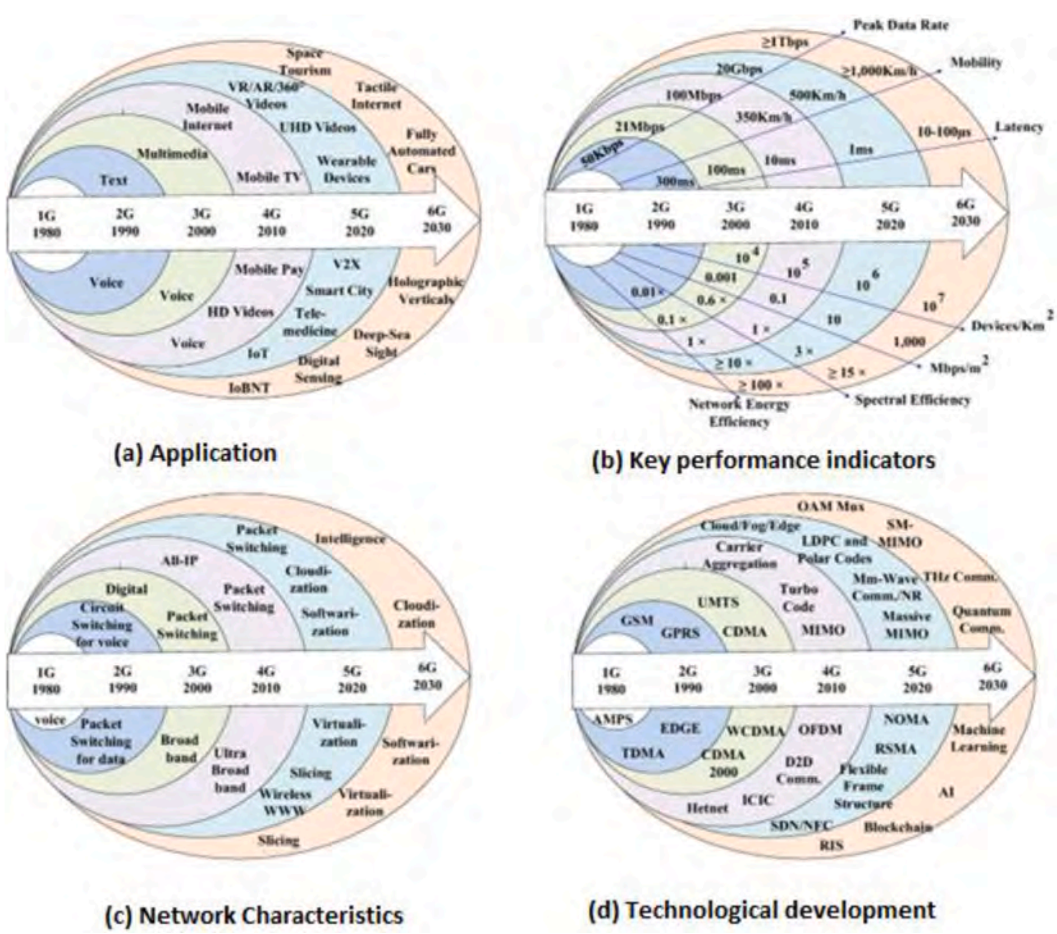

Fig. 1. The transition of wireless communication from 1G to 6G (a) Application; (b) key performance indicators; (c) network characteristics; (d) technological development [11].

a comparison of previous wireless generations, which focused completely on system capacity increment, 5G provides mobile network services from people to things, as well as from clients to upright industries.

The 5G communication is a combination of Filter bank multi-carrier (FBMC) multiple access techniques and Beam division multiple access (BDMA) [5]. 5G system provides a range of services, like Virtual reality (VR), conventional mobile services to Industry 4.0, the Internet of things (IoT), and the automated driving industry [6]. Because of its resistance to Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI), Universal Filtered Multi-Carrier (UFMC) has been considered an important waveform for 5G communication systems. It is also a preferable choice because it is best suited for low-latency configurations [7].

In recent years we saw that wireless communication played an important role in pandemic crises like covid by connecting people and providing 5G applications and services such as digital or online medical consultation, digital education, working from remote, automatic driverless vehicles, drone technology, robots, smart healthcare, etc [8]. Some countries already developed 5G and even using the 5G services but 5G is still being deployed in some countries all over the world, so this is the time to go towards the next era of mobile network communication is 6G to fulfill the various demands of the network and to expand the user capacity of the network. In 6G, the 5G framework will be expanded and further developed. However, concerning performance and user quality of service (QoS), the 6G network will supersede 5G, while also introducing some unique features such as an ultra-reliable network, enhanced mobile broadband, and low latency [9]. The bit rate per user in 6G is predicted to be around 1 Tb/S in many cases. Now we can say that 6 g wireless communication will provide 1000 times more capacity than 5G wireless communication [10].

The industrial revolution started in the 18th century with the first industrial revolution which was related to mass production using water and steam. Instead of human and animal power [12]. After a century, the second industrial revolution-initiated assembly plants as well as the use of oil, fuel, and energy. The Third revolution of the industry, which starts in the middle of the 20th century, revolutionized production by incorporating computers, advanced telecommunications, and data analysis [13]. The fourth industrial revolution and its fundamental digitalization, renowned as Industry 4.0, are advancing at a rapid pace and this revolution stage is completely based on automation and increment in smart devices [14]. The digital revolution is fundamentally altering the way people live and work, and the public remains optimistic about the opportunities for sustainability that Industry 4.0 may provide.

Enhanced efficiency and productivity increased flexibility and agility, and greater profits are all advantages of Industry 4.0 technologies, processes, and systems. Customer experience is also improved by Industry 4.0, which includes more individualized and smart products. With the 5G, mobile communication system recently starting to roll out in several countries, the wireless community is now focusing on the 6G [15]. Following in the footsteps of 5G, 6G is expected to become the major infrastructure foundation of the future smart industry. A combined effect of 6G and emerging technologies such as AI, ML, Digital twin, and Blockchain, etc. in particular, will accelerate the next evolution of Industry 4.0 systems [16]. 6G networks will be capable to utilize high frequency more than 5G networks, resulting in significantly much higher capacity and reduced latency [17]. One of the major significances of 6G is to provide microsecond (μs) latency.

The use of 6G and beyond the wireless network in the industry 4.0 revolution ensures effective latency, high-quality services, enormous IoT infrastructure, and incorporated AI capabilities. 6G networks improve system performance in Industry 4.0 solution that offers intelligent spectrum management, smart mobility, and AI-powered mobile edge computing. 6G systems are likely to satisfy the requirements of a smart information society by providing ultra-high reliability, ultra-high data rates, ultra-low latency, traffic capacity, highly efficient energy, and so on for Industry 4.0 applications.

Table 1 presents the comparative analysis of the present study with previous studies. In the previous studies, the most of studies are focused on discussing the distinct issues of vision, transition, and security of 6G communication. There are limited studies that have focused on the concept of industry 4.0 and sustainability with 6G communication. In the current scenario, sustainability can be achieved with the integration of innovative infrastructure with advanced technologies that minimize resources. From this, we concluded that this study is the first to focus on discussing the 6G communication in a relation to industry 4.0 and the sustainability aspect. The novelty of the study is, it integrates and discussed the sustainability aspect, the vision of the 6G network with fundamental technologies, and Industry 4.0. The recommendations and challenges presented in the study motivate the researchers to carry out the study for future research in implementing 6G communication for achieving sustainability with industry 4.0.

The main contribution of the study:

- The study presented the impact of 6G and its assisted technology towards industry 4.0 with an objective of sustainability.
- In the study, we have addressed the role of enabling technologies such as IoT, AI, Bigdata, Edge AI, blockchain, UAV, and digital twin for 6G to enhance the infrastructure.
- The study presented vital recommendations for future directions with challenges. 6G for low earth observation communication, 6G for data center operations for 6G network nodes, an amalgamation of blockchain and AI with 6G for AR/VR applications, and a future 6G network with aerial computing are the vital recommendations discussed in this study.

The structure of the study (Fig. 2) consists of section 2 covers the methodology of the study; section 3 discusses the Overview of 6G and assisted recent technology in inclination towards industry 4.0; section 4 discusses the fundamental technologies requirement for 6G; section 5 describes the 6G: Enabling technologies; section 6 discuss the recommendation & discussion; section 7 includes the challenges and future research directions.

Methodology of the study

In this section, we have discussed the methodology followed in this study. The present study is focused on discussing how 6G communication is implemented with industry 4.0 enabling technologies. Fig. 3 illustrates the PRISM diagram of the literature considered in this study. Based on this question, the study has followed the search strategy and selection criteria, data collection and extraction, and data analysis. The articles are obtained from relevant research databases such as Scopus, web of science, and IEEE explore. In order to obtain the research articles on the research questions, we have applied Boolean logical operators

Table 1
Comparison of the present study with previous studies.

Research	Contribution	Focus
18	A vision for 6G that could serve as a research guide in the post-5G era	security, secrecy, and privacy
19	New architectural changes associated with 6G networks	Wireless evolution
20	A vision of future 6G wireless communication and its network architecture	Emerging technologies for quality of service
21	Intelligent UAV computing technology to enable 6G networks over smart environments	Ubiquitous computing
22	Investigations for the development of 6G communications systems.	Enabling technologies and architecture
Current study	The study presents the role and significance of 6G communication with industry 4.0 and sustainability	6G vision, Enabling technologies, future directions, and challenges

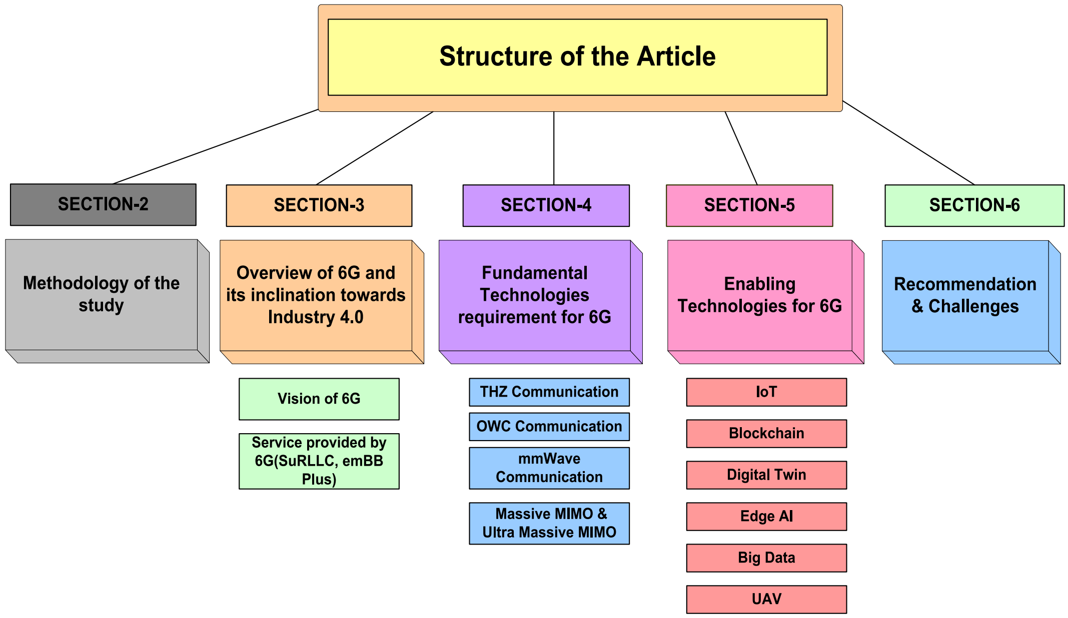

Fig. 2. Structure of the paper.

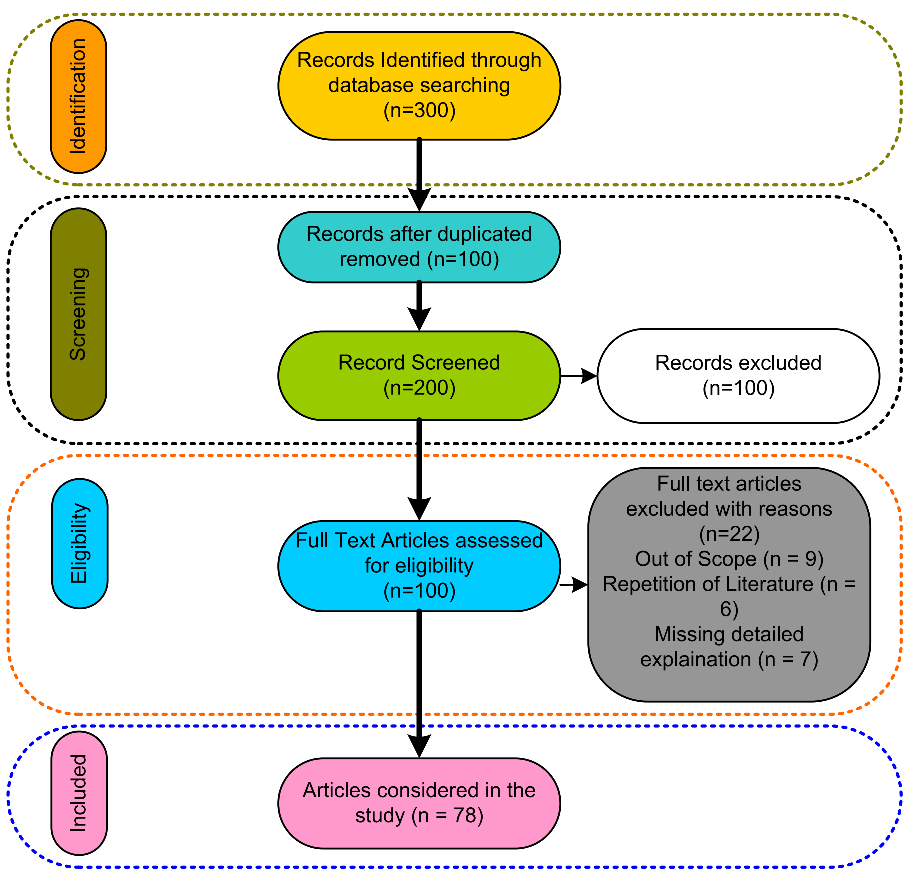

Fig. 3. PRISM Framework.

such as "AND and "OR". In the study, we have used the following keywords such as "Industry 4.0", "6G communication", "Sustainability", "Internet of Things", "Edge computing", "6G vision", "Blockchain", "big data", "Artificial Intelligence", "Unmanned aerial vehicle", "digital twin". After obtaining the article, the next stage is to filter the articles based on the following articles.

The articles such as research, review, and case study which are published in the English language are included. The articles which do not have full text and studies that do not have conducted experiments or any validation are excluded. The articles which are duplicates and also non-peer-reviewed articles are excluded. The book chapters, patents, and conferences are articles that are excluded for maintaining quality research. In the final phase, the complete article is analyzed by considering the framed research questions. Based on the obtained articles, the study discussed the overview of 6G communication with industry 4.0.

Overview of 6G and assisted recent technology in inclination towards industry 4.0

The term “Industry 4.0” was invented in anticipation of a designed “fourth industrial revolution,” with the term evoking software versioning [19]. Recent manufacturing advancements have opened the way for the systematic deployment of Cyber-Physical Systems (CPS) [20]. The manufacturing industry is integrating new technologies like IoT, AI, Big data, Digital twins, blockchain, etc., into their product development [21]. This technological advancement in the manufacturing industry is termed the industrial revolution. The revolution started from the first industrial revolution in the 18 century and currently, in the 21st century, industry 4.0 is the latest buzzword. Industry 4.0 is a ‘digitalization of the production or manufacturing industry with the help of IoT and CPS [13].

In Industry 4.0, linked computer systems, smart machines, and smart materials interact with one another, and the environment, and finally decide things with negligible human interference. Automation has its own defined set of communication requirements in terms of reliability and asynchronous communication, which 6G is prepared to discuss through a disruptive set of technologies [22]. So, Industry 4.0 will create completely autonomous, smart, and intelligent systems. 6G will complete the industry 4.0 revolution that began with 5G. 6G will provide real-time operation with a microsecond delay jitter, and a peak data rate of up to gigabit/second for industrial applications. Currently, most countries are still deploying 5G wireless communications, but the country like China already deployed 6G networks and also launches the first 6G satellite into space. Innovative applications drive every new cellular generation [23]. Table 2 illustrates the technical specifications of wireless communication technology from 4G to 6G.

5G technology has three distinguishing features (Fig. 4) which are ultra-reliable and low latency communication (uRLLC), massive machine type communication (mMTC), and enhanced mobile broadband (eMBB) [24]. With the help of 5G services 6G will support three new services which are Computational oriented communication (COC), Contextually Agile eMBB Communications (CaeC) & Event defined uRLLC (EDuRLLC) [25]. Because of the vast segments of the unused and undiscovered spectrum, the THz Frequency band that ranges between 100 GHz and 3 THz are suitable frequency band for the upcoming wireless communication generation [26]. Due to the unexpected innovations that will be embraced by 6G communications networks, such as THz (enormous bandwidth) and highly intelligent networks that involve scenarios for operations and the environment as well as network services, 6G networks are anticipated to offer wide coverage that includes service to interact with each other anytime, everywhere at a speed of high data rate [27].

The main aim of the 6G network is that it will provide a data-driven society or we can say that it will be majorly dependent upon the internet of everything. The industry 4.0 revolution, which began with 5G, will be fully realized with 6G, that is, the digital revolution of mass production through cyber-physical systems [28]. 6G, combined with various features such as AI & ML and the Internet of Everything (IoE), accelerated the revolution of the industry from industry 4.0 to industry 5.0.

Table 2
Comparison of latest wireless communication technologies.

Parameters	4G	5G	6G
Development	Since 2010	Since 2020	2030
Data Rates (Capacity)	0.07–1 Gbps	Up to 20 Gbps	>1 Tbps
Max. Frequency	6 GHz	90 GHz	10 THz
Bandwidth	1.25–20 MHz	0.25–1 GHz	Up to 3 THz
Modulation	QPSK, QAM, 64QAM	OFDM	STBC-assisted OFDM
Multiplexing	OFDMA	OFDMA	Smart OFDM + IM
Service level	Video	AR/VR	Tactile
Latency	50 ms	5 ms(10 times lower than 4G)	1 ms(5 times lower than 5G)
Architecture	MIMO	Massive MIMO	Intelligent surface
AI assistance	No	Partial	Fully
Application Type	LTE	eMBB, URLLC, mMTC	MBRLLC, mURLLC HCS, MPS
Haptic communication	No	Partial	Full
ER(Extreme Reality)	No	Partial	Full
Satellite Integration	No	No	Full

6G vision

While 5G is still deployed in many countries, many more countries are going to use 5G in the next few years. Various researchers are wondering about the concept of 6G, its deployment, also about the functionality of the network, and many more services. The vision of 6G is already clear it will provide unlimited wireless connectivity with fully supported AI. Features of 6G will be an integration of past mobile generations like 5G features and emerging trends like the internet of everything, smart devices, and AI. Global coverage, a fully automated management system, a self-sustaining network, flexible and scalable network infrastructure, network security, connection everywhere, IoE, etc. are the key features of 6G Communication illustrated in Fig. 5.

The basic vision of the 6G network is to provide intelligent connectivity. Intelligent connectivity is a theory, which envisions the use of 6G, the Internet of things, and AI to speed technical advancement and enable new disruptive digital services. The digital data generated by the machines, gadgets, and sensors that make up the IoT is analyzed and contextualized by AI technologies and presented to consumers in a more relevant and useful way in the intelligent connection vision. Intelligent connectivity can be described in terms of deep, holographic, and ubiquitous connectivity which work on AI and ML [29].

Service provided by 6G

6G will provide vital services consisting of a few earlier developed features of 5G like eMBB (Enhanced mobile broadband), uRLLC, mMTC, IoT, AI, etc. The following services are required for 6G:

- *eMBB-Plus*- 5G NR (New Radio) defined some set of specifications for the core 5G network which include three basic services- massive machine type communication, enhanced mobile broadband, and ultra-reliable low latency communication. eMBB focuses on higher data rates and low-latency network communication. This is useful in modern media applications like AR/VR, 360-degree video streaming, and UltraHD (Fig. 6). eMBB plus is the service of 6G that provides high-quality conventional services.
- *Tactile Internet*- The Tactile Internet will be defined by its incredibly low latency combined with high accessibility, reliability, and privacy.
- *Satellite Integrated Network*- To Provide global connectivity 6G will utilize multiple satellites, UAVs, and terrestrial and airborne networks. The combination of all of these 6 G will provide connection anytime, anywhere, and everywhere [30].
- *Secure ultra-reliable low-latency communications (SuRLLC)*- SuRLLC is the combination of 5G services mMTC and uRLLC [20]. It is used in the 6G network to provide a reliable connection with improved latency and with gigabits/second delay jitter. It provides reliability up to 99.99 % and latency below 0.1 ms. In 6G SuRLLC is used in military and industrial applications. It enables new features for applications such as smart cities, smart transportation, and the revolution

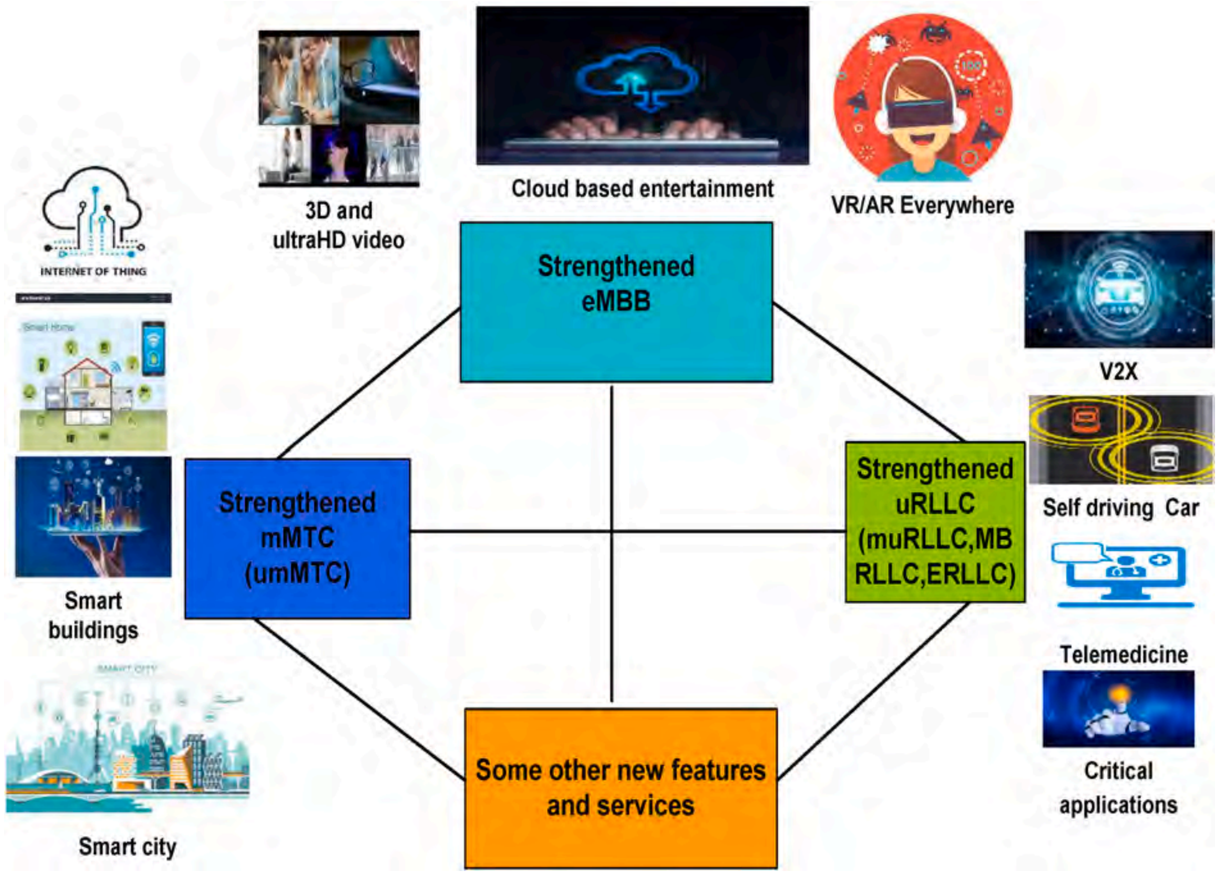

Fig. 4. Three enhanced scenarios for the 6G system.

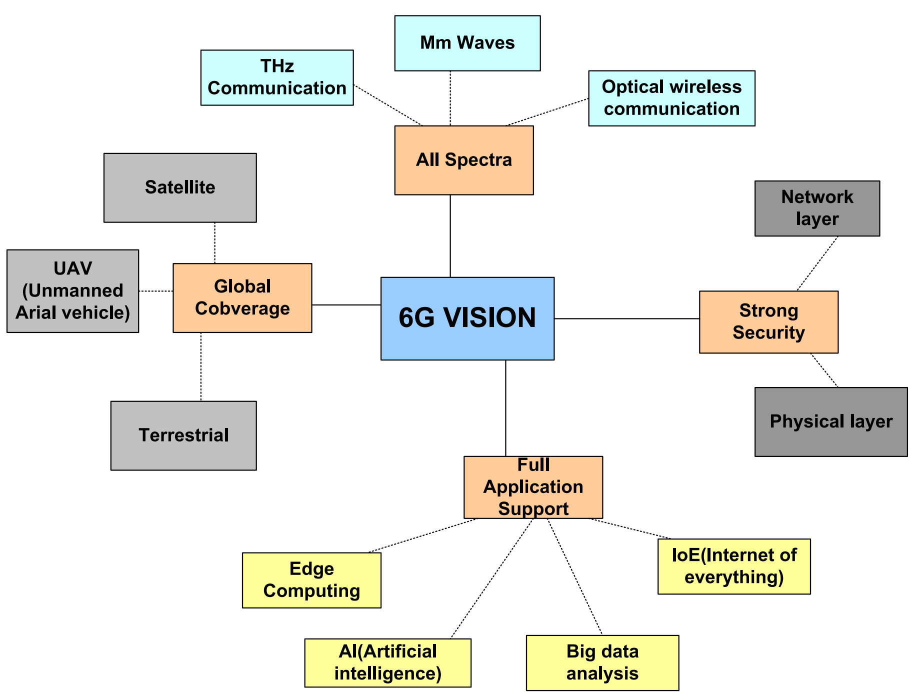

Fig. 5. Predicted vision of 6 G wireless communication.

of Industry 4.0 that has rigorous requirements for reliability, low latency, and availability of resources.

- *Three-dimensional integrated communications*- With the integration of 3D-InteCom expands network enhancement and planning from 2D to three dimensions.

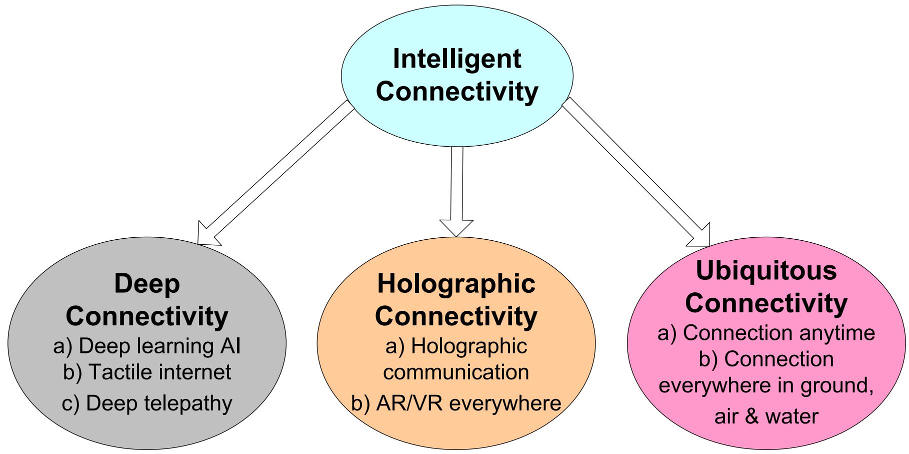

Fig. 6. Services provided by future 6G network.

- *Unconventional data communications (UCDC)*- The UCDC allows for the inclusion of enhanced communication prototypes and frameworks.

Fundamental technologies requirement for 6G

6G will complete the demand for future wireless communication by providing high data rates, ubiquitous coverage [31], and internet connectivity everywhere. To provide all these features 6G will drive some fundamental technologies which are discussed below:

a. *Terahertz communication (THz)*

Terahertz transmission is a wireless technique that enhances communications systems by allowing high-speed wireless expansions of optical fibers beyond 5G. THz waves are appealing for wireless technology since they can provide massive bandwidth, which is required to boost data capacity [32]. THz frequencies will offer a data rate of more than 100 Gigabit/*sec* and latency below 1 ms [33].

Wireless communication in terahertz frequency bands (0.1-10THz) and wavelengths is the key factor of tomorrow's 6G network connections. Because of the vast quantity of existing bandwidth, THz frequencies have the potential to improve wireless capacity performance by enabling high-resolution sensing. Band quasi-opticality, THz-tailored wireless structures, integration with minimized frequency bands, mutual sensing and communication systems, physical layer methods, spectrum allocation strategies, and real-time network improvement are all features of terahertz communication. These distinguishing characteristics aid in understanding how to re-engineer wireless networks.

b. *Optical wireless communication*

The optical frequency band is already a crucial enabler of technology of the world wide web. There has been a considerable rise in both academic and commercial interest in optical wireless communication technologies (OWC) in recent years [34]. Optical wireless techniques are being developed for 6G wireless networks, as well as radio frequency-based communication systems for any network. These network systems also have network-to-backhaul/front-haul network connectivity.

Light detection and ranging (LiDAR), which works in both the optical and radio frequency bands, is an emerging tool for very high-resolution three-dimensional mapping in 6G connections. Optical wireless is assured that it will improve 6G communication system supports for uHSLLC, umMTC, uMUB, and uHDD services. The developments in the manufacturing of LED and LED multiplexing technologies are the two key factors for optical wireless communication in 6G.

c. *Millimeter-wave (mmWave) communication*

mm-wave communications are capable of supporting nearly all wireless communications applications. The mmWave frequency band in the electromagnetic (EM) spectrum ranges from 30 to 300 GHz [35] which spans the microwave (1 GHz to 30 GHz) and infrared (IR) sections. The mmWave framework is studied extensively in many fields, including satellite technology, communication devices, astronomy, and healthcare, among many others. Likewise, mmWave is widely used in entertainment for high-speed video transmission with very high video signal quality [36].

mmWave has much greater bandwidth utilization than low- and mid-bands, which is a very great resource for 6G. mmWave frequencies less than 50 GHz are currently being presumed for 5G, and additional mmWave bands above 100 GHz are predicted to be allowed for 6G. mmWave technology can benefit backhaul, fronthaul, and access networks. Mm-wave is useful for smart factories, autonomous driving, and other applications because it can support high data rates. Additional challenges, particularly for 6G requirements, must be overcome, such as effective transmission and reception, beamforming configuration, modulation coding system execution with reduced power, low price, maximum throughput, and so on.

d. *Massive MIMO & Ultra massive MIMO*

MIMO is a technology related to radio antennae that incorporates various antennas at both the receiver and transmitter to improve radio signal strength, efficiency, and capacity [37]. The application of MIMO technology is in a variety of modern wireless networks and radio-frequency (RF) techniques, which combine LTE and Wi-Fi. The first designed 2x2 MIMO for 4G (LTE) was released in 2008.

Nowadays 4G systems are using 44 MIMO. Due to very short wavelengths at mmWave frequencies, antenna dimensions are reduced, and for 5G, 32 antennas (32 $\times$ 32 MIMO) are released, which will increase to 64 and more in future releases. Massive MIMO will play an essential role in the 6G technology to cover a variety of ubiquitous services. The system performance is also increased when the MIMO technique is evolved. Massive MIMO will be vital in both 6G/5G networks to enhance spectral efficiency and energy efficiency, faster speeds, and high frequency.

Enabling technologies for 6G

Innovative applications drive each new cellular generation. 6G is also a combination of numerous technologies [38]. Earlier 6G architecture was dependent upon 5G but due to the continuous emergence of the new application, the architecture of 6G has been modified. In this section, we are discussing a few emerging and vital technologies for 6G wireless communication as shown in Fig. 7.

a. *IoT in 6G wireless communication*

IoT sometimes referred to as the IoE is a new conceptual framework anticipated as a worldwide network of interlinked devices and machines. The IoT has created an exciting opportunity for the development of technologically advanced industrial networks and software by leveraging the increasing ubiquity of radio-frequency identification (RFID), wireless, portable, mobile, and sensor devices [9]. IoT provides connectivity to billions of network-enabled devices. It is the key factor for industry 4.0, so technologies beyond 4G cannot be imagined without the utilization of IoT [39]. Because of the increasing demand for wireless networks, intelligent services based on IoE are gaining attraction rapidly. Even though 5G networks can provide a wide range of IoE-based solutions, they are insufficient to satisfy the full set of specifications for intelligent applications. 6G wireless communication will provide a fully autonomous and intelligent system with the help of IoT [40].

The usage of IoT-enabled 6G communication can be seen in numerous applications like smart cities, smart farming, smart transportation, e-healthcare, and wearable devices. In comparison to the 5G network, the next generation 6G communication network is expected to offer global coverage with a combination of improved flexibility to assist IoT connectivity and delivery of services [41].

b. *Big data in 6G*

Big data refers to huge amounts of information with complex structures that are difficult to store, evaluate, and visualize for further processes [42]. Big data analytics means discovering a massive amount of data to discover underlying patterns and links. As 6G supports billion of users, minimized latency and big data are some of the vital features of the communication system. There are security and privacy concerns with the data used in a wireless network that must be discussed, which can be done with the help of big data analytics [43]. In a 6G network, latency can be minimized with the help of big data and machine learning by deciding the possible best route to transfer the information or data from the user to the base station [44].

c. *Edge AI in 6G*

The portrayal of human intelligence by computers that are programmed to act and think like humans is known as AI [45]. The main focus of 6G wireless communications is intelligent connectivity. In the development of 4G communication networks, AI was not introduced in it. AI is introduced in a limited way in a 5G wireless system, however, in terms of automation, AI will fully support 6G. The true capacity of radio transmissions will be recognized with AI-empowered 6G, which will facilitate the transition from cognitive radio to smart radio (Fig. 8).

In 6G wireless communication, the main transition will accelerate from connected things to intelligent connectivity. With the progression of big data technology, computational power, and the accessibility of rich data, it is normal to use AI to address complex 6G network issues [36]. Edge AI is a revolutionary technology for 6G that perfectly integrates sense, communication, computing, and intelligence, and maximizes the efficiency, privacy, effectiveness, and safety of 6G networks by embedding model training and inference capabilities at the edge network [46].

Edge computing is an idea that gained popularity in the research and academic sector rapidly. It is a vital factor for technologies like IoT, AR/VR, Vehicle to vehicle communication, etc., related to industry 4.0 and beyond [47]. Intelligent edge computing (IEC) is the new vital enabler of 6G communication networks. IEC is the advanced version of cloud computing that provides easy access to end-to-end users [48]. IEC

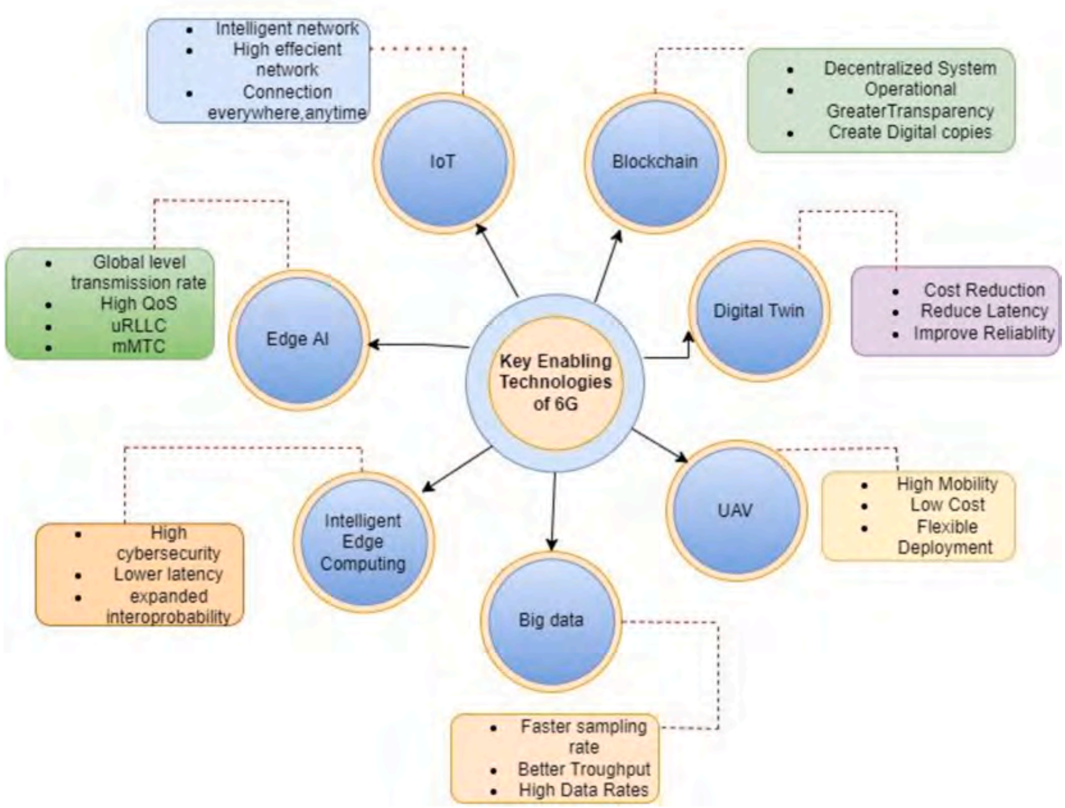

Fig. 7. Necessary foundations and Enabling technologies for 6G.

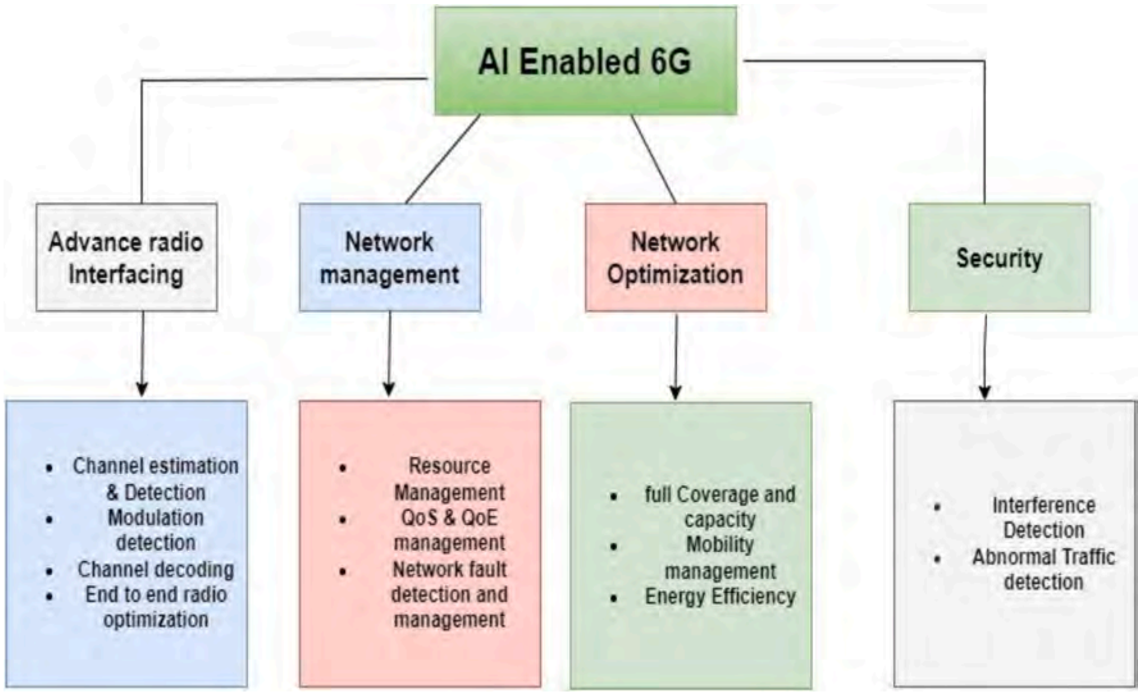

Fig. 8. Features of AI-driven 6G network.

becoming more popular and important as a result of several factors including huge IoT, Industry 4.0, Smart Cities, and AI/ML-dependent applications. This technique is used in modern digital communication systems such as IoT technologies, virtual reality video games, self-driving cars, cloud-based services, and data security. A few of the basic principles of IEC are easily portable, and the ability to connect, interact, and character [49].

d. *Blockchain*

Blockchain technology will be important for managing huge amounts of data in future communications networks. Blockchain is a distributed ledger-type database that spans computing devices or multiple nodes [50]. Blockchain technologies have various advantages like immutability, decentralization, transparency, security & privacy [51]. Regardless of these promising benefits, scalability is a major disadvantage to the widespread adoption of blockchain technology in terms of throughput, storage, and networking. The evolution of 4G telecommunication enabled various resource-constrained consumers to relish cost-effective resources with ease. It does, however, extend its fundamental highly centralized architecture, which raises several issues related to network data availability, network data security, and operations and maintenance infrastructure charges [52].

To provide security and decentralization to a wireless network [53], blockchain's ability in 5G and future wireless connectivity has recently been acknowledged. Blockchains enable decentralized co - operative environmental sensing devices that can be realized on a global scale using 6G technology. In the 6G network, blockchain is used to improve techniques like cloud applications, virtualization, networking technologies, and machine-to-machine communications to enforce critical features like spectrum and radio sharing resources, data sharing and storage, network virtualization, privacy, and security in use case domains like smart city, smart transportation, smart grid, e-health, and unmanned aerial vehicles (UAV). Some research has concluded that blockchain can solve the issue of end users related to resource and infrastructure sharing, and privacy protection [54].

e. *UAV*

UAVs or drones are aircraft operated by either humans or by the autonomous system and fly below regular airspace. The concept of humanless aircraft had already been discovered during the early development of flight but the unmanned aircraft's idea is expanding nowadays. UAVs have tremendous potential in the military, public and private sectors. The military is the sector that is utilizing the UAV for 25 years earlier for border surveillance, strike, target identification, weapon delivery, and many more [55]. Due to their low cost, small size, and low weight typically less than 25 kg, UAVs are utilized in multiple fields like aerial photography, survey, and mapping, agriculture (crop monitoring, crop spraying), military sector, and surveillance [56]. Because of the distinguishable and advantageous features of drones, the role of drones can be seen in wireless communication beyond the 5G network. Aerial access networks are key attributes for future wireless systems beyond 5G [57].

These networks are distinguished by a variety of characteristics including ubiquitousness, accessibility, mobility, synchronicity, and scalability. This network will complete every aspect of future wireless communication and fulfill the demand of users. UAVs can also be used as flying base stations in 5G/6G wireless networks to provide wireless communications and coverage enhancement. To provide cellular connectivity, the base stations are installed in UAVs [58]. A UAV has the advantages that it has a dynamic infrastructure, such as effortless installation, strong line-of-sight links, and a controlled mobility-assisted degree of freedom.

f. *Digital Twin (DT)*

DT is primarily a program that creates simulation models of how a product or service will perform using real-world data [59]. DT technique is a current advancement in digital technology that has captivated the interest of industry and academia in recent years. With no time or space constraints, users in a 6G environment will be free to discover and observe reality in a practical world using digital twins [60].

In Industry 4.0, by combining the cyber-physical world with technologies DT and CPS multiple tasks can be done like surveillance, enhancement of network, and prediction of industrial processes. To enable 6G services, the twin objects communicate with IoE devices and other twins. Although cloud-based DT implementation has a low design complexity in terms of design and management. It faces significant network latency in systems with a significant number of devices [61]. Subscribers in a 6G environment will be free to discover and regulate reality in a digital world using digital twins, with no time or space limitations.

Recommendations and challenges

The goal of a 6G is to achieve sustainability and smartness. To achieve the goal of ubiquitous and intelligent connectivity, the 6G technology should be combined with technologies like AI, IoT, big data analysis, etc. (Fig. 9). Fundamentally, IoT is a technology that empowers one to obtain real-time sensor data from any location through internet connectivity. As the number of IoT devices is increasing, it is an opportunity to implement AI and big data analytics for the prediction and detection of significant parameters for better enhancement. Moreover, to reduce the latency, edge computing technology is integrated with AI for prediction at the edge of the network.

The results of edge analytics are transmitted to the cloud server for visualization. Blockchain technology is integrated into edge AI devices to authenticate nodes and secure data transmission. The amalgamation of all these technologies with extended reality and virtual reality led to the implementation of the digital twin. To implement this technology, low latency, and high-speed transmission are the key features. Here the 6G communication is useful for meeting the goal of the architecture.

a. Recommendations

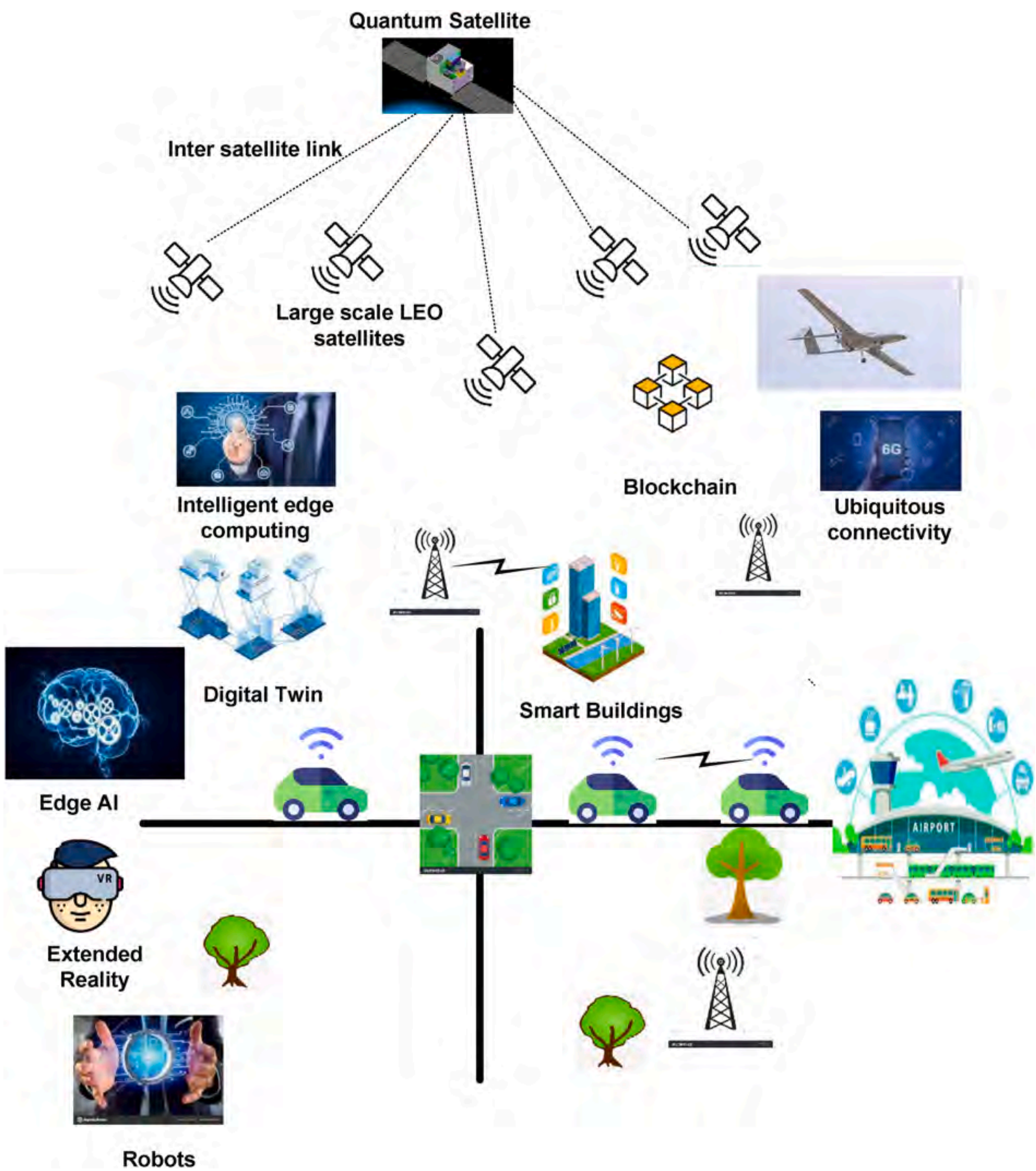

Fig. 9. Future 6G network architecture.

The following recommendation can be made after studying the various 6G research articles.

- As discussed above, 6G communication has the potential for the implementation of intelligent and innovative applications such as telesurgery, Internet of Nano things (IoNT), etc. The key limitations of a communication network are the power supply and memory of the 6G network nodes. Although the data center can store massive amounts of data, it also needs a high data throughput and low latency [62]. Data generation and transfer to the data center can be done simultaneously because of 6G's fast speed. Additionally, the data can be concurrently saved in several places, and also 6G offers security for data transfer.
- With breakthroughs in huge low earth orbit satellite communications, the 6G system will extend beyond terrestrial networks to provide ubiquitous and global three-dimensional coverage via an integrated terrestrial and aerial network. It is predicted in the previous studies that communication with mega-constellations of low Earth orbit (LEO) satellites will be one of the succeeding frontiers of connectivity on the route to 6G, augmenting terrestrial networks to enable limitless access worldwide, thus contributing to bridging the digital barrier [63]. In 6G, terrestrial networks will be narrow, holding mobility between terrestrial and LEO satellite networks. To achieve seamless integration in 6G, we will need to proceed with a new approach by including LEO satellite access in the design of the 6G system from the start, as opposed to the incremental approach used in 5G non-terrestrial networks (NTN).
- AI and blockchain, two of the most recent developing technologies, both have constraints that limit their uses to 6G. To fully grasp the promise of these two techniques and meet the predicted intelligence, distributed, and security requirements, these two rising trends must be combined. Currently, increased holographic projection is supported by 6G networks via ultra-low latency, THz bandwidths, and large device connectivity [64]. The data, however, is shared between autonomous networks over untrusted routes. Thus, blockchain introduces new aspects of user access control, intelligent resource management, and audibility in stored transactions to assure data security, privacy, and trust among stakeholders. As a result, blockchain, AI, and 6G collaboration in future AR/VR applications is a developing research area.
- Currently, innovative computing is proposed by a study named aerial computing. It is an amalgamation of edge computing and aerial radio access networks [65]. This computing offers global computing service, better mobility, and higher scalability with applications such as network energy refilling, softwarization, multiaccess techniques, and AI and Big Data Analytics. Aerial computing empowers assisting the future 6G networks in data collection and computation for the end IoT devices. In comparison to terrestrial computing infrastructures such as cloudlets, and cloud data centers, aerial computing platforms have limited storage capacities and battery capabilities, which would impede the development of aerial computing services such as airplane-based computing.
- 6G necessitates a shift away from radio-centered system design and toward end-to-end three CLS co-design under the supervision of an AI-powered intelligence framework. Collaborating in three-dimensional spaces and transferring away from simple aggregation forward into fine-grained analysis that considers tails, distributions, and quality-of-physical experience (QoPE) are required for 6G performance analysis and optimization. Moving away from the smartphone-based terminal concept, 6G will usher in the era of smart surfaces sharing information with human-embedded implants. The 6G vision will not only limit to the high-frequency spectrum to increase the capacity of the network but it will also be propelled by a diversified collection of features, applications, techniques, and methods.

b. Challenges

To successfully implement a 6G communication network, some technical issues must be resolved. Several potential issues are briefly mentioned below.

- **Ultra-high data rate**-In earlier mobile communication systems high data rate is the main concern. Various predictions have been made that 6G will provide data rates up to Tera (B/*sec*) for applications such as intelligent systems and big data analysis. To expand its capacity, 6G technology demands make utilization of exceptionally high frequency (EHF) bands. The EHF bands' relatively limited communication range is generated by the substantial path losses that electromagnetic waves are subject to in these bands. To leverage this capability, a huge number of access points are necessary, which is a significant economic disadvantage [66,67]. Mobile customers will endure a high number of handovers to stay connected to the 6G network if each access point's coverage area is narrow.
- **3D networking**- The concept of 3D networking to control a wide variety of aerial platforms, such as drones, constellations of Very-Low-Earth-Orbit satellites, and high-altitude platform stations traveling at just a few hundred kilometers in space, to furnish cloud features and functionality while preserving configurable delay restrictions [68]. The 6G network will work on 3D networking phenomena; it implies that one more direction is added to the network. To manage and optimize resources for the mobility of users, multiple access techniques are essential.
- **Complex and heterogeneous hardware**-Due to various techniques involved in the 6G system like massive MIMO, complex routing protocol, and algorithms hardware design will be complex in the 6G architecture [69]. Because of the complex structure the implementation of techniques like AI, and IoT will be challenging in the network. Because the 6G architecture is based on IoT and AI, affordable, reliable, and advanced energy sources are essential for the successful implementation of the 6G Network. So, the usage of renewable energy sources in the 6G network can be a great initiative for the network to make it effective.
- **Management of spectrum resources and interference**-To manage 6G spectrum and interference is not a simple task to do and it also necessitates efficient spectrum management policies and solutions. Researchers must focus on the issue that how to share and manage the spectrum in the heterogenous architecture and also on interference cancellation techniques [68]. Submillimeter (THz) wave frequencies-mm waves have propagation characteristics, and these are dependent upon the atmospheric situation. Because atmospheric conditions are alterable and thus unexpected, channel mathematical modeling for this band would be immensely complicated, and this band doesn't suit perfect channel modeling [18].

Conclusion

In the current scenario, the SDGs set by the united nations need to be achieved by 2030 for a better future with sustainability in terms of environmental, social, and economic. Industry 4.0 technologies can meet sustainability, along with the integration of 6G communication, and also it strengthens the infrastructure with innovation. Based upon the above facts, this study presents an attempt to present the study of the 6G Network which leads to the advancements in industry 4.0. Followed by this, the study discussed the potential requirements, vision, and fundamental technologies of 6G and also discussed the enabling technologies for 6G communication such as IoT, edge AI, big data, UAV, blockchain, and digital twin. Finally, the article presents the future directions and challenges present in 6G communication with an inclination towards industry 4.0. The recommendations for future directions are 6G for LEO communication, 6G for data center operations for 6G network nodes, an amalgamation of blockchain and AI with 6G for AR/VR applications, and a future 6G network with aerial computing. Ultra-high data rate, and 6G network work on 3D networking phenomena are the future directions, and the complex and heterogeneous hardware and management of spectrum resources and interference are the challenges identified in the analysis. The novelty of the study is discussed based on comparison analysis, as there have been few studies that have focused on the concept of industry 4.0 and sustainability with 6G communication. This is the first attempt to combine and discuss the sustainability aspect, fundamental technologies, and vision of the 6G network with Industry 4.0. The recommendations and challenges presented in the study motivate the researchers to carry out the study for future research in implementing 6G communication for achieving sustainability with industry 4.0.

CRediT authorship contribution statement

Yamini Ghildiyal: Conceptualization, Methodology, Software. **Rajesh Singh:** Conceptualization, Methodology, Software. **Ahmed Alkhayyat:** Software, Validation. **Anita Gehlot:** Data curation, Writing – original draft. **Praveen Malik:** Data curation, Writing – original draft, Visualization, Investigation. **Rohit Sharma:** Data curation, Writing – original draft, Visualization, Investigation, Writing – review & editing. **Shaik Vaseem Akram:** . **Lulwah M. Alkwai:** Software, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

[1] Matinmikko-Blue, Marja, et al. "White paper on 6G drivers and the UN SDGs." *arXiv preprint arXiv:2004.14695* (2020).
[2] De Vriendt J, et al. Mobile network evolution: a revolution on the move. IEEE Commun Mag 2002;40(4):104–11.
[3] Astély D, et al. LTE: the evolution of mobile broadband. IEEE Commun Mag 2009; 47(4):44–51.
[4] Akyildiz IF, Gutierrez-Estevez DM, Reyes EC. The evolution to 4G cellular systems: LTE-advanced. Phys Commun 2010;3(4):217–44.
[5] Gupta A, Jha RK. A survey of 5G network: Architecture and emerging technologies. IEEE Access 2015;3:1206–32.
[6] Morgado A, et al. A survey of 5G technologies: regulatory, standardization and industrial perspectives. Digital Commun Networks 2018;4(2):87–97.
[7] Hammoodi A, et al. New 5G Kaiser-based windowing to reduce out of band emission. Comput, Mater Continua 2021;71(2):2721–38.
[8] Siriwardhana Y, et al. The role of 5G for digital healthcare against COVID-19 pandemic: Opportunities and challenges. ICT Express 2021;7(2):244–52.
[9] Saad W, Bennis M, Chen M. A vision of 6G wireless systems: Applications, trends, technologies, and open research problems. IEEE Netw 2019;34(3):134–42.
[10] Gui G, et al. 6G: Opening new horizons for integration of comfort, security, and intelligence. IEEE Wirel Commun 2020;27(5):126–32.
[11] Akhtar MW, Hassan SA, Ghaffar R, et al. The shift to 6G communications: vision and requirements. Hum Cent Comput Inf Sci 2020;10:53. https://doi.org/10.1186/s13673-020-00258-2.
[12] Lasi H, Fettke P, Kemper HG, Feld T, Hoffmann M. Industry 4.0. Bus Inf Syst Eng 2014;6(4):239–42.
[13] Ghobakhloo M. Industry 4.0, digitization, and opportunities for sustainability. J Clean Prod 2020;252:119869.
[14] Dalenogare LS, Benitez GB, Ayala NF, Frank AG. The expected contribution of Industry 4.0 technologies for industrial performance. Int J Prod Econ 2018;204: 383–94.
[15] Akpakwu GA, Silva BJ, Hancke GP, Abu-Mahfouz AM. A survey on 5G networks for the Internet of Things: communication technologies and challenges. IEEE Access 2017;6:3619–47.
[16] Zeb S, Mahmood A, Hassan SA, Piran MJ, Gidlund M, Guizani M. Industrial digital twins at the nexus of nextG wireless networks and computational intelligence: A survey. J Netw Comput Appl 2022:103309.
[17] Dogra A, Jha RK, Jain S. A survey on beyond 5G network with the advent of 6G: Architecture and emerging technologies. IEEE Access 2020;9:67512–47.
[18] Jiang W, Han B, Habibi MA, Schotten HD. The Road Towards 6G: A comprehensive survey. IEEE Open J Commun Soc 2021;2:334–66. https://doi.org/10.1109/OJCOMS.2021.3057679.
[19] Vaidya S, Ambad P, Bhosle S. Industry 4.0–a glimpse. Procedia Manuf 2018;20: 233–8.
[20] Lee J, Bagheri B, Kao H-A. A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manufacturing letters 2015;3:18–23.
[21] Lasi H, et al. Industry 4.0. Bus Inf Syst Eng 2014;6(4):239–42.
[22] Wollschlaeger M, Sauter T, Jasperneite J. The future of industrial communication: Automation networks in the era of the internet of things and industry 4.0. IEEE Ind Electron Mag 2017;11(1):17–27.
[23] Jiang W, et al. "The road towards 6G: A comprehensive survey." *IEEE Open Journal of the*. Commun Soc 2021;2:334–66.
[24] Jiang, Dajie, and Guangyi Liu. "An overview of 5G requirements." *5G Mobile Communications* (2017): 3-26.
[25] Letaief KB, et al. The roadmap to 6G: AI empowered wireless networks. IEEE Commun Mag 2019;57(8):84–90.
[26] Rappaport TS, et al. Wireless communications and applications above 100 GHz: Opportunities and challenges for 6G and beyond. IEEE Access 2019;7:78729–57.
[27] Alsharif MH, et al. Sixth generation (6G) wireless networks: Vision, research activities, challenges and potential solutions. Symmetry 2020;12(4):676.
[28] Giordani M, et al. Toward 6G networks: Use cases and technologies. IEEE Commun Mag 2020;58(3):55–61.
[29] Ali S, et al. New Trends and Advancement in Next Generation Mobile Wireless Communication (6G): A Survey. Wirel Commun Mob Comput 2021 (2021)..
[30] Saeed N, et al. "Point-to-point communication in integrated satellite-aerial 6G networks: State-of-the-art and future challenges." *IEEE Open Journal of the*. Commun Soc 2021.
[31] Dang S, et al. "What should 6G be?." *Nature*. Electronics 2020;3(1):20–9.
[32] De Alwis C, et al. Survey on 6G frontiers: Trends, applications, requirements, technologies and future research. IEEE Open J Commun Soc 2021;2:836–86.
[33] Song H-J, Nagatsuma T. Present and future of terahertz communications. IEEE Trans Terahertz Sci Technol 2011;1(1):256–63.
[34] Han C, et al. Terahertz communications (TeraCom): Challenges and impact on 6G wireless systems. arXiv preprint arXiv:1912.06040. 2019.
[35] Haas H, Elmirghani J, White I. Optical wireless communication. Phil Trans R Soc A 2020;378(2169):20200051.
[36] Kong L, et al. Autonomous relay for millimeter-wave wireless communications. IEEE J Sel Areas Commun 2017;35(9):2127–36.
[37] Baker RJ. CMOS: circuit design, layout, and simulation. John Wiley & Sons 2019.
[38] Lu L, et al. An overview of massive MIMO: Benefits and challenges. *IEEE J Selected Topics Signal Process* 2014;8(5):742–58.
[39] Da X, He LW, Li S. Internet of things in industries: A survey. IEEE Trans Ind Inf 2014;10(4):2233–43.
[40] Osseiran, Afif, et al. "Internet of things." IEEE Communications Standards Magazine 1.2 (2017): 84-84.
[41] Nguyen DC, et al. 6G Internet of Things: A comprehensive survey. IEEE Internet Things J 2021.
[42] Palattella, Maria Rita, et al. Internet of things in the 5G era: Enablers, architecture, and business models. *IEEE journal on selected areas in communications* 34.3 (2016): 510-527.
[43] Sagiroglu S, Sinanc D. Big data: A review. 2013 international conference on collaboration technologies and systems (CTS). 2013.
[44] Stergiou CL, Psannis KE, Gupta BB. IoT-based big data secure management in the fog over a 6G wireless network. IEEE Internet Things J 2020;8(7):5164–71.
[45] Yang P, et al. 6G wireless communications: Vision and potential techniques. IEEE Netw 2019;33(4):70–5.
[46] Zhang S, Zhu D. Towards artificial intelligence enabled 6G: State of the art, challenges, and opportunities. Comput Netw 2020;183:107556.
[47] Lovén L, et al. EdgeAI: A vision for distributed, edge-native artificial intelligence in future 6G networks. In: The 1st 6G wireless summit; 2019. p. 1–2.
[48] Khan WZ, et al. Edge computing: A survey. Futur Gener Comput Syst 2019;97: 219–35.
[49] Yang X, et al. Energy efficiency based joint computation offloading and resource allocation in multi-access MEC systems. IEEE Access 2019;7:117054–62.
[50] Blanco B, et al. Technology pillars in the architecture of future 5G mobile networks: NFV, MEC and SDN. Computer Standards & Interfaces 2017;54:216–28.
[51] Zheng, Zibin, et al. "Blockchain challenges and opportunities: A survey." *International journal of web and grid services* 14.4 (2018): 352-375.
[52] Aste T, Tasca P, Di Matteo T. Blockchain technologies. The foreseeable impact on society and industry. 2017.
[53] Poongodi M, et al. 5G based Blockchain network for authentic and ethical keyword search engine. IET Commun 2022;16(5):442–8.
[54] Nguyen DC, et al. Blockchain for 5G and beyond networks: A state of the art survey. J Netw Comput Appl 2020;166:102693.
[55] Maksymyuk T, et al. Blockchain-empowered framework for decentralized network management in 6G. IEEE Commun Mag 2020;58(9):86–92.
[56] Gupta L, Jain R, Vaszkun G. Survey of important issues in UAV communication networks. IEEE Commun Surv Tutorials 2015;18(2):1123–52.
[57] Zeng Y, Zhang R, Lim TJ. Wireless communications with unmanned aerial vehicles: Opportunities and challenges. IEEE Commun Mag 2016;54(5):36–42.
[58] Dao N-N, et al. Survey on aerial radio access networks: Toward a comprehensive 6G access infrastructure. IEEE Commun Surv Tutorials 2021;23(2):1193–225.
[59] Li B, Fei Z, Zhang Y. UAV communications for 5G and beyond: Recent advances and future trends. IEEE Internet Things J 2018;6(2):2241–63.
[60] Boschert S, Rosen R. Digital twin—the simulation aspect. Mechatronic futures. Springer: Cham; 2016. p. 59–74.
[61] R. Minerva, G. M. Lee and N. Crespi, "Digital Twin in the IoT Context: A Survey on Technical Features, Scenarios, and Architectural Models," in Proceedings of the

IEEE, vol. 108, no. 10, pp. 1785-1824, Oct. 2020, doi: 10.1109/JPROC.2020.2998530.

[62] Khan LU, et al. Digital-twin-enabled 6G: Vision, architectural trends, and future directions. IEEE Commun Mag 2022;60(1):74–80.

[63] Akyildiz IF, Kak A, Nie S. 6G and beyond: The future of wireless communications systems. IEEE Access 2020;8:133995–4030.

[64] Lin X, Cioni S, Charbit G, Chuberre N, Hellsten S, Boutillon JF. On the path to 6G: embracing the next wave of low Earth orbit satellite access. IEEE Commun Mag 2021;59(12):36–42.

[65] Bhattacharya P, Saraswat D, Dave A, Acharya M, Tanwar S, Sharma G, et al. Coalition of 6G and blockchain in AR/VR space: challenges and future directions. IEEE Access 2021;9:168455–84.

[66] Pham QV, Ruby R, Fang F, Nguyen DC, Yang Z, Le M, et al. Aerial computing: A new computing paradigm, applications, and challenges. IEEE Internet Things J 2022;9(11):8339–63.

[67] Chen S, Liang YC, Sun S, Kang S, Cheng W, Peng M. Vision, requirements, and technology trend of 6G: How to tackle the challenges of system coverage, capacity, user data-rate and movement speed. IEEE Wirel Commun 2020;27(2):218–28.

[68] Gui G, Liu M, Tang F, Kato N, Adachi F. 6G: Opening new horizons for integration of comfort, security, and intelligence. IEEE Wirel Commun 2020;27(5):126–32.

[69] Mahdi MN, Ahmad AR, Qassim QS, Natiq H, Subhi MA, Mahmoud M. From 5G to 6G technology: meets energy, internet-of-things and machine learning: A survey. Appl Sci 2021;11:8117. https://doi.org/10.3390/app11178117.