What You Should Know About Next Generation 6G Mobile Technology

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Sarmad Ahmed Shaikh[1(✉)], Muneer Ahmed Shaikh[1], Ruqiya[1], Muhammad Arshad Khan[1], Kamlesh Kumar Khatri[1], Asif Ali Wagan[1], Fatima Zohra Shaikh[2]
[1] Department of Computer Science, Sindh Madressatul Islam University, Karachi, Pakistan
[2] Sindh Government Dispensary Bilawal Shah Noorani, District East Karachi, Pakistan
sarmad@smiu.edu.pk

Abstract—The fifth generation (5G) mobile communication technology though, is being deployed in various parts of the world to improve the wireless systems in terms of infrastructure and quality of services, in view of mobile communication history, the 5G may be unable to handle the deluge mobile network traffic of the future digital society. In general, new wireless technologies are introduced every 10 years, and services mature every 20 years, and therefore sixth generation (6G) mobile communication technologies, which have a great potential to impact on the market, are expected to be commercialized around 2030. In order to secure technological leadership in mobile communication, which is an essential infrastructure for everyday life and industrial sites, advanced countries around the world have begun to develop 6G technology. The expected main features of the 6G technology include: providing 10 to 100 times more performance than 5G, maximizing performance by utilizing the terahertz band which was not utilized by existing communication networks before, use artificial intelligence techniques for smart networking, and combining the previously isolated technologies. This paper provides an overview on the profile, advancements, implications, architecture, expected applications, and challenges of the futuristic 6G wireless communication systems described by innovative researchers and major global organizations.

Keywords—6G, mobile communication, intelligent systems, next generation networks, artificial intelligence, terahertz communication

1 Introduction

The rollout of the fifth generation (5G) wireless technology has already commenced in many parts of the world to further advance the mobile communication systems. However, given the demand for automation and ever increasing need of bandwidth, the existing capacity is anticipated to run out by 2030. It looks like that 5G mobile communication would not fully satisfy the increasingly growth of technological requirements [1]. Thus many researchers have already started working on the sixth generation (6G) technology which is expected to revolutionize the digital world [2]. Several countries are actively developing 6G network techniques including the

United States, Japan, China, France and Finland. A study in [3], shows that rise of advanced applications in 2030 will require fully intelligent network which might be realized by 6G. We are moving towards completely internet based automated society along with smart machines. 6G is expected to provide canvas over which complex procedures and interfaces would operate with the least human interface. Some of the key technologies that could make 6G possible are the use of the Terahertz (THz) frequency spectrum in communications, new smart antenna technologies to improve the coverage of high frequency signals, advanced duplexing technologies, evolution of network topology, the usage of artificial intelligence (AI) and big data techniques in spectrum sharing to make the use of frequencies more efficient [4], machine learning and virtual reality tools usage for system capacity improvements [5], massive devices connectivity, and efficient data security schemes. The other associated technologies are smart wearable devices, medical implants, self-driven vehicles and drones. It is estimated that the 6G system driven wireless connectivity would be upto 100 times more efficient than 5G [6]. All this would lead to smart society with environment monitoring, protection, disaster mitigation and management. Moreover, self-driven vehicles will be supported by advanced technologies such as audio-visual sensors radar, and global positioning system (GPS). Similarly, 6G enabled unmanned aerial vehicles (UAVs) will be commonly exploited on high scale in numerous fields including to support military reconnaissance, smart agricultural activities monitoring and operations, and location based services i.e., parcels deliveries. In addition to this, the AI enabled 6G networks would intelligently control the processes of the machines ever done throughout 1G to 5G.

It is predicted that in 2024 the mobile networks traffic will be three times greater than the traffic in 2017 due to a significant increment in smart mobile phones, tablets, internet-of-things (IoT) networks, and big data based internet contents i.e., Facebook, YouTube, Netflix, etc [7]. To tackle this massive traffic issue, currently 5G mobile communication technology is being expanded all around the globe. The 5G technology, in general, contains three typical application scenarios which include enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable low-latency communications (URLLC) [8]. Furthermore, scientists from all around the world are working to suggest innovative solutions to various aspects of the 6G technology. As shown in Figure 1, the vision of 6G includes global coverage by enhancing the performance and capabilities of the technologies, for instance, unmanned vehicle (UAV), terrestrial communication, satellite, maritime, and deep space; utilization of available frequency (f) spectra consisting of Sub-6 GHz where $f <$ 6 GHz, millimeter wavelength (λ) where $f >$24 GHz and $f <$ 300 GHz, and optical/Terahertz (THz) where $f >$ 1 THz [9]; strong security on network as well as physical layers including cyber security and network authentication techniques; and wide range of applications i.e., AI, machine learning, and Big data.

The article is further structured as follows. The comparison between 5G and 6G technologies is provided in Section 2. Section 3 describes the 6G architecture and its key performance requirements in detail. The main applications and research challenges are highlighted in Section 4 and Section 5, respectively. Finally, we conclude the article in Section 6.

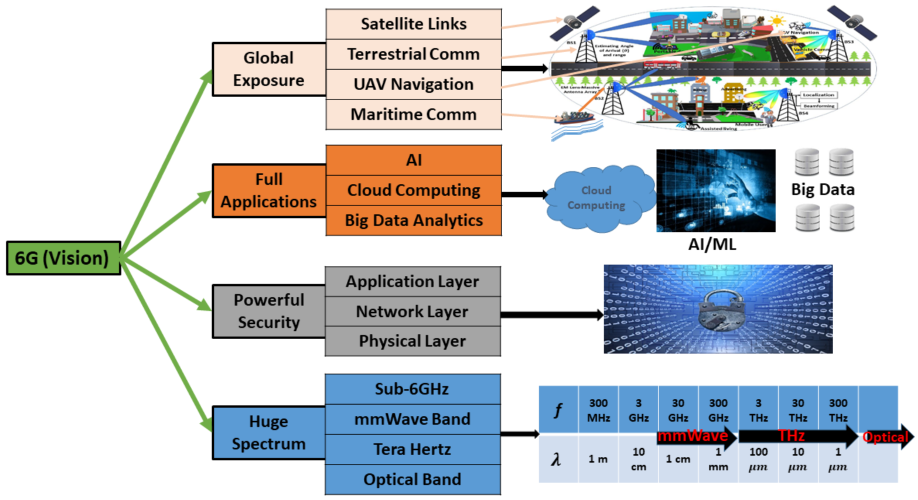

Fig. 1. An overview of the vision of the 6G wireless communication networks

2 Comparison between 5G and 6G technologies

The comparison between the 5G and the 6G technologies can be made by various ways such as summarized in Table 1. However, below we describe the main features of both technologies for the sack of understanding.

Frequency spectrum: Up to 4G technology, most types of wireless communications took place in the sub-6 GHz range and the spectrum was distributed to television (TV) services, military communications, and cellular communication [10, 11]. In 5G, the frequencies 26 GHz, 28 GHz, and 38 GHz, i.e. beyond the 6 GHz spectrum are first time used. On the other hand, in 6G, the terahertz frequencies, probably in band D (such as 0.11 THz to 0.17 THz), are expected to be used. In addition, 6G could also use millimeter (mmWave), THz band, and visible light communication (VLC), in parallel [11, 12, 13, 14]. The VLC is a promising optical communication approach for short-range communication that uses visible light ranging between 400 and 800 THz. However, both technologies 5G and 6G will uninterruptedly continue to use the frequencies under 6 GHz as well.

Data rate: While the 5G is expected to achieve a peak data rate of around 20 gigabits/second (Gbps), the 6G is intended to provide a peak data rate of more than 1 Tera bits per second (Tbps). There is also a significant difference between the data rate per user. In 5G, around 100 megabits/second (Mbps) is considered while in 6G around 1 Gbps is expected.

Latency: 5G is expected to have a latency of around 1 millisecond and higher. In contrast to this, 6G would reach far less than a millisecond (ms), probably 100 microseconds (μs). Applications including holographic communication, virtual, augmented, and mixed reality, as well as remote medical diagnosis and surgery, require exceptionally low latency [15]. In these applications, the network must offer very high reliability, low latency and extremely high data rates at the same time [16, 17, 18]. In contrast to 5G, 6G technology aims to fulfill all of these necessities at the same time.

Table 1. Features comparison between 5G and 6G technologies

Feature	5G	6G
End-to-End latency	1 ms	10 µs
Peak data rate for each device	10-20 Gbps	1 Tbps
User Data rate	100 Mbps	> 1 Gbps
Spectral efficiency	30 bps/Hz	100 bps/Hz
Energy efficiency	NA	1Tb per J
Mobility	500 km/hr	> 1000 km/hr
Maximum Frequency	90 GHz	10 THz
Channel bandwidth	1GHz	100 GHz
Coverage	70%	99%
Receiver capacity	-120 dBm	-130 dBm
Autonomous Vehicle	Limited	Yes
Services Level	3D VR, AR	Tactile
Architecture	Massive MIMO	Intelligent Surface
Satellite connectivity	No	Yes
THz communication	Very Limited	Widely
Core network	IoT	IoE
Multiplexing	OFDMA	Smart OFDMA + IM

There are still no complete solutions reported in the literature for 6G today. The actual layout of 6G depends on how 5G evolves, and where and how its shortcomings are. However, the following characteristics are believed to be included in 6G enabled systems [1, 2] which might not be available in 5G.

- Data, Computing, & Intelligence
  - Smart AI/ML techniques
  - Computation using Quantum
  - Big Data
- Spectrum Extension & Management
  - VLC
  - mmWave bands
  - sub-THz and THz bands
  - Full-Duplex and NOMA techniques
  - Dynamic sharing and allocation of spectrum
- Cell-Free or Tiny-Cells
  - Distributed Systems and networks
  - UAVs-assisted communications

Although above features have been lined-up to be realized in 6G enabled systems, the research is in progress to solve its fundamental challenges. In order to have a viable and efficient 6G technology enabled systems, new and improved techniques will have to be used such as described as follows.

2.1 Terahertz (THz) frequency bands

One area that is envisioned to be a vital component of 6G is the utilization of optical frequency spectrum i.e., THz, in mobile communications. Using these extremely high frequencies, huge bandwidth and data rates will be readily available [19]. The range of THz frequency described by IEEE and the ITU is between in range of 300 GHz to 3 THz. However, research literature and industry discussions often consider anything beyond 100 GHz to be THz band. The term "sub-terahertz" is also used to designate the range between 100-300 GHz.

2.2 Millimeter Wave (mmWave) technologies

The use of much higher frequencies always opens up more spectrums and also allows for many wideband channels. Although millimeter-wave (mmWave) technologies are primarily thought of for 5G communication, they are being further developed due to the enormous data rates and bandwidth required for 6G. The frequency spectrum between 30 and 300 GHz falls under the mmWave technology. Occupied between microwave and infrared waves, this band can provide high-speed wireless communications as seen with the latest 802.11ad Wi-Fi standard (operating at 60 GHz).

2.3 Dense networks and duplex methods

Many active researchers [20, 21] propose methods to improve the downlink and uplink time-frequency resources, as depicted in Figure 2. Presently, wireless systems use either frequency division duplex (FDD) or time division duplex (TDD). In addition to the Flexible duplex for 5G, other options have been proposed for 6G, such as Fully Flexible duplex or Free duplex, where the time or frequencies allotted change depending on the demand, or a new system known as single-channel full-duplex or split-duplex [22, 23].

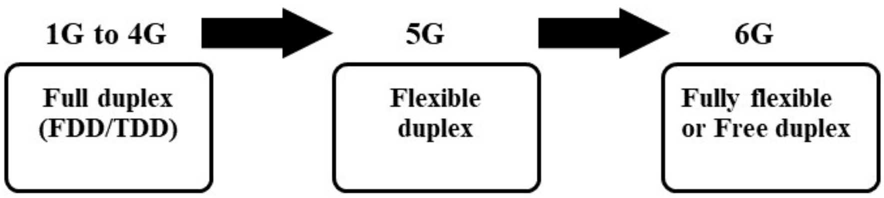

Fig. 2. Advancement in duplex mode of wireless communication

2.4 Spectrum sharing

6G technology intends to provide the spectrum for multiple entities i.e., the Citizens Broadband Radio Service (CBRS) band (3.55-3.7 GHz) [24]. Alliance has been developed, the so-called Coexistence Manager (CxM), between spectrum access systems (SAS) and general authorized access (GAA) to support the sharing of the spectrum between GAA users in a semi static fashion for the permissible spectrum highlighted in [25]. To enhance the spectrum sharing opportunity in this situation, one can prefer dynamic spectrum sharing rather than a semi-static method based on the database. The challenge of dynamic spectrum sharing is to avoid/minimize the overlapping of spectrum usage among different entities while permitting to access the spectrum in a dynamic manner [26].

3 6G architecture

It is expected that after 2030, explosive growth of wireless data traffic due to real-time and interactive applications, 5G will not be able to compete with the existing architecture. The 6G is supposed to fill up this gap. 6G networks need to support quality of service to massive data obtained from connected smart devices and interactive applications. This requires to have an intelligent architecture to support the quality of service. The authors in [27] have proposed an artificial intelligent (AI) based architecture for 6G networks that uses data mining, smart controlling, and automatic configuring. The proposed architecture is based on four layers such as Smart application layer, Intelligent sensing layer, Data mining & analytics layer, and Intelligent control layer.

6G communication network must have higher AI characteristics, not fully but integrated with AI networking features. Most of the researchers believe that this is as an "AI-empowered" communication network with privacy, security, and risk mitigation attributes [28]. Such autonomous network uses AI algorithms i.e. convolutional neural networks (CNNs) for signal classification and channel decoding, deep neural networks (DNNs) for signal detection and channel estimation, supervised/transfer algorithm for frame flow related operations, and K-means algorithm for mobility/load/route management [29]. Additionally, to make communication, data caching and computing converge efficiently, and data caching and computing functions in different entities, the fog-computing based radio access network architecture has been proposed. In the meantime, the intent based radio access network has been introduced to make the flexible and simple architecture through software definition and re-configuration for the ubiquitous intelligent mobile society with economical cost. Two other architectures have been also presented in [30] which include de-cellular network architecture and user-centric ultra-dense networks (UUDN). The de-cellular and UUDN architectures seem to be fit for the higher frequency bands i.e., mmWave, THz, and visible light band.

4 Applications

4.1 Extended reality

In various devices, extended reality or XR to include virtual augmented and mixed reality, would be made available commercially. It will essentially be a computer generated reality experience. It will provide a 3rd experience without time and location constraints using uHLSLLC [31].

4.2 Connected robotics and autonomous systems

Our everyday lives can change drastically with an autonomous vehicle based on 6G wireless connectivity. The 6G framework has a significant potential to facilitate the actual introduction of self-driving vehicles based on different sensors. UAV air craft will use 6G wireless networks more frequently. Moreover, UAV will be used as base station in its absence [32].

4.3 Smart healthcare communication

In the futuristic health care sector, remote surgeries will be possible using robots and AI. The 6G high-data-rate, low latency, ultra-reliable (zero-error) network can help to easily and efficiently transmit big amounts of medical data and improve the quality of care. The functionality of uHLSLLC and uMTC will help the real deployment for such smart health care centers [33].

4.4 Automation and manufacturing

The term “automation” refers to the automatic machine control in manufacturing the goods in industries. In this regard, the 6G services of uHDD and uHLSLLC and uMTC will help in industrial automation which will definitely efficient in terms of productivity and cost [34].

4.5 Five senses information transfer

6G communication networks would be capable of transferring the data collected from the five senses remotely. Smart phones are the main devices in 4G and 5G networks. However, in recent years there has been an increase in the number of wearable devices, whose functions are gradually replacing those of smart phones. Devices associated with these applications range from smart wearable to integrated headsets and smart implants, whose sensors can receive direct signals from human senses [35].

4.6 Internet of Everything (IoE)

IoE will have full 6G support. Every internet device will be connected to the network from living to non-living objects such as drones, vehicles, home appliances, smart sensors, robots, and industrial machines. In a study [36], it is predicted that world will have huge number of connected devices by 2030 about 59 times more than the world population. It is said that 2010 was age of mobile applications, 2020 is age of IoT and after 2030 the age will be of AI augmented IoE [25, 35].

4.7 Holographic teleportation

With unprecedented speed in high-resolution rendering, wearable displays and wireless networking, mobile devices will be able to provide multimedia rendering to display a 3D hologram using 6G networks. Hologram is a new generation media technology that can represent gestures and facial expressions using a holographic display. In order to ensure that the hologram is displayed as part of real-time services, high data rates, hundreds of times faster than the current 5G system, are essential.

5 Challenges and opportunities

Some open challenges and opportunities for 6G are described as follows.

Integrating AI in Wireless: AI technology brings multifold research directions for intelligent 6G wireless systems. To operate the 6G wireless systems efficiently and reliably, and deliver the applications listed above, there is need for massive, small data analytics as well as using the machine learning (ML) and AI-based SSNs (i.e., reinforcement learning) algorithms [27].

Networking: It is a serious requirement to create a network of networks in which several resources are combined into a diverse digital ecosystem. The integration of ground and airborne networks demand that 6G must support the communications in 3D space including deploying 3D base stations (i.e., temporary UAVs/drones or tethered balloons) [35]. This requires to conduct the research in multiple angles including new methods for 3D frequency and network resources planning, proper network optimization for resource management, mobility tracking and routing, as well as modeling of the 3D propagation environment.

Combining different physical interfaces: Integrating different physical nature RF and non-RF interfaces is also a significant research gap. This provides an opportunity to conduct the research on designing the joint RF and non-RF hardware, analysis on system level of joint RF and non-RF devices, and application of these RF and non-RF systems in 6G services.

Reducing hardware and computational complexity: Due to usage of THz frequencies in 6G communication systems and massive antenna arrays at RF front-end, the cost of hardware and software will be dramatically increased. It requires to conduct a serious research to provide intelligent techniques to reduce these types of complexities such as those mentioned in [36, 37, 38, 39].

6 Conclusion

In this paper, we have outlined the features of 6G mobile communication technology, its applications and research challenges. Though 5G technology is under implementation in many countries, the researchers have started working on the 6G technology which will use further higher frequency bands i.e., THz, to provide further higher data rates, more capacity, and intelligently handled network of many networks including internet of everything and many more. It will incorporate state-of-the-art AI technology to make the mobile communication more efficient, robust and reliable than before. Furthermore, in this paper, we have discussed the major differences between 5G and 6G technologies, and hence found out many reasons and research gaps of 5G which can be addressed well by 6G technology. A few 6G architectures are suggested in the literature i.e., AI-enabled 6G architecture based on 4 layers (Data mining & analytics layer, Smart application layer, Intelligent sensing layer, and Intelligent control layer), and optimized functional safety architecture. Moreover, we have identified various applications of 6G such as extended reality, connected robotics and autonomous systems, smart healthcare and education communication, automation and manufacturing, IoE, and Holographic. Additionally, the main open challenges reported in the literature include integration of AI technology in wireless systems, making networking of many massive networks, integrating different physical nature RF/non-RF interfaces, and reducing hardware/computational complexity. Once the proposed 6G architectures and the open challenges are successfully addressed, the 6G mobile communication technology will significantly revolutionize the way of communications ever possible with the existing technologies.

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9 Authors

Dr. Sarmad Ahmed Shaikh was born in Pakistan. He received the Ph.D. degree in Information Technology from the University of Klagenfurt, Klagenfurt, Austria, in 2018. He is currently an Assistant Professor with the Faculty of Information Technology, Sindh Madressatul Islam University (SMIU), Karachi, Pakistan. His research interests include RF/microwave engineering, radio source localization, antenna arrays designing, and wireless sensor networking (IoT) & artificial intelligence.

Muneer Ahmed Shaikh was born in Pakistan. He received the Bachelors Degree in Computer Systems Engineering from Mehran University of Engineering & Technology Jamshoro, Pakistan, in 1994, the M.E. degree in Computer Systems Engineering from NED University, Karachi, Pakistan, in 2010, and the Ph.D. degree (Continued) in Computer Science from SMI University Karachi Pakistan. He is currently an Assistant Professor in Computer Science, College Education Department, Government of Sindh, Karachi, Pakistan. His research interests include RF/microwave engineering, radio source localization, antenna arrays designing, and wireless sensor networking (IoT) & artificial intelligence.

Ruqiya is doing Ph.D. in computer science from Sindh Madressatul Islam University, Karachi, Pakistan. She received her MS Computer Science degree in 2021 from Sindh Madressatul Islam University, Karachi. Her research interests include machine learning, deep learning, AI, Operating system, and wireless Technology.

Muhammad Arshad Khan received MS Computer Science degree in 2021 from Sindh Madressatul Islam University, Karachi, Pakistan. Between 2000 and 2006, he taught at Pakistan Steel Cadet College as a lecturer. Then, he joined a polytechnic institute in Karachi, as an Assistant Professor, in 2006. His research interests include data mining, sensor network, and the Internet of Things.

Dr. Kamlesh Khatri was born in Pakistan. He obtained his Bachelors Degree in Computer Science from Shah Abdul Latif University, Khairpur, Pakistan, in 2006, the Master's Degree in Computer Science from SALU Khairpur, Pakistan, in 2010, and the PhD Degree in Computer Science & Technology from UESTC China in 2016. He is currently serving at Sindh Madressatul Islam University, Karachi, Pakistan, as an Assistant Professor in the Department of Software Engineering. His research interests include Image Processing, Computer Vision, Machine Learning, Knowledge Discovery and Data Mining, and Content Based Image Retrieval System.

Dr. Asif Ai Wagan has earned his PhD in Information Technology from University Technology PETRONAS, Malaysia. Dr. Wagan has more than 10 years of professional experience in teaching and research. Dr. Wagan has experience of working with Hitachi, Japan and Realityone Sensor, Singapore. He is author of 18 international journals/conferences articles. His research interest includes wireless communication, network security, software-defined networking, big data, and data mining.

Dr. Fatima Zohra was born in Pakistan. She received her MBBS degree from LUMHS Jamshoro, Pakistan in 2014. She did her training as a general physician at different tertiary care centers. Currently, she is working as a commissioned officer (WMO) in the health department of the Sindh Government, Pakistan. Her research interests include medicines.

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