# A Brief Review of Massive MIMO Technology for the Next Generation

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**Abstract:** *Massive Multiple Input Multiple Output (MIMO) is an evolving technology based on the principle of spatial multiplexing which consists in using at the same time the same radio frequencies to send different signals. The several transmitting antennas from a base station can transmit different signals and several receiving antennas from a device can receive and divide them simultaneously. Due to the physically difficult of installing antennas close to each other, standard MIMO networks generally limit four antenna-side transmitters and receivers for data transmission while it could be more. The study aims to review the traditional MIMO different types as well as investigates the Signal-to-Noise Ratio (SNR) between Single Input Single Output (SISO) and MIMO to ensure the best wireless connection functionality. In addition to that, a simple comparison to distinguish between SISO, SIMO, MISO, and MIMO in term of capacity and data rate to provide an indication for the quality of the wireless connection. The work's contribution is to illustrate technological benefits like MIMO, which boosts data speeds and increases the reliability of wireless networks. The outcome shows a SISO system would have a lower data rate than other systems because it only has one antenna at the transmitter and receiver, whereas a MISO system would typically have a greater SNR than a SISO or SIMO system because it uses several transmit antennas. MIMO, however, took advantage of all the positive characteristics and emerged as the best solution overall.*

**Keywords:** *MIMO, SISO, SIMO, MISO, 5G, SNR, antenna.*

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## 1. Introduction

With the rapid growth of Internet applications, it is expected that mobile traffic will increase explosively and leads to the significant growth in requirements for digital wireless communication. Massive MIMO technology with multiple inputs and multiple outputs is an important and timely topic, largely driven by the demand for fifth-Generation (5G) wireless communications [18]. A system that uses massive antenna networks to serve multiple users is called a “massive MIMO communication system”. They can withstand the attenuation of millimetre-wave signals in higher frequencies, provide wireless backhaul and reduce as possible interference in multilayer and dense networks [20].

The development of telecommunications systems is improved with the new 5G radio technology and beyond; which can support the exchange of large amounts of data with a wide variety of types of communications such as Internet of Everything (IOE) [23]. To withstand the challenges of reducing access collisions and massive connectivity, Non-Orthogonal Multiple Access schemes (NOMA) have been introduced as a potential solution for future radio access which allows for the cohabitation of two or more users per subcarrier or sub-band of frequency through offer users access to the channel in a non-orthogonal equity way through multiplexing either in the power domain or in the code domain [7, 31]. The demand for data services has increased rapidly in recent years, which is likely to accelerate the growth of traffic such as the Internet of Things, multimedia, and other advanced health and transportation services and to support these services, limited network resources must be used optimally to meet the quality of service and provide connection reliability.

So, the researchers have to think about a new model to serve various user nodes in the same time-frequency resource block which the aggressive spatial multiplexing with large antenna networks offered by Massive MIMO [4, 34]. While multiplying the number of antennas, many researchers in [32] have come up with a problem of complexity and degradation of performance in their systems for mobile radio communications. The other type of researchers has chosen to implement their algorithms either with the Single Input Single Output (SISO) or MISO model as indicated in their articles in [10, 11, 13, 15]. At the context, new model has been studied with a hint of mobile generations and then working with a review massive MIMO technology through spotlight of different techniques types. The traditional MIMO has been presented and characterized to guide the researchers forward with the technology and open the door to add more sophisticated services to come up with the upcoming revolutionary era.

## 2. Evolution of the Different Generations to the Fifth Generation

In decades, the world has undergone a profound change through four generations. These generations refer to a change in throughput, technology, frequency, data capacity, latency. Bravely, the 1G technology was analogue with very low levels of efficiency and safety, based on circuit communication and frequency modulated with Multiple Frequency Division Access (FDMA). While the 2G is a digital technology that takes into account new functionalities, including text messaging and low-speed communications, “1G and 2G finally give everyone access to mobile telephony”. Similarly, 3G provides a high-speed data transmission rate of up to 14 Mb/s, increased and improved capacity through the use of packet switching. However, LTE technology is considered 4G based on a fully IP technology capable of providing data rates of up to 1Gbps through with the use of a new interference-fighting OFDM access technique. The technology offers various multimedia services mobile television, HDTV, digital video broadcasting. LTE-Advanced technology is the evolution of the 4G LTE network with more improvement features in heterogeneous networks, carrier aggregation, coordinated multipoint transmission and reception, and the use of MIMO antenna technology [1, 20, 25, 27]. Consequently, a new technology under the name “5G” which is quite different from previous generations started in front of the scene due to the volume of mobile data has grown exponentially and the huge number of data transfers between users has been a key research topic since the early 2000s [2, 16].

Indeed, the forecast for the number of connected devices by 2023 predicts to exceeding the expectations; in other words, the growth in the number of mobile devices will overtake the number of people in the next few years. This increase is due to the need of users to transmit in terms of increasing throughput. Table 1 contains a detailed description of the various recent generations.

Table 1. Detaille description of most important generations.

| Performance Index | 4G | 5G | 6G |
|---|---|---|---|
| Data Rate | 100 Mbps | 10 G/bps | Up to 10 T/bps |
| Latency | 10 ms | 1 ms | 0.1 ms |
| Connection Density | 0.1 million devices/km2 | 1 million devices/km2 | 10 million devices/km2 |
| Energy Efficiency | 1× | 100 × 4G | 100 × 5G |
| Spectral Efficiency | 1× | 100 × 4G | 100 × 5G |
| Available Spectrum | Up to 6 GHz | Up to 300 GHz | Up to 3 THz |
| Mobility | 200 m/h | 300 m/h | 600 m/h |

While the main requirements that should continue to contribute to the achievement of the following objectives could be summarised in the upcoming points below:

- The end-to-end latency time is reduced by a factor of 10, the latency level is less than 1 millisecond.
- High flow, 1000 times higher per unit area (1 Gb per second)
- Energy-efficient devices have 10 times the longer battery life and lower energy consumption
- Low complexity and signal overload.
- Triple Spectrum Efficiency: optimized Bandwidth Utilization - Energy-Efficient Network

## 3. Multiple Input Multiple Output (MIMO)

The purpose of this review is to introduce the MIMO as an emerging technology of the most promising methods for revolutionary 5G and Internet of Things (IoT) systems due to technological development requires powerful and reliable communication systems. As part of the possible improvements in the Massive MIMO, the explore of traditional MIMO technology and the development to understand the technological progress with some research work dealing with existing methods for access based on massive MIMO.

### 3.1. Traditional MIMO

The main objective when using MIMO technology is a higher data clearly uses multiple transmitters and receivers to transfer more data simultaneously. The phenomenon of radio waves bounces on many obstacles, called multiple paths, where information reaches the receiving antenna several times from different angles and at a slightly different time shift. These echoes are interferences for the rest of the communication called Fading. With multiple journeys, MIMO technology uses multiple smart transmitters and receivers with an additional spatial dimension to boost performance and range. Hence, the technology offers many antennas to send and receive several spatial streams simultaneously [5, 24]. Whereas, the antennas play a role in combining multiple data streams from different paths with a slight time shift to provide an increase in the receiver’s signal capture power [26]. Smart antennas take advantage of spatial diversity to make the most of surplus antennas.

### 3.2. Principle of MIMO Technology

As explained, the main source of signal noise disturbances during the transmission could be from natural and sometimes man-made sources, and that would impact entire signal channel and lead to block, multi-path propagations, and sometimes shifts in frequency or time [21]. MIMO systems are based on several diversity types such as Frequency diversity which is consists of sending copies of the signal on two different carriers simultaneously to make the best use of the frequency diversity with taking into account the coherence bandwidth, whereas the second diversity is Temporal which is sending the same signal several times at different times to make better use via careful signals spaced at least the time of coherence of the channel, in addition to the previous, the third diversity is spatial which considers the signal emits on several distinct points of space. Moreover, many MIMO types could occur based on the specifications of the system and antennas conformation, the SISO - Single Input Single Output, SIMO - Single Input Multiple Output, MISO - Multiple Entry Single Output, and MIMO - Multiple Input Multiple Output are the main MIMO types that could go through them to distinguish their properties [19].

### 3.3. SISO (Single Input Single Output)

The first type is SISO which contained only one antenna on the transmitter and receiver side as shown in Figure 1 and considers the easiest to implement and design among the four types of antennas available [22].

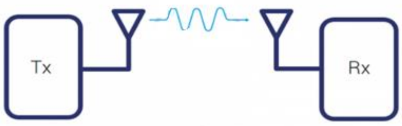


Figure 1. SISO configuration type.

In SISO, there is no diversity and no additional treatment, the simplicity considers the main feature compared to other types of systems, while it could discover applications in Wifi, television, and broadcasting, even though the limitation in bandwidth considers the major issue and follow the Shannon law;

$$C = B\,log_2(1 + SNR)[bit/s] \quad (1)$$

Where $C$ is channel capacity; $B$ channel bandwidth; $SNR$ signal to noise ratio.

In SISO systems, the transmitter and receiver each have a single antenna. They are utilized in relatively basic wireless communication systems such those found in Bluetooth devices or basic wireless routers.

### 3.4. SIMO (Single Input Multiple Output)

SIMO technique shown in Figure 2, only one transmit antenna and multiple antennae at the reception help improve the reception diversity where it is used to combat the effects of antenna fainting and ionospheric interference without increasing channel capacity [3].

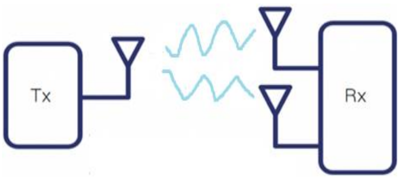


Figure 2. SIMO configuration type.

The channel capacity of the SIMO follows the law of:

$$C = B\,M_r\,log_2(1 + SNR)[bit/s]$$

Where $M_r$the number of antennas used on the receiver side is, $C$ is the capacity of the channel; $B$ is the channel bandwidth, and SNR is the signal to noise ratio

SIMO system discovered applications with shortwave listening/receiving stations and demonstrated a better advantage than SISO in diversity improvement. The feature provides a bit quite acceptable in some performance such as when searching for the most powerful signal and switching it to this antenna and combines a couple of signals to give a combination and contribute to the overall signal. In other words, one antenna serves as the transmitter in SIMO systems, whereas several antennas serve as the receiver. They are employed in wireless communication systems, such as wireless sensor networks and industrial control systems, where the aim is to increase the reliability of the communication channel. So long as shown limitation to certain physical parameters such as battery size, and cost.

### 3.5. MISO (Multiple Input Single Output)

In Figure 3 MISO, when transmitting a signal only a receiving antenna is capable of receiving the same data that is transmitted redundantly from multiple transmitting antennas, in other words, there are different sources available but there is only one available destination where the latter can receive the optimal signal to extract the required data [29].


Figure 3. MISO configuration type.

The main feature of the configuration allows recovering the original signal at reception with a lesser loss of path than SISO and SIMO while reducing the effect of fading by multiple routes during transmission. Also due to high diversity gain, a wide range of applications could be applied such as Digital TV, radar systems, and mobile phone user equipment where it benefits from the term space for antennas and reducing the level of processing required by the receiver for redundancy coding. This results in optimization in the size, cost and consumption of the battery.

### 3.6. MIMO (Multiple Input Multiple Output)

The MIMO mode uses more than one transmits antenna from which the signal can be transmitted through any antenna and follow any path to reach the receiving end as shown in the Figure 4. In simple words, it takes advantage of the multi-journey environment by using the different antennas located at different points where the path followed by the signal depends on the position of the antenna, hence when moving the antenna in a small position, the path will be changed. Fainting introduced into the signal from several paths can be described as multi-trip fainting as a result of different objects appearing between the transmitter and the receiver [1, 8, 14, 28].

Previously, these multiple paths were only used to introduce interference with providing additional channel/data throughput robustness which results in a subsequent improvement in the SNR.

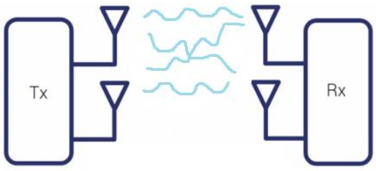


Figure 4. MIMO configuration type.

In spatial diversity, the signal is transmitted simultaneously on different antennas during the broadcast. A simplified version is used to improve the signal-to-noise ratio and improve the system's performance against different types of fainting. As a result, the diversity implies an increase the signal-to-noise ratio but requires that the MIMO sub-channels have to be decoupled as much as the MIMO spatial multiplexing give significant characterized by the division of each message into sub-messages on each of the transmission antennas which is leads to increases transmission rates and improves capacity [33].

The problem is that the maximum amount of data that can be transmitted via a radio channel is limited by the physical limits defined in the Shannon law which defines the maximum rate at which data can be transmitted without error over a given bandwidth in presence of noise [30]. It is expressed as the following equation:

$$C = N\, B\, log_2(1 + SNR)[bit/s] \qquad (2)$$

Where $C$ is channel capacity, $B$ is channel bandwidth, $N$ number of $SNR$ spatial flows the signal-to-noise ratio.

The equation shows that when increasing the signal-to-noise ratio of a channel results in marginal gains in channel flow. So, the traditional way to achieve high data throughput is to increase the bandwidth of the signal. The problem with this increase in width while increasing the flow of symbols of a modulated carrier causes a rather significant increase in the sensitivity to weakness by multiple routes. A partial solution to the multiple-trip problem has been mentioned, using a series of overlapping narrow-band subcarriers [17]. Not only the use of overlapping OFDM sub-carriers evolves spectral efficiency, but also some of the lower symbol rates used by subcarriers narrow-band carriers play an important role in combating the impact of multi-route signal products.

Antenna Systems MIMO have been operating for years in the wireless standard, citing IEEE 802.11n, 3GPP LTE and WiMAX mobile systems, and takes into account a high data rate against any type of interference, signal fade and multiple paths. The demand for an improvement in high data throughput over a long distance considers one of the main motivations behind the evolution of Orthogonal Frequency Division Multiplexing (OFDM) communication systems [27].

Because of some issues of multiple-way propagation that requires different signal paths, MIMO communication systems have developed an important solution that consists in operating via various combinations of antennas so that the signal can route several routes to acquire information about the channel. With the use of the spatial dimension of a communication link, the advantage offered by MIMO communications systems is to achieve significantly higher data rates than traditional SISO channels [36].

In a 2x2 MIMO system, through channel knowledge, a receiver can recover and generate two independent spatial streams from each of the transmitter's antennas; the scheme plays role in achieving a maximum bit rate that is effectively doubles that of a 1x1 SISO communication system. Whereas beam forming considers being the major novelty that traffic signalling using different antennas to control the direction allows to concentrate at multiple users in different desired directions and not to broadcast without distinction the entire environment as is the case today with 4G antennas [12]. The same signal could propagate via several antennas separated by a space between them (at least ½ wavelengths), while the receiver could receive copies of the same signal, while the destructive or constructive signals appear based on the phase's copies [9, 31]. However, spatial multiplexing equipped by a large number M of antennas to serve a number K of users under the assumption M >> K as shown in Figure 5.

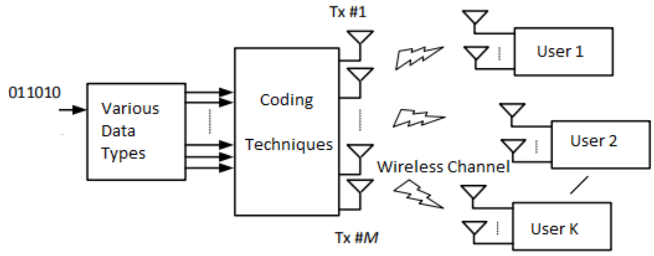


Figure 5. Spatial multiplexing.

The number of antennas in the transmitter-receiver assembly is respectively M and N with the following the radiation signal through the radio propagation channel concept, while the data stream is conducted after having undergone coding and modulation. The signal received at time t is expressed as in the following equation:

$$y_j(t) = \sum_i h_{ij} X_i(t) + n_j(t) \qquad (3)$$

Where:

$$X(t) = [X_1(t), X_2(t), \dots\dots\dots\dots\ X_N(t)]$$

$$H = \begin{bmatrix} h_{11} & h_{12}\cdots & h_{1m} \\ h_{21} & h_{22}\cdots & h_{2m} \\ \vdots & \vdots \ \ddots & \vdots \\ h_{n1} & h_{n2}\cdots & h_{nm} \end{bmatrix}$$

$$n_j = [n_1, n_2, \ldots n_M]^T$$

Where *H* is the channel matrix of the (i-th) interference signal, *X*(*t*) is the source data signal, n (t) is AWGN (additive white Gaussian noise), and is the channel response between the transmitter and receiver antenna [6, 35].

However, through analysis SNR also could explain the performance clearly between SISO as a normal case and MIMO case as shown at the next two Figures 6 and 7.

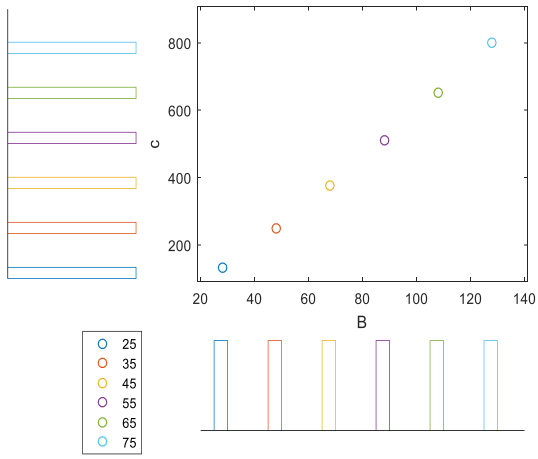


Figure 6. SISO case analysis.

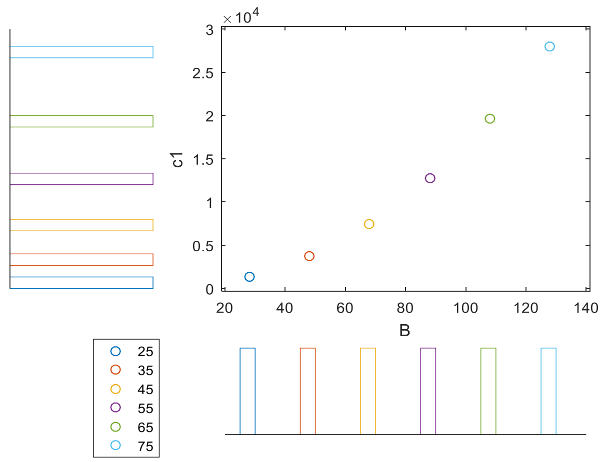


Figure 7. MIMO case analysis.

## 4. Result and Discussion

For a convenience the study assumes most significant SNR rate in a range start from 25 up to 75dB and give a sound to variation station SNR rate; for instance, the first one has a received signal of -65 dBm and a noise of -90 dBm which obtained 25dB SNR, the estimation just to let the reader familiar with the concept. Consequently, the main advantages of Massive MIMO could cover various aspects such as high spectral efficiency gain through the M antennas at the base station, serving K users at a single antenna. High spectral efficiency is achieved by spatial multiplexing of multiple terminals sharing the same time-frequency resources during communication, whereas due to a large number of antennas, it could play a key role in the simplicity of signal processing. In addition to that, increasing antennas provide more diversity and hence improve reliability and entire performance. Moreover, processing results consistency would a reduction of power radiation and cut cost-effectively, and a large number of the antenna at the receiver makes massive MIMO resilient against fading.

From the SISO and MIMO prospective and under the same conditions such as bandwidth B and SNR values, the calculations capacity in SISO (c) and in MIMO (c1) could demonstrate a notable improvement such as increasing SNR would lead to higher capacity at MIMO exponentially while steady equally at SISO. Also, from 25 up to 35dB the slow gradual has happened at MIMO and then start to higher enhancement. Overall, the lowest capacity in MIMO which is considering 1000 is higher than the highest capacity at SISO which is 800.

Accordingly, to provide a suitable comparison between them in terms of SNR and Capacity utilizing their equation formulation, the comparison of the entire technologies, including MIMO, is necessary for a comprehensive understanding. Figure 8 shows clearly the comparison

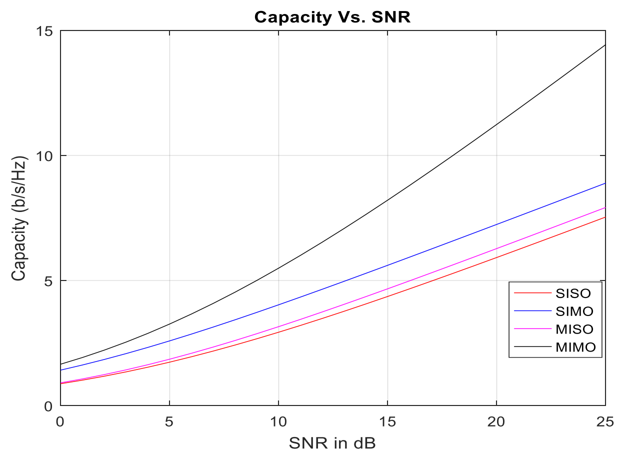


Figure 8. SISO, MISO, SIMO, and MIMO analysis.

Where the key elements can be evaluated in Table 2 to determine which system is better for a given application:

Table 2. Evaluation applications.

| Factor | Best Practice Technology | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| **Data rate** | MIMO | MISO | SIMO | SISO |
| **SNR** | MIMO | MISO | SIMO | SISO |
| **Link reliability** | MIMO | SIMO | MISO | SISO |
| **Tx Power Consumption** | SISO | SIMO | MISO | MIMO |
| **Tx Complexity** | SISO | SIMO | MISO | MIMO |
| **Tx Cost** | SISO | SIMO | MISO | MIMO |
| **Spectrum Efficiency** | MIMO | MISO | SIMO | SISO |
| **Lower Latency** | MIMO | MISO | SIMO | SISO |

From the evaluation point of view, given the limited number of antennas, SISO systems often have a lower data rate than MISO or SIMO systems when comparing the amount of data that can be transmitted in a given amount of time. Due to the use of multiple transmit antennas, MIMO and MISO often have greater Signal-to-Noise Ratios (SNR) than SISO or SIMO systems. SNR is a measurement of the ratio of the signal power to the noise power. Due to the employment of multiple receive antennas, MIMO and SIMO systems typically offer higher link reliability than SISO or MISO systems in terms of the probability that a transmitted signal will be successfully received. MIMO often uses more power than SISO systems since it uses multiple antennas, which is a significant consideration when calculating the Transmit Power Consumption factor in wireless systems. MIMO and MISO are typically more complex than SIMO and SISO because they require the use of multiple antennas and signal processing methods. The Transmitter Complexity Factor assesses how challenging the system is to develop and install. Due to the usage of many antennas and signal processing technology, MIMO often has a greater cost than SISO when considering the system cost in any design. Another important factor in monitoring systems effectively is spectrum efficiency. MIMO often has a higher spectrum efficiency than SISO since it can transmit data via several spatial channels. Finally, the lower latency addresses the delay between transmitted and received signal. Because MIMO and MISO may simultaneously send multiple signals, they often have lower latency than SISO.

## 5. Conclusions

In this paper a review study of Massive MIMO technology presented which could provide an impressive gain in network performance by simply directing radiated waves, precise directions, and exceedingly data rate receiver, while due to aggressive spatial multiplexing, the radiated energy is heavily concentrated on user-centred areas and offers the reliability of the link. The study also offered a comparison result using evaluation performance elements to distinguish between best practice technology in terms of MIMO generations, and the result demonstrates despite some limitations of MIMO but considered the best technology in data rate, SNR, link reliability, spectrum efficiency, and lower latency. The revolution development of technology pave the way to accommodate more data rates and hence keep up with the upcoming generation's demands, while MIMO technique through serve by focusing power to bring vast improvements in throughput and send out energy efficiency with reduced latency via avoid fading dips would be indispensable for the next wireless generations and could supply unprecedented outcomes with considering the other connection parameters and many deployment MIMO base station scenarios that can be envisioned such as cylindrical, rectangular, and distributed antenna configuration. The future work could look into the Dynamic Massive MIMO Directivity.

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## Conflicts of Interest

The authors of the study have no conflicts of interest to declare.

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