Systematic Analysis of Modern 5G and 6G Technology

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Abstract. Stepping into the 2020s, 5G and 6G are guaranteed the most widely used mobile technology in people's daily lives. Meanwhile, to some extent, they undoubtedly profoundly impact people's lives. In this paper, the main target is to illustrate these two evolutional mobile technologies. Firstly, attention should be attached to their current development. Among these paragraphs, a typical sort of technology utilized in these mobile schemes, Multiple Input, Multiple Output (MIMO), and several of its advanced branches, would be introduced. They significantly contribute to the network throughput and efficiency. Next, features containing some defects and limitations will be highlighted and analyzed for a more objective overview of these two schemes. Next, sighting their future promising development in different areas, some expected available applications would also be suggested and listed based on their features, like high spectral efficiency, etc. This paper aims to offer a general view of modern communication schemes, 5G and 6G and navigates them with logical analysis and accurate description. It illuminates their crucial role by overviewing their current state and underscores the relationship between technological advancement and life quality in the digital era.

Keywords: 5G, 6G, Massive MIMO, Modern Communication Technology

1 Introduction

Looking back on the history of the development of modern communication technology, humans have witnessed various milestones: In the 2010s, the birth of 3GHz spectrum mobile devices signified the era of 3G mobile technology, which was a significant leap in mobile broadband (MBB) capabilities, improving speeds and connectivity for consumers; As the globe has already entered the 2020s' generation, these advanced technologies such as MIMOs, Ultra-Reliable Low-Latency Communication (URLLC) and Massive Machine Type Communication (MTC), are brought about and have already become irreplaceable components of the 5G networks. These technologies enable diverse applications, including Cloud Computing, massive communication for smart cities, etc [1]. Recently, the globe witnessed an incredible evolution in mobile communication technology, with the widespread use of 5G and 6G networks. In the current digital era, these two communication technologies have become the foundation of innovation and daily

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functionality, influencing how people connect, communicate, and work worldwide. Stepping into the 2030s, integrating Artificial Intelligence (AI) into communication networks may result in more efficient and highly adaptive technologies that could transform the interaction with devices and data. This transformation is expected to extend beyond conventional communications, influencing diverse domains in our lives.

This paper also provides a clear and comprehensive view of the progress from 5G to 6G technologies with their current developments, diverse features, particularly the attached introduction of MIMO technology, and differences among parameters and performance discussed to fulfill understanding and recognize modern communication technology.

2 5G Technology

5G technology possesses various extraordinary features, such as its speed/bandwidth, which is several times greater than 1 Gbps, and its frequency band between 3GHz and 300GHz. 5G is well-designed in a specific structure containing different layers based on the basic OSI model. 5G's application model has already made some advancements, and its layers are Application Layer, Open Transport Protocol (OTP) Layer, Upper and Lower Layers, and Data Link Layer, which operates based on the Open Wireless Architecture. Additionally, due to the good functional parameters, 5G is widely utilized in video telephony, high-definition multimedia streaming, multimedia newspapers, HD online TV, etc. It is a type of wireless communication with almost no limits supporting the World Wide Web (WWWW) [2, 3]. These advancements have been made possible by pioneering technologies such as massive MIMO arrays, which enable the simultaneous transmission and processing of multiple data signals over the same channel. In this paper, the MIMOs are discussed in detail for an expansion of the development of the 5G mobile scheme.

2.1 Basic MIMO Technology

The MIMO utilized in communications aims to improve the performance via the antenna of both the transmitter and receiver sides. It allows the transmission of more than one data signal at the exact moment over the same radio channel, which can significantly increase the capacity of a wireless communication system without requiring an additional spectrum. Generally, MIMO helps transit numbers of data streams over the same frequency band utilizing advanced signal processing techniques so that the network can serve more users within the same spectral resources, reducing the cost per bit and enhancing users' experience. Figure 1 describes the working principle for the antenna of MIMO. Tx stands for the antenna at the transmitter side, while the Rx stands for receivers that accept transmitter signals. Every transmitter has its signal path and spreads out individual signals. The colored directional lines represent the MIMO channel, showing the system's complexity and uniqueness. This describes the multipath environment where signals can overcome

various obstacles, creating multiple signal paths for the receivers [4]. Fundamental MIMO Structure Architecture is shown in figure 1.

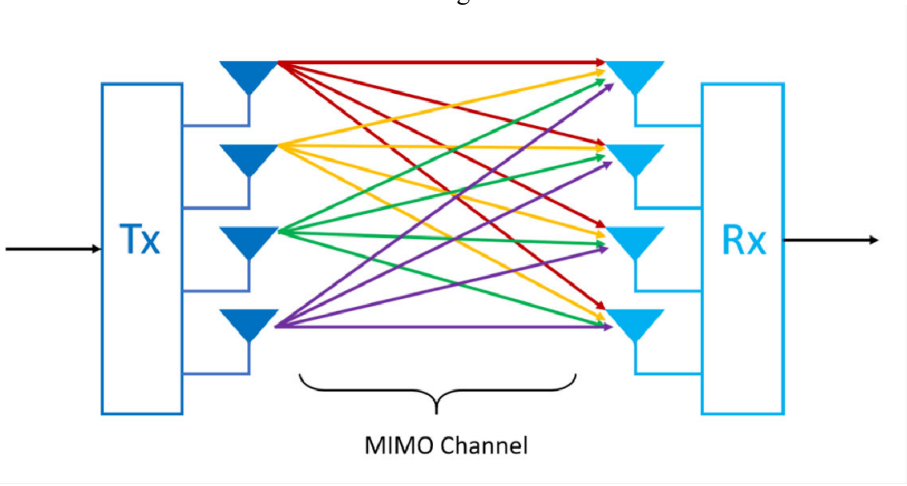

Fig. 1. Fundamental MIMO Structure Architecture [4].

2.2 Massive MIMO Technology in 5G

However, even though various new MIMO technologies are suggested, such as single-user MIMO (SU-MIMO), multi-user MIMO (MU-MIMO), and network MIMO, they are still incapable of satisfying the rapidly daily increasing demand of users as humans enter the 5G era [5-11]. Therefore, massive MIMO, a new type of high-capacity technology based on basic MIMO, should be introduced in the 5G era. Compared with the traditional MIMO structure, Massive MIMO gathers tens or even hundreds of antennas at the base station and serves tens of users at the same time. This vastly improves the signal quality for the users' mobile devices, as illustrated in Figure 2 [12].

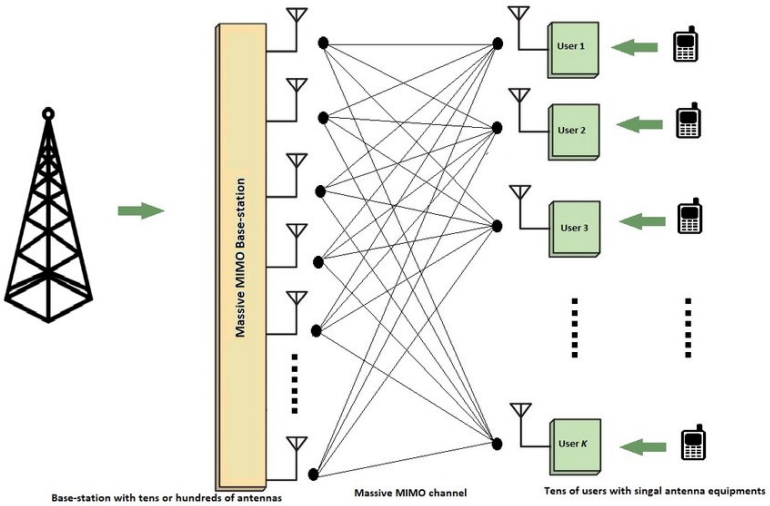

Fig. 2. Massive MIMO Structure [12]

Tens of users could individually receive the signal from a transmitter (base station) with a higher transmitting speed.

2.3 Performance of Massive MIMO

Generally, some key aspects influence greatly on Massive MIMO's performance:

2.3.1 Channel Capacity

The Channel Capacity, which represents the maximum rate at which information can be transmitted through a channel. For the Massive MIMO, many antennas are facilitated so that a larger volume of information's simultaneous transmission is successful, and the whole system approaches a high channel capacity.

2.3.2 Signal-to-Interference plus Noise Ratio (SINR)

SINR indicates the quality of a received signal relative to the background noise and interference level. Higher SINR values in Massive MIMO systems are due to the antennas' capacity to gather the transmission of signals and reception better, reducing some potential interference.

2.3.3 Beamforming

Beamforming assists signal processing in the Massive MIMO and helps direct both the transmitting signal and the received signal into their proper direction, respectively. Beamforming is also vital for targeting signals toward respective users and

minimizing the total leakage to other channels, enhancing the transmission process's efficiency and effectiveness.

To conclude, these elements greatly optimize the use of available bandwidth and improve signal quality and system reliability. Moreover, the Massive MIMO also provides the whole system with lower energy consumption and a broader signal coverage for the target area. Besides, its architecture is beneficial for obtaining a strong signal indoors. The huge MIMO network's increased number of antennas will also make it more resistant to interference and purposeful jamming than present systems that are just taking advantage of a few antennas [13]. Many carriers have already commercialized Massive MIMO technology to adapt to increasing abundant needs. For instance, in early September 2017, Ericsson announced the debut of a new Frequency Division Duplexing (FDD) radio that supports 5G and Massive MIMO. It stated that this would bridge the gap between 4G and 5G, increasing the capacity of current 4G LTE while laying the groundwork for 5G.

2.4 Defects and Limitations

5G possesses great functions and covers a lot of device consumption in different countries and regions. Even though this specific sort of mobile technology has achieved a high level of development and advanced its quality in diverse parameters, compared with 1 to 4G in the past generations, 5G still has some obvious drawbacks.

Due to a high reliance on the frequency band, 5G possesses much more limited coverage than other communication schemes. The demand for a frequency band around 300GHz would lead to a high budget for the carriers to get the spectrum. These high-frequency signal waves, with their shorter wavelengths, need help to cover long distances, requiring a denser network of base stations to ensure reliable connectivity for users, thus escalating the network's complexity and even extra expense.

3 6G Technology

3.1 Basic theory of 6G

In the future, 6G could provide users with a better experience, reducing the transmitting signal's propagation delay with the support of its broader coverage, more brilliant antenna, and higher processing capacity of the receiver devices. The data rate can reach almost ten times that of 5G, and the volume of connections can reach 1 million, so it can provide such a large amount of data for the users.

Unlike 5G, which has already developed an individual mature operating system, 6G is still growing and inventing trends. In the next ten years, 6G will widely utilize new technologies. Based on the current 5G application scenarios, two new application fields, AI and Sensing, would be added for the 6G scheme.

In the 6G era, more applications will emerge: Extended Reality (XR) cloud services, haptic feedback, and holographic displays are expected to become

mainstream. The exponential growth of single-device traffic and the high requirements for latency and reliability make large capacity the primary challenge for the design of a 6G network; besides, with the rapid growth in the volume of IoT devices and the emergence of new wireless sensing capabilities that provide extensive big data to learn specific algorithms, AI will become an automation engine for all kinds of jobs. Big data is expected to motivate the 6G network throughput by orders of magnitude. Diverse performance would become a significant feature of 6G. However, it is a fact that some of these technologies still need to reach that high development level. Thus, much effort must be made to push the further development of the 6G technology.

3.2 Comparison: 5G & 6G

This paragraph compares 5G and 6G by listing specific parameters that differ in evaluating a communication system. A table containing these parameters is attached. Ideally, 6G has a broader spectrum as it is exploited with higher signal frequency. Therefore, only a few of the parameters will be discussed.

3.2.1 Signal-to-Noise Ratio (SNR)

5G has already performed well on this parameter. 5G networks operate in diverse frequencies, counting from the sub-6 GHz bands and even mm Wave bands (24 GHz and above) for high data rates. The application of Massive MIMO would significantly improve the SNR via beamforming. Based on 5G, some unique AI and Machine Learning (ML) methodologies could optimize the transmitting signal and enhance the user's experience.

However, 5G and 6G's SNR values could be affected and vary a lot, as mmWave frequencies generally experience higher path loss and susceptibility to blockages, thus potentially reducing the SNR in specific environments. The population of users in a particular region and the density of its interference could also impact the transmitting signal.

3.2.2 Peak Data Rate

The peak data rate indicates the maximum achievable data transmission rate under ideal conditions. For 5G, this largely depends on the user's environment and the amount of interference so that the peak data rate can range flexibly from several Gbps to around 10 Gbps. For 6G, it takes advantage of frequencies in the sub-THz and THz bands. Thus, a higher generated bandwidth would lead to peak data rates exceeding 100 Gbps, possibly approaching one terabit per second (Tbps) in highly optimized scenarios. Each generation of communication schemes introduces new frequencies and technologies to satisfy the growing data requirements and expand the network capabilities. Generally, the peak data rates of 5G and 6G reflect a continuous push for higher bandwidth and spectrum utilization efficiency.

3.2.3 Latency

Signal propagation in the 5G scheme always faces a higher path loss. As it is expected to discover deeper on a frequency level of sub-THz and THz, 6G has a shorter effective communication distance than 5G. Besides, the coverage area of antennas or operating cells becomes smaller, which means 6G would possess a lower propagation delay.

3.2.4 Spectral Efficiency

For 5G, enhancing the area throughput is a great challenge. Simply simulate this parameter as:

$$\textit{Area throughput (bit/s/km\^2)} = \textit{Bandwidth (Hz)} \times \textit{Cell density (cells/km2)} \times \textit{Spectral efficiency (bit/s/Hz/cell).} \quad (1)$$

This formula implies that three major components can be enhanced to achieve a higher area throughput: More bandwidths can be served for 5G services. The network can be densified by adding more cells with independently operating access points. Data transmission efficiency (per cell and for a given bandwidth) [14].

The application of Massive MIMO has also greatly helped by focusing the transmitting signals into narrow beams directed toward the individual users for the 5G scheme. 5G has shown excellent spectral efficiency in practical communication systems. Additionally, turning out to 6G to approach a more rapid launch, 6G is expected to tackle the obstacles to chase better performance, utilizing methodologies like higher-order QAM (Quadrature Amplitude Modulation) to achieve further optimization in developing the 6G scheme.

3.2.5 Energy Efficiency

In modern communication engineering, energy efficiency is always defined as the number of bits transmitted per unit of energy (bits per joule). Both spectral efficiency and power to transmit these bits must be considered to weigh this parameter. Besides, to optimize the system's energy efficiency, we can utilize advanced modulation techniques to increase the bits transmitted or introduce power control models to reduce energy consumption.

Parameters presenting the difference between 5G and 6G are shown in table 1.

Table 1. Different features of 5G and 6G

Parameters	5G	6G
SNR	Urban Area: 10 to 25 dB Indoor: 0 to 20 dB	Outdoor: -10 to 30 dB Integrated Network: 30 dB
Peak Data Rate	10Gbps	1Tbps (Highly Optimized)
Latency	1ms	Normally from 1GHz to 24GHz

Spectrum	Normally from 1GHz to 24GHz	Up to THz level
Spectral Efficiency		
Energy Consumption	Good	100 times of 5G
Efficiency		

4 Conclusion

The unpredictable evolution from 5G to 6G is not merely a step but a leap toward a hyper-connected future. This paper illustrates some basic operation principles of 5G and 6G technologies. The Massive MIMO in 5G technology is also stressed, and a comparison of 5G and 6G by weighing their evaluation parameters, providing a clear perspective on their respective capabilities and innovations. Exploring 5G and 6G technologies is far more than a mere evolution of modern mobile communication standards. It represents a shift towards a hyper-connected future globally. 5G technology, with its wide bandwidth, improved latency, and specific integration with Massive MIMO technology, has already become a millstone in human network communications. It initiates an era of higher data speed and reliability, crucial in sustaining current digital infrastructures. And 6G intends to grow on these basic foundations by combining newer technology like AI to enable applications such as extended reality, cloud services, and holographic displays, indicating a growing trend of new digital life. Even though the leap from 5G to 6G has already faced numerous challenges, the promising exponential development in connectivity and data-transmitting processing capacity would help overcome the obstacles, making them more prevalent and crucial to solidifying our social communication and economic systems. Undeniably, the ongoing development of these technologies is critical for improving communication and processing capacities, fulfilling the full potential of a digitally connected world so that a more innovative future with mobile technologies would come to life.

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