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5G Techniques & Application

Aditya Donadkar, Rehan Sheikh
G H Raisoni University Amravati

Abstract: 5th Generation wireless communication technology (5G) is a revolutionary step change in the field of mobile networks. 5G is an advancement in the existing 4G system that is intended to address the growing demands of data-hungry applications requiring higher transmission speeds, extremely low latencies and better reliability. Unlike the voice and mobile broadband focus of the previous generation, 5G is a unifying communications framework that incorporates enhanced mobile broadband, massive machine-type communication and ultra-reliable low-latency communication, enabling new digital services and communication capabilities that go far beyond the capabilities of previous networks.

Key underlying technologies driving 5G include the use of higher frequency bands (specifically millimeter-wave or mm Wave bands) to provide huge amounts of bandwidth that is necessary to support multi-gigabit data rates. These higher frequencies will likely lead to a reduced coverage area, the radio signals will be attenuated by objects. Massive Multiple Input Multiple Output (Massive MIMO) which increases the efficiency and capacity of wireless networks through the use of large arrays of antennas at the base station and beamforming that strengthens and focuses the signal strength toward specific user by directing it, are implemented in 5G networks to address the limitations posed by the higher frequency spectrum.

The benefits of 5G networks include massive increase in speed that may go up to several gigabits per second in ideal situations, extreme low latency in near real-time communication between devices and immense scale to support a massive number of simultaneously connected devices to handle the growth of global data traffic which is projected to grow exponentially. Billions of devices will be connected to 5G networks worldwide that include smart phones, IOT devices and sensors; and generation of considerable economic gains is also expected from new digital services, business models and industrial solutions made possible by 5G technology.

In the health sector, 5G facilitates applications such as telemedicine, real-time remote monitoring and robotic surgery. For these applications, connectivity should be reliable and the latency should be extremely low, and these can be satisfied by 5G technology, thereby medical professionals can carry out the diagnosis, monitor the health of patient even perform procedures from a distant location with high precision. Vehicle-to-everything (V2X) communication made possible by 5G in transport sector enable vehicles to communicate with each other and with road infrastructure which play a critical role in facilitating autonomous driving, reducing traffic congestions and improving road safety.

Smart factories rely on 5G networks to make Industry 4.0 possible, the smart factories equipped with 5G networks support automation, robotics, and real-time data analytics to boost production efficiency. In a smart factory environment thousands of devices and sensors supported by Massive Machine-Type Communication networks, can be deployed to perform tasks like predictive maintenance, seamlessly collaborate with each other and monitor the production in real time. Smart cities use the potential of 5G to implement smart transport systems, energy grids and environmental monitoring and improved public services. Additionally augmented reality and virtual reality systems (AR and VR) heavily rely on high bandwidth and low latency to provide more immersive experiences.

Keywords: 5G Technology, High-Speed Internet, Wireless Communication, Low Latency, Massive MIMO, Beamforming, Network Slicing, Smart Devices, Internet of Things (IoT), Smart Cities, Telemedicine, Self-Driving Cars, Industrial Automation, Augmented Reality (AR), Virtual Reality (VR).

1. Introduction

Communication technology has witnessed dramatic developments over the last few decades. Initially, mobile networks were utilized for voice communication only. As the 2nd generation (2G) networks were introduced, text messaging and simple data access were enabled. Subsequently, 3G and 4G mobile communications, which have revolutionized communication and provided support for mobile internet access, video calling, and online streaming, were developed. According to Shafi et al. [15], with each generation of wireless communication, we witnessed better performance in terms of speed, capacity, and service quality. Currently, the world is progressing towards the next advancement in wireless communication, which is the 5th generation (5G).

5G is not an improvement of 4G, but a complete rethinking of mobile communication systems. Andrews et al. Describe 5G as a unified platform designed for improved mobile broadband, ultra-reliable low-latency communications and mass machine-type communications [1]. The ITU-R IMT-2020 framework further stresses that 5G is envisioned as a response to the rising demand for digital communication for various societal applications by offering higher data rate, enhanced reliability and massive scalability [6]. Unlike previous generations of wireless communication that are mostly built for human communication, 5G offers both human and machine communication capabilities in an optimized manner.

In today's society, the Internet has become an indispensable service for education, business, healthcare, entertainment, and socialization. Communication devices such as Smartphones, laptops, smartwatches and smart home systems demand stable high speed and reliable Internet access. Businesses require seamless data transmission between machines such as sensors, automated machines and cloud servers. The Cisco Annual Internet Report indicates a substantial growth in both global traffic volume and number of interconnected devices, thereby pointing to the necessity for advanced networks like 5G [7]. The 4G network cannot provide the necessary coverage and bandwidth required for current demands and thus, it often leads to traffic congestion and data transfer delays.

One of the prominent characteristics of 5G is its incredibly high data rates. Dahlman et al. State that the 5G NR system supports multi-gigabit per second data rates that allow for downloaded and uploaded content within seconds [5]. This has been achieved through technological advancement such as utilization of millimeter wave spectrum, and improvement in the design of the radio interface. Millimeter wave frequencies are able to support higher bandwidth than the lower frequencies, thereby, leading to significant faster data transfer speeds. This has been detailed by Rappaport et al. [11] who highlight that 5G utilize the higher frequencies spectrum and have more capacity to deliver high data rates than lower frequency spectrum.

Another essential attribute of 5G networks is their low latency. Latency refers to the delay in the transfer of data from source to destination. Boccardi et al. Define ultra-reliable low-latency communications as one of the four revolutionary innovations brought about by 5G technology [12]. Low latency communication is essential for applications that involve real-time interaction such as video conferencing, online gaming, remote robotic surgery and autonomous vehicles. In the health sector for example, remote robotic surgery demands real-time communication between the devices used and the doctor, that can only be provided by 5G network [6].

In 5G networks, the system can handle connection of large number of devices at once without degradation in performance. Gupta and Jha suggest that 5G network infrastructure is designed to accommodate the Internet of Things (IoT) by efficiently handling connection of massive number of interconnected devices such as sensors, smart meters, cameras and industrial machines [3]. The 5G technology thus holds immense potential for smart city applications such as traffic control and management as well as massive machine communication in industrial scenarios [4]. The 5G NR technology encompasses several enabling technologies, some of which include Massive Multiple Input Multiple Output (Massive MIMO), beam forming, network slicing and advanced antenna technologies. As per the 3rd Generation Partnership Project (3GPP) Release 15, the features are the core technologies for the standard 5G networks globally [13]. Massive MIMO utilizes multiple antennas in the transmitter to increase capacity by improving

directivity and beam forming increases signal strength towards the specific user [14]. These technologies ensure a stable connection even when dealing with crowds, for instance at stadiums, train stations and shopping centers.

The applications of 5G networks cut across all the relevant industries such as healthcare (telemedicine, remote patient monitoring, robotic-assisted surgery [6]), transportation (autonomous vehicles, smart traffic management system, road safety improvement [4]), industrial sector (industry 4.0, automation and smart manufacturing [10]), AR and VR technologies, cloud services, online education and so forth [1]. There are some drawbacks to the deployment of 5G technology, one of which is the initial high deployment cost for base stations and other necessary equipment as a result of high densification requirements for small cells. Security and data privacy risks is another major concern, because the increasing number of interconnected devices implies more attack surface for potential security threats [3]. Nonetheless, recent reports from industry bodies such as Ericsson and Qualcomm indicate continuous research and investment, aimed at resolving the shortcomings associated with 5G technology [8][9].

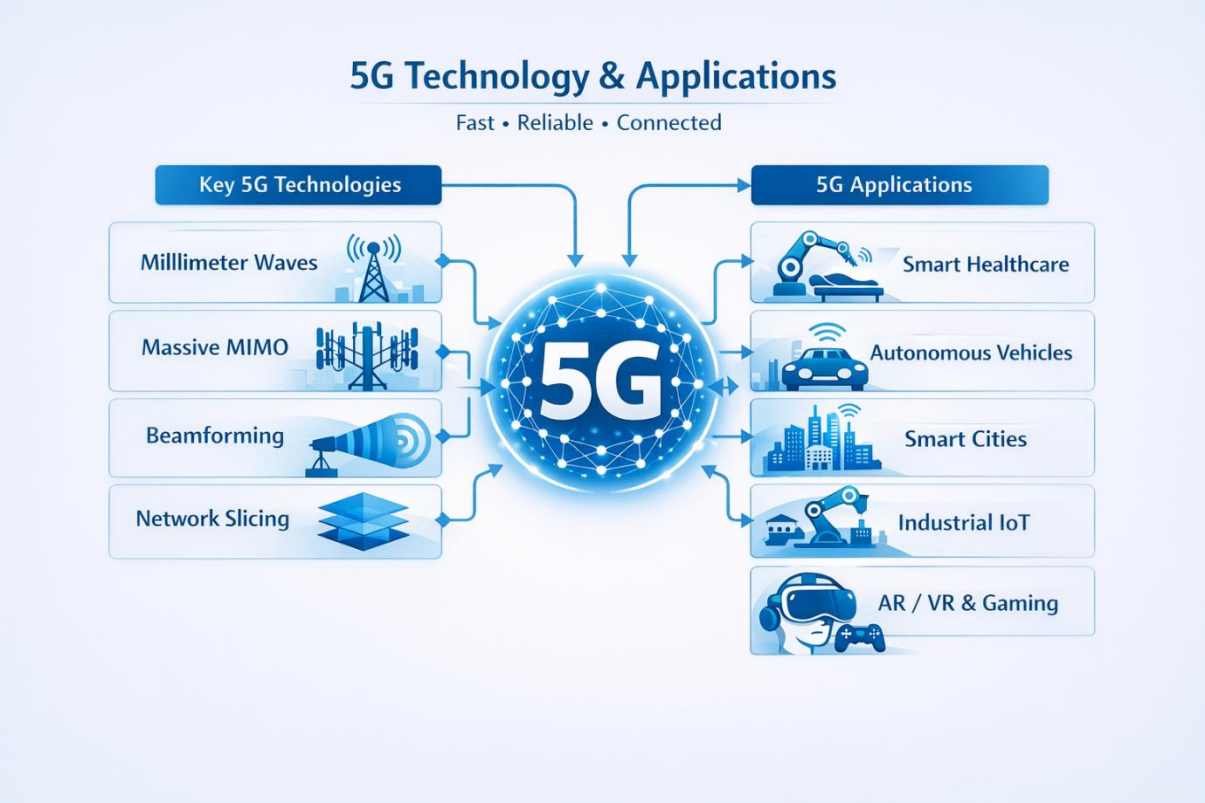

Fig 1. Structural Flow Diagram of 5G Technology and Its Applications

2. Literature Review

Since a few years, 5G technology has emerged as one of the most significant research areas in wireless communications. All over the world, numerous researchers have studied its technical architecture, the improvements in its performances, its advantages and possible weaknesses. The different mobile communication generations, that have existed so far (2G, 3G and 4G), have each led to substantial innovations. 2G allows digital voice calls and SMS services, 3G allows mobile internet access, and 4G enhances significantly the speeds of data transmissions allowing video-streaming and online-gaming as presented by Shafi et al. [15]. However, given the fast growth of Internet users and interconnected devices, researchers have anticipated that 4G would not support the needs for future communication requirements, leading to the development and research on 5G technology.

One of the main goals of 5G is to offer higher data rate, an ultra-low latency, better reliability and the capability to connect a massive number of devices simultaneously [1]. The ITU-R IMT-2020 specification describes 5G as targeting Enhanced Mobile Broadband, Ultra-Reliable Communication and Massive

Machine type communication [6]. Our everyday life is increasingly based on interconnected devices such as smart phones, smart televisions, wearable gadgets, cloud services and the Internet of Things. Internet users, traffic and interconnected devices have been growing exponentially as observed by Cisco's Annual Internet Report, and require better than 4G technology [7]. Researchers realized that the 4G network suffered from traffic congestion, poor reliability and insufficient number of connected devices per cell especially in dense urban areas and explored ways to tackle such problems.

Massive MIMO is one of the most studied technology on 5G. It is based on the principle that base stations deploy a massive number of antennas in order to transmit and receive multiple data streams at the same time, which would dramatically increase the spectral efficiency and the capacity of the network [12]. Moreover, Gupta and Jha mention that massive MIMO improves signal quality and network coverage even in congested urban areas [3]. The main advantage of this technology is to increase the usage of available frequency resources and therefore allow more users access to the network.

Millimeter wave (mmWave) is another very studied topic in the field of 5G communications. Rappaport et al. Explain that millimetric waves are frequencies higher than the existing cellular ones, enabling the transmission with much higher bandwidth and leading to multi-Gigabit speeds [11]. However, this technology has its own limitations. MmWave signals have a much smaller transmission range compared to sub-6GHz signals and they can be easily blocked by obstacles such as trees, walls, and buildings. Osseiran et al. Argue that a dense deployment of small-cell networks can compensate these effects and ensure coverage [4].

Beamforming is another technology extensively discussed in the research. Beamforming can be defined as the technique of directing the wireless signal to a specific user rather than spreading the radio energy in all directions [14]. This increases the power of the signal received by a given user and reduces the interference and it will be particularly useful in dense environments like an airport, stadium or a shopping center where people often need network connection.

Finally, the network slicing concept is largely discussed. A single physical network will be divided in several virtual networks tailored to specific service requirement [13]. For example, it will be possible to set up a network slice adapted for video streaming which needs higher throughput and a slice adapted for sensitive application like medical uses where ultra-reliability and low-latency are required [6].

Researchers typically classify 5G services into three types: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC) and massive Machine-Type Communication (mMTC). EMBB covers the needs for very-high speed data transfer applications such as very-high-definition video-streaming or online-gaming. URLLC addresses the demands for low latency data transfer applications such as remotely controlled surgeries, autonomous vehicles or industrial robots. And mMTC enables the massive connectivity of Internet of Things devices (sensors, smart meters, etc) [6].

Research on the applications of 5G technology exists in numerous sectors, for example in the field of healthcare, 5G provides applications like remote-control surgery or remote-monitoring through data transmission in real-time [6]. Transportation is another field benefiting from 5G with the connection of vehicles and their management in intelligent traffic systems [4]. Smart factories, using a lot of automated systems, rely on 5G technology for enhanced productivity [10]. And we could also list augment reality (AR) and virtual reality (VR), cloud computing and online-education among the fields benefiting from this technology [1].

Although, the literature brings up several issues regarding the implementation of 5G technology, namely the costs associated to the development of the infrastructure, which is expensive given the need to install a large number of base stations, as reported by Gupta and Jha [3]. Security is also a very important issue, because of the number of interconnected devices and people will use this new technology. Cybersecurity attacks and privacy concerns need to be prevented through the usage of advanced techniques [9]. Energy consumption is also a concern that should be investigated because of the large number of base stations and connected devices [12]. And finally, spectrum allocation and regulation are also important issues that

must be studied in order to manage the frequency bands efficiently [6].

3. Research Methodology

The investigation technique of this paper for studying the techniques and applications of 5G, is descriptive and analytical. Main goal of this research is to describe the key technologies of 5G networks and analyze their actual applications in industries like healthcare, transportation, industries, and smart cities, etc. With the aim to achieve a deep and comprehensive understanding of the technology foundations as well as practical implementations, a strict methodologic structure has been constructed through the literature review and validated technical materials available in the public domain.

This research employed a qualitative research method since it is about analyzing the published literature and not experiments and primary data collection. Reliable secondary data were selected carefully because the 5G technology is globally standardized and rapidly changing. Secondary data included the following ones: peer-reviewed articles of scientific journals, conference papers, textbooks, technical white papers and telecommunication reports. To comprehend the concept of the 5G system, studies were carried out on seminal research like Andrews et al [1] as well as survey works of 5G technology like Agiwal et al [2]. To understand technical standards about 5G NR (New Radio), documentation from the 3rd Generation Partnership Project (3GPP Release 15) [13] was considered. Also the IMT-2020 vision frame published by International Telecommunication Union [6] provides information about the global performance targets and objectives of 5G networks.

In addition, comparative analytical techniques were used in order to demonstrate the difference between 4G and 5G in terms of speed, latency, spectral efficiency, network capacity, and reliability. Technical papers were selected like Rappaport et al [11] about millimeter-wave communications and Boccardi et al [12] about disruptive technologies of 5G were analyzed to prove the improvement of performance in 5G systems. The analysis was supplemented by information from reports of industries such as Ericsson, Cisco and Qualcomm [7][8][9] regarding deployment tendency and application scenarios of 5G networks.

This paper uses descriptive and analytical research to investigate the techniques and applications of 5G. The purpose of this paper is to explain the basic techniques of 5G technology and to analyze its real applications in several industrial areas, including medicine, transportation, factory automation, smart city and so on. In order to gain a thorough understanding of both technical foundations and application scenarios, we formulate an methodological framework by reading widely and analysing verified technical literatures.

Since we only reviewed some existing literature and performed no experiments or data collections, qualitative research method was chosen to describe the technical and application details of 5G, Reliable secondary data were carefully chosen as the information about the technique and applications of 5G were highly standardized worldwide. Secondary sources including peer-reviewed journal articles, conference papers, textbooks, white papers and telecommunication reports were consulted. In order to have a fundamental knowledge of 5G network and architecture, some foundational research like Andrews et al. [1] and thorough survey study like Agiwal et al. [2] were consulted. In order to understand the standards about 5G NR, the document of 3GPP Release 15 [13] was searched and referred to. Besides, the IMT-2020 vision document [6] which presents the IMT-2020 objectives was reviewed, which demonstrates that the main targets of IMT-2020 include enhanced mobile broadband, ultra-reliable low-latency communication and massive machine type communication.

In addition, comparative analytical technique was used to illustrate the difference between 4G and 5G on factors including speed, latency, spectral efficiency, network capacity and reliability. Through referring to the technical paper [11] by Rappaport et al. About millimeter wave communication, and the technical paper [12] by Boccardi et al. About disruptive 5G techniques, we presented the dramatic enhancement in system performances. Industrial reports from famous telecommunication providers including Ericsson, Cisco and Qualcomm [7][8][9] were also collected in order to analyse the deployment status and emerging application cases.

A thematic classification was also adopted in order to structure and manage the data more effectively. Massive MIMO, beamforming, millimeter wave communication, network slicing, etc. Were individually analysed and explained on their mechanisms and how they contributed to achieve the IMT-2020 requirements [6][13]. For each specific technique, its performance improvement, scalability, economic feasibility and the limitations in the context of implementation were studied based on literatures and industrial reports [7][8]. Integrating academic knowledge and practical information together ensures comprehensive analysis.

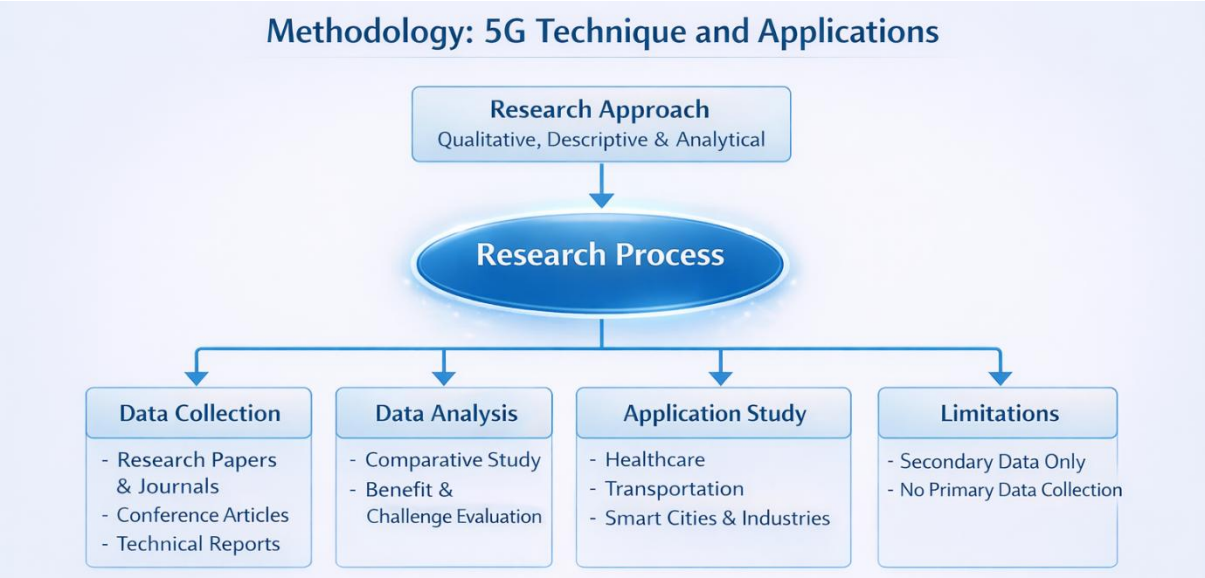

Fig 2. Analytical Framework of 5G Techniques and Applications Study

4. Results

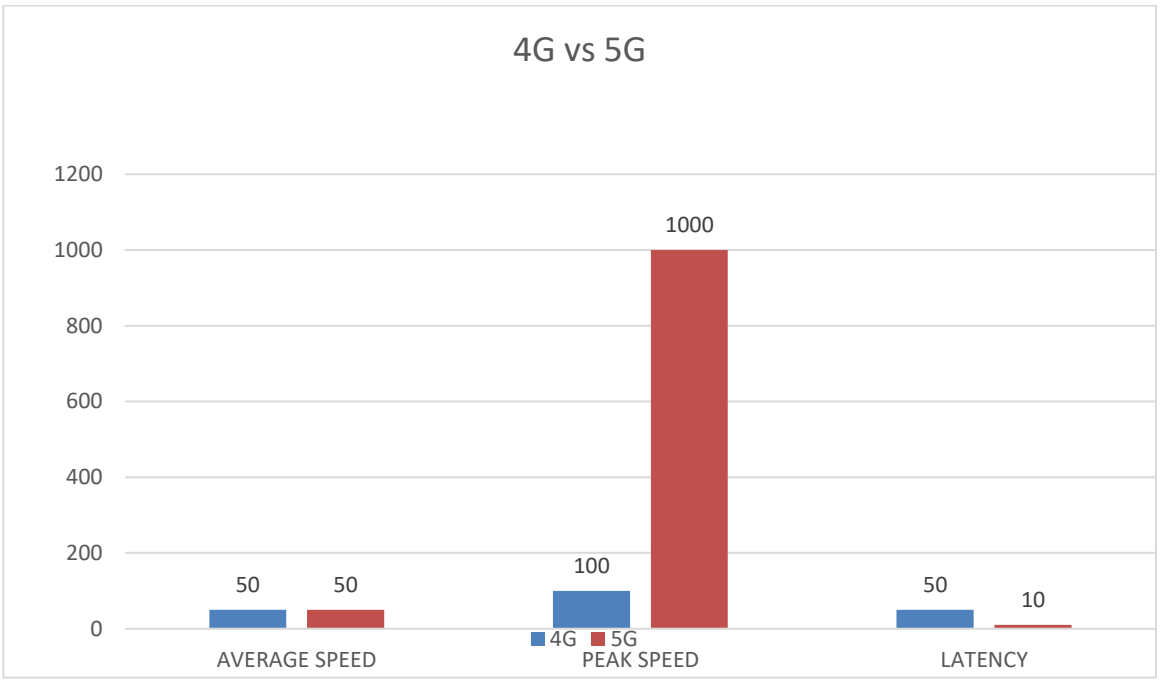

Fig 3. Speed testing of 4G vs 5G

5. Conclusion

The objective of this research paper is to understand better the 5G technology, the main underlying technologies, and the variety of applications of it in different fields of life. Through analyzing the main concept, the performance improvement and applications of 5G in different fields, we can conclude that

5G technology is a radical leap forward in the mobile communication systems. The design objectives for 5G is to support Enhanced Mobile Broadband (eMBB), Ultra-reliable Low-latency Communication (URLLC) and massive Machine Type Communication (mMTC) as defined by the International Telecommunication Union in IMT-2020 [6]. Thus, 5G is not a successor to the 4G technology but a totally new generation of the mobile network that will lead to paradigm shift.

From the conclusion of this research paper, there are several important findings. First of all, the data rates for 5G technology were significantly enhanced. Through analyzing the literature research on 5G technical investigation such as [1] and [5], the research papers indicates the 5G NR will support the data rates up to multiple gigabits per second, which would be the fastest rates possible using 3GPP release 15 [13]. High data rates can enable people to enjoy several benefits like ultra high definition (4K and 8K) media, cloud computing and games and quick downloads in several seconds. For businesses, the faster speeds allow cloud services to accelerate performance, improve data synchronization and facilitate remote collaboration.

The second obvious advancement of the 5G technology is the ultra low latency it could support. Latency is defined as the delay between sending and receiving of the information. The typical 4G latency is around 30-50 milliseconds and for 5G this figure is expected to reduce to around 1 millisecond in best case scenario [6]. This low latency allows real time communication between systems which is essential for time critical application, such as robotic surgery, autonomous cars and intelligent traffic control where even slightest delay can result in drastic outcome.

The third essential achievement for 5G is Massive MIMO, beamforming and millimeter wave technologies. As stated in [12], Massive MIMO which uses large number of transmitting and receiving antennas simultaneously to increase the capacity and spectral efficiency of the system. Beamforming technology allows transmitting antenna to focus signals in particular direction towards specific user so that overall throughput can be improved and interference can be reduced [14]. Moreover, using the millimeter wave frequency spectrum offers vast amount of radio resources that can achieve extremely high data rates [11] but this can require more cells to be installed because of limited range and vulnerability of millimeter wave signal, so the deployment of more small cells in dense area is needed. Also, 5G has network slicing which is a paradigm that allows for multiple virtual networks to be created on a single physical infrastructure. Each virtual network can be designed specifically for the demands of an application or business sector [13].

The forth point is the substantial boost to Internet of Thing (IoT). MMTC capability of 5G network can support over a million devices per km 2 [6], which is incredibly huge compared to previous generations. Such technology will enable 5G to transform the cities into smarter environment in which thousands of sensors are deployed to monitor traffic, pollution, energy consumptions and safety issues. This is the enabling technology for industry 4.0 where M2M (Machine-to-Machine) communication will enable real time machine control, predictive maintenance, fully automated factory etc., to raise the productivity.

Apart from general applications, 5G can also enable various industry-specific applications. For health care sector, telemedicine and remote health monitoring will be improved due to stability and low latency of connection [6]. Doctors are capable to remotely control robot to do the surgery from faraway place. In education field, high bandwidth and low latency would provide students better experiences with interactive virtual classrooms and AR/VR technologies [7]. For transportation, connected cars, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication will improve road safety and reduce the traffic congestion [4].

There are several challenges that 5G implementation need to overcome. Financial aspect is certainly the foremost, since building a 5G network requires significant amount of capital to install base stations, optical back haul and high performance hardware [3], it is particularly costly when the densification of cells (especially millimeter wave small cells) is needed. The security and privacy also pose major challenges because of the huge number of connected devices and the confidential information that can be extracted from it. Furthermore, the rural areas are expected to have the slower rollout of 5G network due to the lack

of profit for telecom providers and high installation costs [10]. Governments and network providers must work closely together to promote 5G rollout in an equitable and inclusive manner.

In conclusion, 5G is a landmark advancement in wireless communication systems offering massive bandwidth, unprecedented speed, extremely low latency, vast connectivity and enhanced network flexibility. Despite facing challenges in financial, technical, and security realms, the long-term rewards of 5G deployment far outweigh these impediments. With continuing research and development, 5G is anticipated to act as the catalyst for innovation in smart cities, autonomous systems, intelligent healthcare, and immersive entertainment. Consequently, 5G represents not just an incremental upgrade, but a fundamental shift toward a hyper-connected, intelligently functioning future.

References

1. J. G. Andrews, S. Buzzi, W. Choi, S. Hanly, A. Lozano, A. Soong, and J. Zhang, "What Will 5G Be?" IEEE Journal on Selected Areas in Communications, 2014.
2. M. Agiwal, A. Roy, and N. Saxena, "Next Generation 5G Wireless Networks: A Comprehensive Survey,"IEEE Communications Surveys & Tutorials, 2016.
3. A. Gupta and R. K. Jha, "A Survey of 5G Network: Architecture and Emerging Technologies," IEEE Access, 2015.
4. A. Osseiran, F. Boccardi, V. Braun, et al., "Scenarios for 5G Mobile and Wireless Communications," IEEE Communications Magazine, 2014.
5. E. Dahlman, S. Parkvall, and J. Sköld, 5G NR: The Next Generation Wireless Access Technology. Academic Press, 2018.
6. International Telecommunication Union Radiocommunication Sector (ITU-R), IMT Vision – Framework and Objectives for 2020 and Beyond, 2015.
7. Cisco Systems, Cisco Annual Internet Report (2018–2023), Cisco White Paper, 2020.
8. Qualcomm Technologies, The 5G Economy Report, Qualcomm Publication, 2021.
9. Ericsson, Ericsson Mobility Report, Ericsson Research, 2021.
10. Huawei Technologies, 5G Deployment and Future Applications, Huawei White Paper, 2019.
11. T. S. Rappaport, S. Sun, R. Mayzus, et al., "Millimeter Wave Mobile Communications for 5G Cellular," IEEE Access, 2013.
12. F. Boccardi, R. Heath, A. Lozano, T. Marzetta, and P. Popovski, "Five Disruptive Technology Directions for 5G," IEEE Communications Magazine, 2014.
13. 3rd Generation Partnership Project, Release 15 – 5G NR Standards Documentation, 2018.
14. J. Zhang, X. Ge, Q. Li, M. Guizani, and Y. Zhang, "5G Millimeter-Wave Antenna Design and Challenges," IEEE Wireless Communications, 2019.
15. M. Shafi, A. Molisch, P. Smith, et al., "5G: A Tutorial Overview of Standards, Trials, and Deployment," IEEE Journal on Selected Areas in Communications, 2017.