Quantum Computing's Role in the Transition from 5G to 6G- it's Potential and Challenges

Dhriti Bhasin[1], Sudhakar Kumar[2], Karan[3] and Anamika Sharma[4]

[1,2,3,4]*Chandigarh College of Engineering and Technology, India*

Abstract

In the coming decade, techno-economic trends are likely to continue and even accelerate. The global economy will continue to be driven by innovation in the field of communication systems. With the deployment of some discrete Artificial Intelligence (AI) functions, 5G is expected to build the groundwork for intelligent networks which will allow for more efficient service management controls. This will be followed by 6G and smart networks and services being utilized at the end of the decade. Quantum Computing (QC), Artificial Intelligence (AI), and Quantum Machine Learning (QML), as well as their union with communication networks, might be considered fundamental in enabling smart systems. This paper briefly addresses topics such as the rise of quantum computing, what is meant by 5G and 6G communications and the advantages of 6G networks over 5G networks. The paper also provides a quick overview of the role of quantum computing in 5G and 6G communication systems, the capabilities of these technologies and the various challenges that can be expected while implementing them. Quantum computing in 6G communication seems to be very promising from the very beginning and is commonly being regarded as the future of wireless communication.

Keywords

Quantum Computing, Quantum Information Technology, 5G, 6G Communication Systems, Wireless Networks, Quantum Communications.

1. Introduction

In the last several years, quantum technology rollout has accelerated at an unparalleled rate [1]. Added to this, the implementation of low-latency and ultra-broadband network infrastructures such as 5G networks has led to a global digitization of various fields [3]. However, only Beyond-5G (B5G) networks will be able to provide completely intelligent network orchestration in order to provide revolutionary services [4]. Thus, 5G exhibits many fascinating capabilities but 6G will be needed in the coming time for providing novel telecommunication services with high productivity. Researchers and tech enthusiasts are thus working profoundly in laying the foundation for 6G networks. Quantum Computing will play a major role in this transition from 5G to 6G communications systems, consequently paving way for smart systems and advanced computing.

1.1. The Rise of Quantum Computing

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EMAIL: dhritibhasin11@gmail.com (A. 1); sudhakar@ccet.ac.in (A. 2); karan2301@outlook.com (A. 3); co20306@ccet.ac.in (A. 4)
ORCID: 0000-0001-9451-3023 (A. 1); 0000-0001-7928-4234 (A. 2); 0000-0003-0271-1845 (A. 3); 0000-0002-3989-2224 (A. 4)

Until recently, quantum computing was thought to be purely theoretical. It is now expected to assist us in overcoming some of humanity's most daunting problems, moving us forward into the future. Quantum Information Technology (QIT) and other disruptive information and communication technologies (ICT) have emerged as crucial facilitators and catalysts for a variety of new paradigms from numerous key viewpoints, including computing, communication, security, and intelligence [6,37]. Quantum computers are rapidly approaching the stage where they will be able to outperform regular computers in terms of size and dependability. Quantum computing is thought to have the potential to change the landscapes of artificial intelligence and data analytics. It will be especially critical in today's Big Data era, which necessitates the processing of massive volumes of data collected on a daily basis [9].

Quantum computing is based on quantum physics' ideas of superposition, entanglement, and quantum interference. Quantum computers are immensely powerful when compared to ordinary computers because they apply these concepts to computing in ways that allow them to handle some extremely difficult tasks. Qubits (quantum bits) are the primary unit of information in quantum computing, much as bits (classical bits) are in classical computing. A qubit can have a value of 0, 1, or a quantum superposition of 0 and 1. A classical bit or a binary digit can have only one of the two values i.e., 0 or 1 [10].

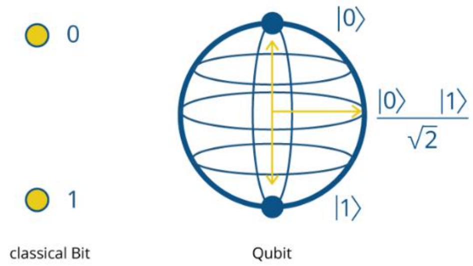

Figure 1: A classical bit Vs a Quantum bit (Qubit) [12]

Quantum computers exploit these benefits of quantum parallelism, which enables exponentially faster processing than classical computing and, in some cases, quantum supremacy such as in some optimization problems. Quantum Processing Units will be the name for next-generation processor units that use quantum computing (QPUs). Google's Sycamore, for example, is a QPU [6].

2. Quantum Information Technology (QIT)

Quantum Information Technology (QIT) combines two important 20th-century breakthroughs, which are: quantum physics and information technology. Quantum mechanics is one of the most precise scientific theories which encapsulates the world at its most fundamental level. At the same time computers, digital communication, and other technologies owe their existence to information technology, which has changed the way we live. Quantum Information Technology will harness quantum physics' capacity to usher in a revolutionary new era of technology [13]. The theoretical groundwork and the building blocks for quantum communications, quantum computers, quantum sensing, and quantum metrology is laid by Quantum mechanics. Quantum Computing is the computing concept built upon the principles of quantum theory like superposition and entanglement. Instead of classical bits, qubits (quantum analogue of classical bits) are used for computing. These qubits reflect the behavior of material energy at different atomic and subatomic levels and can exist in more than one state (both "0" and "1" at the same time) [14]. Quantum Computing is based on 2 principles: Superposition and Entanglement. Entanglement, for example, may be used not just for quantum communications. It may also be used for quantum sensing and quantum computation. Furthermore, quantum communications and quantum computing may complement one another and be merged to transform the traditional internet into the quantum internet of the future [6]. Quantum Communications is the domain of QIT aims at efficient and secure transfer of information through quantum computing. It is based on the principles of quantum mechanics, quantum information processing and quantum teleportation. The quantum cryptographic model which is developed using all these principles helps in secure transmission of qubits between 2 different quantum servers. Quantum key distribution (QKD) is the most well-known application of quantum cryptography [15]. Quantum Sensing and Metrology is domain aims at eliminating or reducing all sorts of noise produced by quantum fluctuations by using the principles of quantum physics. It involves measurement of the magnitude and direction of tiny magnetic fields and interferometric measurements of phase shifts using atomic ensembles, trapped ions, solid-state atom like systems and cold atoms. It has been proposed that qubits used for sensing quantum components and energies on the basis of their quantum states will set the foundation of new hardware for sensing and metrology [16].

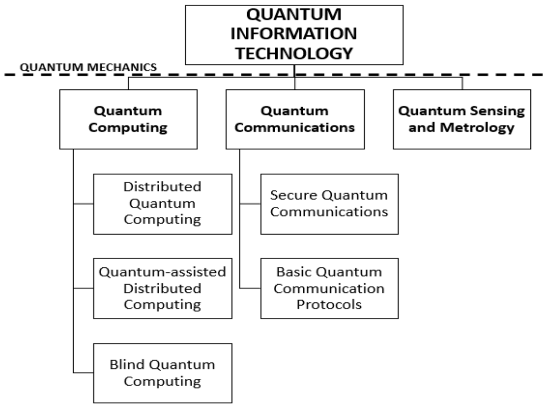

Figure 2: QIT Domains

When contrasted to our experience of the classical or ordinary world, the characteristics that make quantum physics so strange and amazing also drive its potentially transformative implications in IT. A quantum processing unit or a multi-qubit processor allows highly parallel quantum computing. Interference among all the amplitudes in such devices might theoretically be designed to offer solutions to those problems that even the most powerful traditional supercomputers would never be able to solve in the future. Using photon qubits and digital communications, two correspondents can communicate with assured security due to the irreversibility of quantum measurement [17].

3. 5G Communication

The short name for the fifth generation, which began in the late 2010s, is 5G technology. It is built on top of the Open Wireless Architecture (OWA) It also supports WWWW (Wireless World Wide Web). The 5G mobile data transfer rate can reach 10 Gbps. It has a 1 millisecond delay. It can link up to 100x the number of devices per unit area [20].

The 5G network's reduced latency will enable new applications that take advantage of 5G's power, the internet of things (IoT), and artificial intelligence. Increased capacity on 5G networks can help reduce the impact of demand spikes, such as those that occur during sporting events and breaking news stories [20].

4. 6G Communication

The sixth generation of wireless communications is referred to as 6G. It transmits data at higher frequencies, allowing for faster sampling rates in 6G. (To convert a continuous signal to a discrete signal, the number of measurements taken is called the sampling rate.). 6G data transfer rates are in the gigabytes per second range. As a result, the amount of data that can be transferred over 6G, also known as throughput, is far higher than it was with prior wireless communication technologies. Microsecond

latency of 6G wireless data allows communication between people to be instant and resulting in a distance of zero. A microsecond delay is 1000 times as fast as a millisecond transmission [11].
The following technologies were utilised to implement the 6d data network:

WCDMA Multiplexing (Wideband Code Division Multiple Access), UWB (Ultra White Band) Radio Technology, LTE (Long Term Evolution), 3GPP (3rd Generation Partnership Project), E-UMTS (Evolved Universal Mobile Telecommunication System), and E-EDGE (Evolved Evolutionary Data Rates for GSM (Global System for Mobile) [4].

6G cellular data is advantageous since it secures and protects mobile data. It also enables for buffer-free ultrafast streaming. 6G can also be used to play online games in real time. During gaming, 6G reduces lag significantly. 6G also aids in call forwarding to other numbers. It has smart batteries, increased storage capacity, and a high Mobile - TV resolution. 6G network technology necessitates a mobile device with a smart antenna, a high-capacity fibre optic network, and a huge internal memory [23].

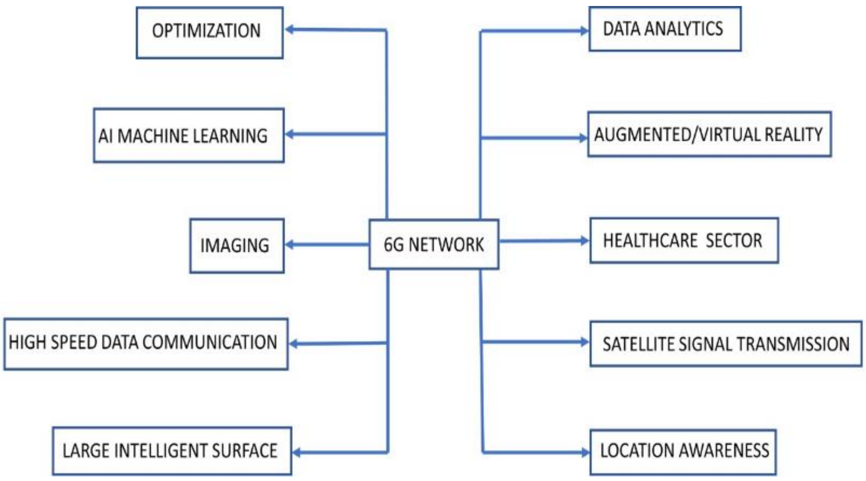

Figure 3: Applications of 6G network

5. Advantages of 6G over 5G

Despite being 50 times faster than 5G, having a 100-fold increase in reliability, having a wider coverage area, and handling 10 times as many devices per square kilometer as 5G, the 6G network provides greater reliability than 5G by more than 100 times. By facilitating augmented/virtual reality, data analytics, imaging, location awareness, and AI machine learning, the 6G network will transform the healthcare industry. The technology uses Terahertz waves. These waves are utilized in space to achieve lossless communication between satellites. In order to get the most out of LEDs, 6G wireless relies on visible light, such as high bandwidth and lighting. The 6G network was recommended in light of the critical advantages of 6G networks above 5G networks in terms of technological advancement [23].

6. Quantum Computing in 6G Communication Systems

In the future, the progressively demanding performance fulfillment of the deployment of new technologies like may finally be triggered by emerging networks from surfaces with very large intelligence, electron-orbital angular momentum, visible light communications and cell-free technology communication. The field of quantum communication has also been picking up steam in recent years and is likely to contribute substantially towards two of the essential criteria of 6G, as it enhances data security and reliability. The inherent security of quantum entanglement, which cannot be duplicated or accessed without tampering, suggests that it is suitable for systems that use 6G and beyond [24]. Quantum communication is not the answer to all security and privacy concerns, however [38]. Many works have demonstrated the feasibility of quantum key distribution (QKD) and associated protocols[32,34]. Another advantage of quantum communications is that they can be adapted to wide area communications. Even though quantum cryptography for quantum communication has advanced significantly over the past few years, long-distance quantum communication is still difficult due to the attenuation of fibers and operational errors. The current repeater concept, however, will not work for quantum communication since entanglement cannot be cloned.

7. Challenges Implementing 6G

1. Lack in Infrastructural design to meet expected scale:
   The use of 6G tends to be a very high use of computation prowess. 6G networks are multidimensional, high level, difficult, and reforming due to the network cluster, users desire, connection loads and the transmission of resources that are available. Thus, for wireless connection, automatic network configuration is crucial. Similarly, for motile node positioning in the event of a disaster, intelligent mobility management is crucial.
   These tasks, however, require a significant amount of computational power. In addition to edge computing, federated artificial intelligence, etc. 6G will be able to resolve those difficulties. There are still challenges involved with implementing these technologies. Problems exist both in the individual technologies and in the integration of 6G.
2. Lack at Instrumental level of technological requirements:
   For implementing 6G requirements, there is no real technological solution. Even though 6G offers reassuring advancements, its technical needs are miles behind which could bring it far beyond 5G. The essential for 6G mobile communications keep increasing exponentially from 5G. Because 6G doesn’t have any foundation tech, it casts doubt on the visioning process at this point[27]. Introduction of 5g has just been done recently. And the quality of experience of 5g is very limited to small areas.
3. Lack in means to achieve desired coverage:
   The 6G will require exceedingly effective and cost-efficient transmitter and receiver antennas. In order to achieve high integration, the needed radio frequency transceiver should use advanced silicon nodes, such as bulk CMOS and SiGe BiCMOS, and use carefully designed, highly effective antennas.[29] It is essential to find a new balance between RF technologies, communication, and signal processing in order to meet 6G's requirements.
4. Infrastructural designs for Terahertz communication:
   Continuous THz signals are required for 6G transmission. It is however more difficult to generate continuous THz signals, since the antenna/transmitter design is much more complicated and has stricter requirements regarding size. In addition, generating THz signals is expensive. In order for 6G to take advantage of the low-cost advantage claimed by the technology, its transmission aspect must be low cost. It is also important to note that THz signals are short-range communication signals (e.g., a few meters, which are still encountered with 5G mm Wave).
5. Energy Consumption and conservation for real world usage:
   A sophisticated signal processing mechanism will be implemented by every piece of hardware in 6G, from intelligent systems to access points. Additionally, they must process vast quantities of Big Data, which requires high levels of processing power. 6G will have to utilize advanced technologies like AI, Edge in its network nodes, which also dissipate a considerable amount of energy, so the 6G network will also have to work on the fields of energy harvesting, charging, and conservation. Furthermore, the transmission of data also demands huge energy, as discussed.
6. Internet of Everything:
   The 6G will open the possibility of IoE and which will generate huge amounts of small blocks of data. This data is retained, processed and utilized using Cloud Computing[35,39]. With the Data on Internet of Everything (DIoE), a brand-new set of will arise. Up to now, no technology has been developed that can retain, process, and utilize Exabytes of small blocks of data.

7. Security and Privacy within Quantum realm:
   6G will have to have an eminent level of security, secrecy, and privacy. It is foreseen that THz communication will contribute to 6G becoming unreachable by means of eavesdropping and jamming [30]. Similarly, quantum computing has the potential of providing unbreakable security to the 6G, like, quantum cryptography for secrecy[33]. Privacy is the major concern for the individuals, peculiarly, healthcare desires a significant amount of privacy protection[38]. A Blockchain-based system can be considered for desired security, privacy, and secrecy[36]. Federated AI is another technology that increases security. Another thing to keep in mind is that 6G guarantees physical layer security. AI will be integrated into 6G to achieve this. Several researches have been done to explore this option and still in underway [31].

8. Conclusion

The authors have presented a brief review of quantum computing, quantum information technology, and 5G/ 6G communications in this study. They briefly covered the shift from 5G to 6G technology, as well as the importance of Quantum Computing in that process. This research looks at the possibilities of 6G communication technologies as well as the obstacles that come with creating and implementing them. It is reasonable to say that every generation of communication technology provides new and exciting features. High data transmission rates and reduced latency are only two of the many exciting features of 5G communication technology. However, by 2030, 5G is expected to be unable to fulfil the growing demand for wireless access. As a result, 6G technology will be required. 6G research is still in its early phases and is being closely examined. (QIT) has the potential to enhance and strengthen 6G. Over 5G, 6G is predicted to feature a combination of incremental and revolutionary advancements. In order to serve new applications and sectors such as augmented reality, AI Machine Learning, Satellite Signal Transmission, IoT, Data Analytics, and others, 6G networks must be more efficient, secure, intelligent, and autonomous. QIT has been envisioned as one of the pivotal technologies for allowing secure, efficient, intelligent networks and reliable operations.

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