
Quality Improvement of Wireless Mobile Communication Systems

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Abstract: Within the last two decades, communication advances have reshaped the way we live our daily lives. Wireless communication has grown from a relatively obscure service to an omnipresent technology that serves almost half of the people on Earth. Wireless communication systems designers are faced with several challenges. These include the limited availability of the radio frequency spectrum and a complex time-varying wireless environment (fading and multipath). In addition, meeting the increasing demand for higher data rates, the better quality of service (QoS), fewer dropped calls, higher network capacity and user coverage calls for innovative techniques that improve spectral efficiency and link reliability. The system employing MIMO offers a powerful paradigm for meeting these challenges. MIMO wireless is an emerging cost-effective technology system, that is used to enhance the data transfer rates both at device and network levels. It incorporates multiple antennas both the transmitter and receiver end in a wireless system, popularly known as space-time (ST) wireless or multiantenna communications or smart antennas technology to accommodate more data and ultimately leads to improvements in these measures. This paper presents a Quality improvement of wireless mobile communication systems that leads to the emergence of new ideas and techniques to increase performance in terms of reliability, spectral efficiency, and improved radiated energy efficiency. The use of a large number of antennas results in high throughput, increased spectral efficiency per unit area, enhanced diversity, and compensation for the path loss of the existing and future mobile networks. In this paper, we review and analyze two types of antennas theoretically and practically to have a clear view regarding how the signals are processed in all the two types and what are the advantages and limitations of using each of them, and what are the limitations in SISO, which makes the MIMO technique the most suitable among the two. Also, we have compared all of them practically using BER (comparison parameter) to support the theoretical analysis. Based on the analysis obtained we can derive that MIMO provides the next major leap forward for wireless communications and has led this technology to become the next frontier of wireless communications. As a result, it has received the attention not only of the international R&D community but also of the wireless communications industry.

Keywords: Adaptive Antenna, Interference, Phased Array, QoS, Signal Propagation, Smart Antennas, Multiple-input Multiple-output (MIMO) Systems

1. Introduction

As with fixed communication systems, the performance of wireless mobile communication networks is indicated by several parameters such as channel capacity, throughput, data transmission rate, quality of signal reception/ accuracy, and the reliability of communication services [1]. A high-quality performance can be better achieved if communication

engineers consider and implement the standard requirements of planning, operating/maintaining, and optimizing wireless networks [2].

The main factors that determine the success of wireless network applications in each generation of communication technology are the QoS, complexity, and flexibility of the system, economic costs, and power consumption. It should be noted that there is a trade-off between the complexity of

wireless communication systems and their implementation costs. More advanced wireless communication systems are more expensive to implement and maintain. In the typical wireless communication system illustrated in Figure 1, there are three components involved in the communication process: users (both at the source and destination) of the intended data/information; the communication equipment, referred to as transceivers (transmitter and receiver) and the communication link. To improve the quality of communication services there is little the engineer can do with the users and the channel condition. The only possible ways to maintain high-quality communication are exploiting the potential benefits of the communication equipment and manipulating the data/information inside the transceivers by employing sophisticated tools/techniques.

Over the years, many techniques have been employed to address some of the challenges associated with the development of wireless communication systems. The usual technique to improve the S/N ratio in wireless communication networks include: (a). Directional antennas to reduce multipath effects and consequent symbol delay; (b). Low noise electronics; (c). The selective null of interference; (d). Reduced bandwidth to minimize the effect of incoherent noise. The other techniques include but are not limited to modulation techniques, and intelligent directional antennas (also known as smart antennas) [3, 4]. Various multiple access methods are available at presents such as FDMA, TDMA, CDMA, and OFDM. Using one of these multiple access techniques will significantly resolve bandwidth problems associated with cost and size. Meanwhile, coding and modulation are two different techniques that are usually

applied together, interactively, to boost the performance of communication from the transmission error.

This error is due to poor signal quality (transmitted or received) or the effects of some natural phenomena such as noise and multipath propagation problems (fading, interference, delay spreading, etc.). Commonly used coding techniques in the communications discipline include Manchester coding, convolutional coding, trellis coding, Viterbi coding, STC technique, and turbo coding. The modulation techniques can be in the form of BPSK, QPSK, QAM, M-array PSK, FSK, ASK, etc.

Multiple array antenna techniques are also referred to as space-time coding (STC). STC exploits the potential benefit of multiple array antennas set up. The application of multiple antennas in communication systems could enhance the efficiency of the dedicated bandwidth spectrums to users [5]. It is especially useful when addressing the presence of a multipath propagation environment due to some random events, such as reflection, scattering, and diffraction. Thus, the quality of RF signal power is maintainable. Another promising method that could be applied in the large infrastructure of wireless communication systems is the combination of coding and modulation techniques. This could improve the capacity, efficiency, and optimal reuse frequency of wireless networks. To achieve those system performances, [6] outlined two other possible methods: the optimal wireless system configuration and the RF power steering. Moreover, [6] argued that the optimum design of RF signal control in the complex wireless environment correlated to the efficient compactness of technology.

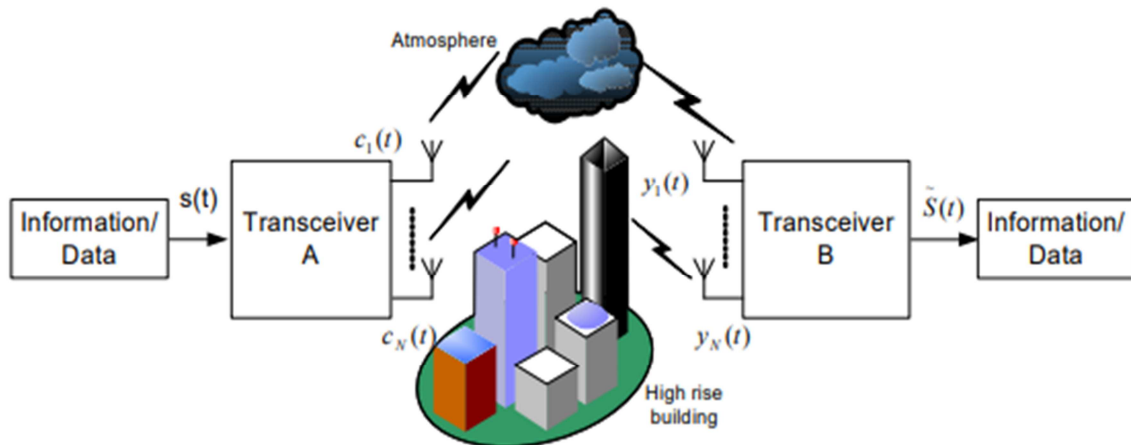


Figure 1. Communication employed multiple antennas.

2. Signal Propagation

The general trend in the development of wireless communication is the use of higher data rates (broader frequency band), propagation in more complex environments, employment of smart antennas, and use of multiple-input multiple-output (MIMO) systems. Before implementing designs and confirming the planning of

wireless communication systems, accurate propagation characteristics of the environment should be known. Propagation prediction usually provides two types of parameters corresponding to the large-scale path loss and small-scale fading statistics. The path-loss information is vital for the determination of coverage of a base station (BS) placement and for optimizing it. The small-scale parameters usually provide statistical information on local field variations and this, in turn, leads to the calculation of

important parameters that help improve receiver (Rx) designs and combat multipath fading as shown in Figure 2 and Figure 3 respectively. Without propagation predictions, these parameter estimations can only be obtained from field measurements which are time-consuming and expensive. Smart antenna systems exploiting space diversity require information on the angle of arrival of the multipath in addition to the usual parameters such as path loss and delay spread. A MIMO system uses the multipath to provide higher capacity [7, 8], completely different from the classical systems where multipath is considered harmful. All these new systems involve space-time and space-frequency channel models. The problem of capacity has been associated solely with cochannel interference and with the depletion of channels due to the high number of users. However, multipath fading and delay spread also play a role in reducing system capacity [9, 10]. Fortunately, because of the ability of smart-antenna systems to adapt to the signal environment, they can considerably reduce delay spread and multipath

fading, thereby increasing capacity. This section gives a brief overview of signal propagation; for an in-depth study of the subject, the reader is referred to [11, 12].

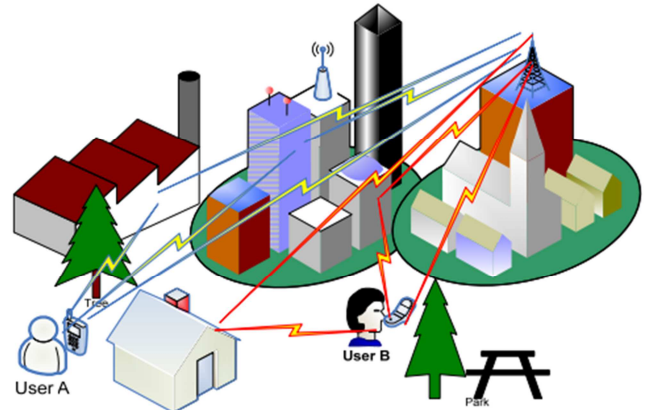


Figure 2. Multipath Fading environment in a wireless communication system.

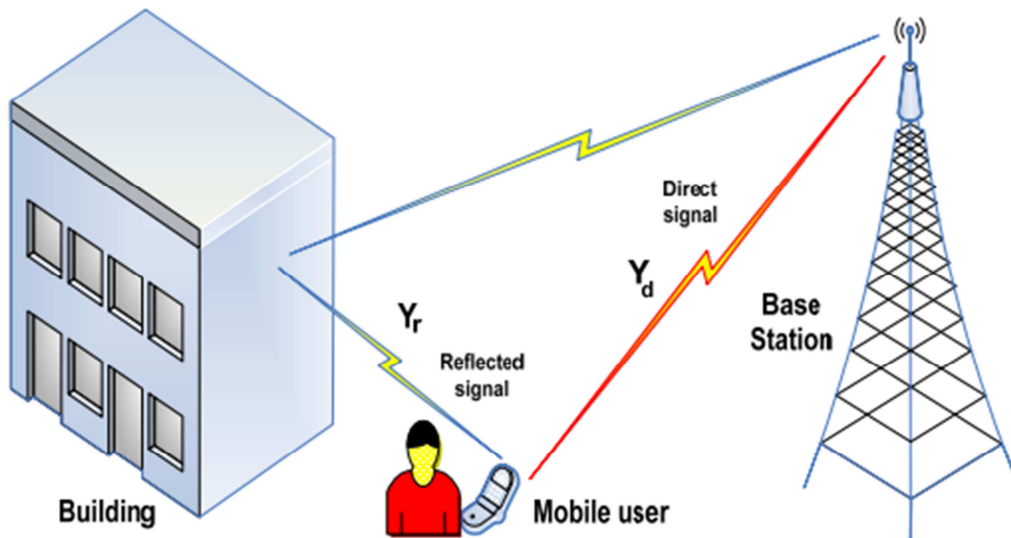


Figure 3. Two path links due to reflection from a high building in the cellular network area.

3. Smart Antennas as a Solution

Sectorization of cells is the common technique used in present mobile communication systems to reduce interference and hence increase capacity. This is achieved by employing dedicated antennas and RF coverage in each sector. The main disadvantage of the current sectorization scheme is that it becomes inefficient, with the increase in the number of sectors because of the antenna pattern overlaps and the increase in the number of handoffs within the cell. Smart antennas have been offered as a more efficient technique to reduce interference in mobile communications systems using directing narrow beams towards a desired user/clusters of users while focusing nulls towards interfering users. This interference reduction means the improvement of the system capacity. Furthermore, as a smart antenna's high directional gain can improve the link budget, an increase in coverage and range can also be expected. A smart

antenna is an array of antenna elements connected to a digital signal processor. Such a configuration dramatically enhances the capacity of a wireless link through a combination of diversity gain, array gain, and interference suppression. Increased capacity translates to higher data rates for a given number of users or more users for a given data rate per user. With the exponentially increasing demand for wireless communications, the capacity of the current cellular system will soon become incapable of handling the growing traffic. Since radio frequencies are diminishing natural resources, there seems to be a fundamental barrier to further capacity increase even in hierarchical cellular infrastructure. The solution can be found in smart antenna / adaptive antenna systems which utilize the SDMA approach. The principle of SDMA is quite different from the beamforming approaches. The operation of SDMA is analogous to that of human hearing (Intelligent System approach). As you can identify the direction from which the desired signal is coming with remarkable accuracy with the help

of a computer system inbuilt into the adaptive antenna system. Because SDMA employs spatially selective transmission, an SDMA base station radiates much less total power than a conventional base station. One result is a reduction in network-wide RF pollution. Another is a reduction in power amplifier size. First, the power is divided among the elements, and then the power of each element is reduced because the energy is being delivered directionally. With a ten-element array, the amplifiers at each element need only transmit one-hundredth the power that would be transmitted from the corresponding single-antenna system. Space Division Multiple Access (SDMA) can be used to multiply the capacity given by conventional multiple access techniques such as FDMA, TDMA, and CDMA. However, the actual capacity gain, which can be achieved with SDMA is highly dependent on the SDMA channel assignment and the considered scenario (propagation, user distribution, traffic, mobility, etc. [13-15].

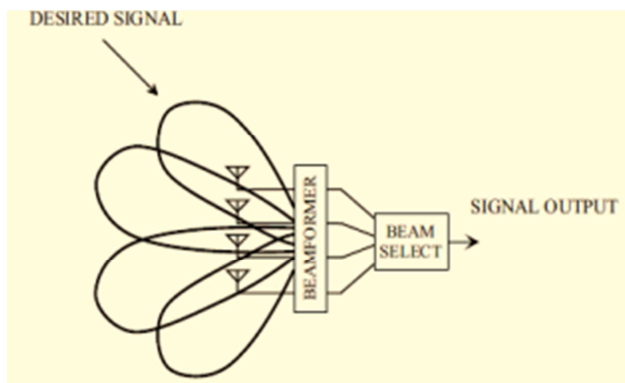


Figure 4. Phased array [16].

3.1. Types of Smart Antennas

There are two types, a phased array and an adaptive array [16].

3.1.1. Phased Array

A phased array antenna uses an array of simple antennas, such as omnidirectional antennas, and combines the signal induced on these antennas to form the array output. Each antenna forming the array is known as an element of the array. The direction where the maximum gain would appear is controlled by adjusting the phase between different antennas as shown in Figure 4. The phases of signals induced on various elements are adjusted such that the signals due to a source in the direction where the maximum gain is required are added in phase. This results in the gain of the array (or equivalently, the gain of the combined antenna) being equal to the sum of the gains of all individual antennas.

3.1.2. Adaptive Antenna Array

The term adaptive antenna is used for the phased array when the gain and the phase of the signals induced on various elements are changed before combining to adjust the gain of the array dynamically, as required by the system. In a way, the array adapts to the situation, and the adoption process is normally under the control of the system. This

essentially puts the main beam in the direction of the desired signal and nulls in the direction of the interference as shown in Figure 5. The basic aim of a mobile adaptive antenna system is to improve the performance of the system in the presence of both noise and interference.

3.2. Applications [16]

A smart antenna uses a phased or adaptive array that adjusts to the radio environment. For using the phased array, the beam is steered or different beams are selected as the desired user moves. For using the adaptive array, the beam pattern changes as the desired user and the interference move. The use of a switching beam or adaptive beam for tracking is shown in Figure 6. The advent of powerful low-cost digital signal processors (DSPs), general-purpose processors (and ASICs), as well as innovative software-based signal-processing techniques (algorithms) have made intelligent antennas practical for cellular communications systems as shown in Figure 10. These systems are providing greater coverage area for each cell site, higher rejection of interference, and substantial capacity improvements Figure 11 shows an overview of the benefits that can be achieved from the deployment of adaptive (smart) antenna mobile communications networks.

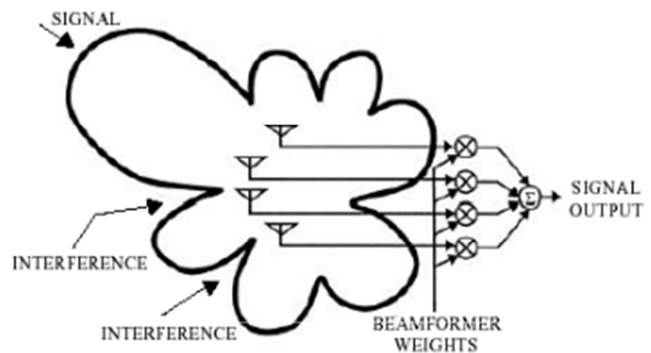


Figure 5. Adaptive array [16].

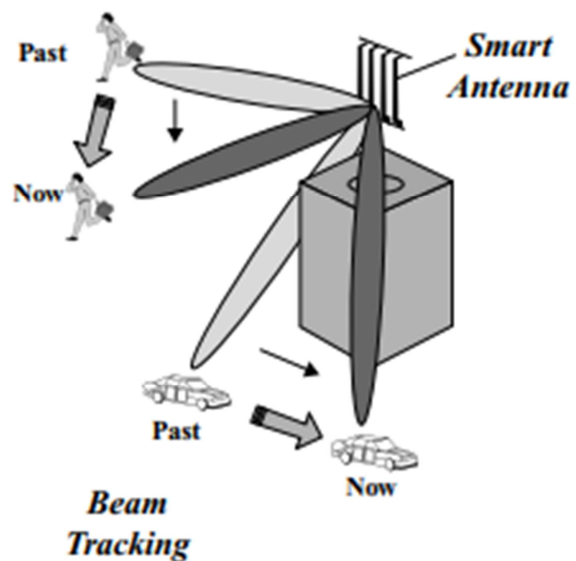


Figure 6. Smart antenna technology—Beam Tracking.

4. Multiple Antenna Communications

The wireless communication industry is currently experiencing a prolonged exponential growth in the demand for network traffic with no sign of it slowing down; the same is expected for the number of connected devices. Current networks are reaching their capacity limits concerning the physical layer (because of the so - called 'spectrum deficit' or 'data tsunami'), especially in highly populated urban areas with a high density of connected devices.

A seminal information theory paper by Foschini and Gans of Lucent Technologies [4] shows that the capacity of these systems can increase linearly with the number of transmit antennas as long as the number of receive antennas is greater than or equal to the number of transmit antennas. As an increase in capacity means the capability of faster communication, this unmatched capacity improvement over regular one-antenna systems has fueled a huge interest in MIMO techniques, thus leading to the development of many forms of MIMO systems.

Wireless communication systems with one transmit and one receive antenna are denoted as single-input single-output (SISO) systems, whereas systems with one transmit and multiple receive antennas are denoted as single input multiple output (SIMO) systems, and systems with multiple transmit and one receive antenna is called multiple-input single-output (MISO) systems. The SISO systems offer limited data rates; researchers have been looking forward to new techniques to achieve high data rates. It is found that the multiple antenna configuration is one of the best solutions to overcome this problem. Therefore researchers have strained different techniques such as Multiple Input Single Output (MISO), Single Input Multiple Output (SIMO), and MIMO. Although SIMO and MISO use multiple antenna techniques, they do not offer the amount of data rates that are required. The use of multiple antennas at transmitter and receiver, popularly known as multiple-input multiple-output (MIMO) wireless is an emerging cost-effective technology that offers substantial leverages in making 1-Gb/s wireless links a reality. Wireless communication which is inherently limited by the available spectrum and impaired by path loss, interference, and

multipath propagation difficulties can be erased using an efficient wireless transmission scheme of multiple-input multiple-output (MIMO) smart antenna systems. MIMO technology provides a promising improvement in link capacity, enhanced data rate demands of audio/visual (AV) applications or link reliability, range, network availability, and energy usage [17, 18]. Table 1 show the theoretical comparison of SISO and MIMO antennas system.

The most recent, and arguably more powerful, application of adaptive antennas is the class of systems known as MIMO systems. This antenna technology for wireless communication used multiple numbers of controllable antennas. In 2017, it has been deployed 4X4 MIMO, which supports 32 antennas at the base station, this configuration is called Full-Dimension MIMO. The main role of Massive MIMO is limiting path loss by using high antenna gain, which implicates improving coverage (by 6dB - 9dB); to be precise, the antenna gain is controlled by the output power, the number of antenna elements, and the number of transceivers. The MIMO technique exploits both uplink and downlink to enhance the transmission reliability and data rate. MIMO increases spectral efficiency with low latency via simultaneous transmission of streams to many users. The system capacity is enlarged by installing many antennas in the base station [20]. Besides, it provides interference reduction capability, diversity gain, and spatial multiplexing gain [21].

In wireless communication, MIMO has been introduced in the new IEEE 802.11n standard [IEEE P802.11n] to improve the transmission quality as well as the system's spectral efficiency. The IEEE 802.11n.

The physical layer supports data rates up to 600 Mbps in 4 × 4 MIMO configuration and 40 MHz bandwidth. Different communication standards include IEEE 802.11n (Wi - Fi), HSPA+ (3G), Wi - MAX (4G), and LTE (4G). Recently, it has been used for Power Line Communication for three-wire installations as a part of ITU G.hn standard and Home Plug AV2 specification. Figure 7 shows a cellular base station and a Wi - Fi access point, both equipped with multiple antennas which is an example of MIMO technology used in our everyday life [22-25].

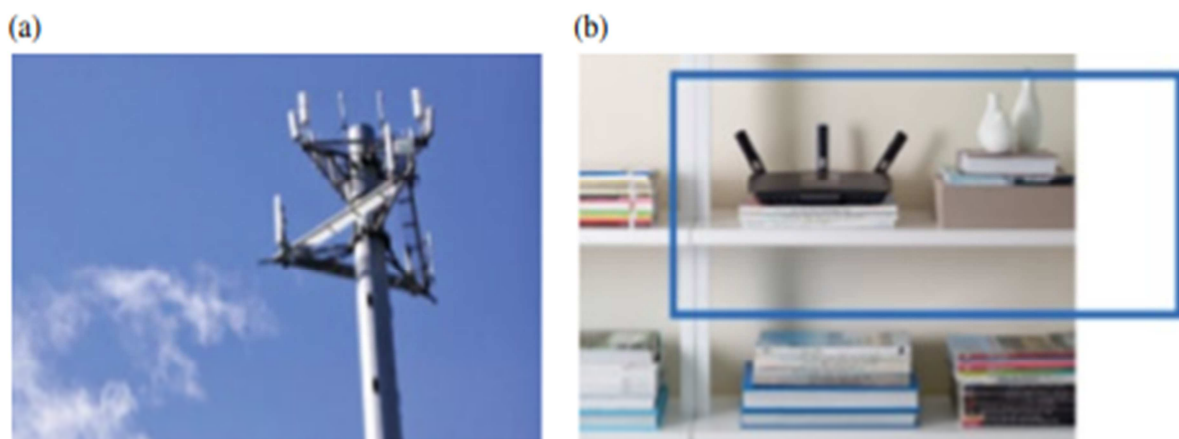


Figure 7. (a) A cellular base station tower with multiple antennas; (b) a Wi-Fi access point with multiple antennas [26].

Table 1. Theoretical comparison of SISO and MIMO Antennas System.

Type	T _x antenna	R _x antenna	Data rates	Capacity	Coverage	Applications
SIMO	Single	Single	Less	Less	Less	Wifi, TV, Radio Broadcasting.
MIMO	Multiple	Multiple	greater	greater	greater	It is cleared that the success of MIMO system integration into commercial standards such as 3G, 4G, WiMAX, WLAN, LTE, OFMD, IDMA, etc.

Table 2 provides a summary of the theoretical peak data rates for various DL/UL ratios assuming a 10 MHz channel bandwidth, 5 ms frame duration with 44 OFDM data symbols (out of 48 total OFDM symbols), and PUSC sub-channelization. With 2x2 MIMO, the DL user and sector peak data rate are theoretically doubled. The maximum DL peak data rate is 63.36 Mbps when all the data symbols are dedicated to DL. With UL collaborative SM, the UL sector peak data rate is doubled while the user peak data rate is unchanged. The UL user peak data rate and sector peak data rate are 14.11 Mbps and 28.22 Mbps respectively when all the data symbols are dedicated to UL. By applying different

DL/UL ratios, the bandwidth can be adjusted between DL and UL to accommodate different traffic patterns. It should be noted that extreme cases such as all DL and all UL partitions are rarely used. The DL/UL ratios range from 3:1 to 1:1 to accommodate different traffic profiles. The resulting peak data rates that will typically be encountered are in between the two extreme cases. Peak rate is often used to describe channel capacity and is a good metric for comparative purposes. It should be noted, however, that in practice the achievable peak data rates may be lower due to the specific traffic, propagation, and interference conditions encountered.

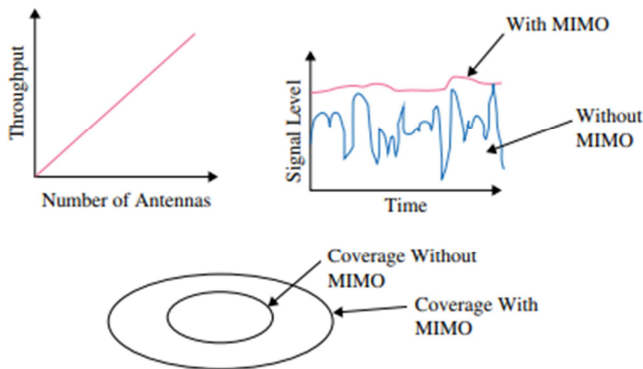
Table 2. Data Rates for SIMO/MIMO Configurations (For 10 MHz channel, 5 ms frame, PUSC sub-channel, 44 data OFDM symbols).

DL/UL Ratio			1:0	3:1	2:1	3:2	1:1	0:1
User Peak Rate (Mbps)	SIMO (1x 2)	DL	31.68	23.04	20.16	18.72	15.84	0
		UL	0	4.03	5.04	6.05	7.06	14.11
	MIMO (2x 2)	DL	63.36	46.08	40.32	37.44	31.68	0
		UL	0	4.03	5.04	6.05	7.06	14.11
Sector Peak Rate (Mbps)	SIMO (1x 2)	DL	31.68	23.04	20.16	18.72	15.84	0
		UL	0	4.03	5.04	6.05	7.06	14.11
	MIMO (2x 2)	DL	63.36	46.08	40.32	37.44	31.68	0
		UL	0	8.06	10.08	12.10	14.12	28.22

4.1. Combined Advantages of MIMO

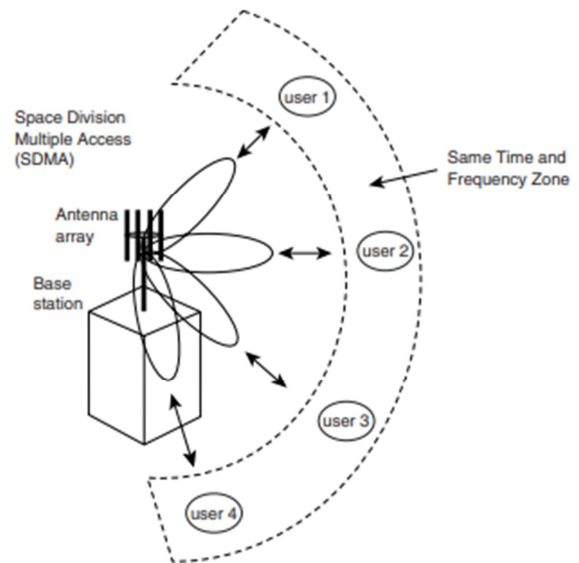
Throughput, signal level, and coverage of a wireless communication system increase with MIMO technology, as shown in Figure 8.

- 1) It provides better spectral efficiency at a low cost than the alternative antenna technology.
- 2) The MIMO system capacity grows linearly with several antennas. 2x2 MIMO doubles the capacity.
- 3) Supports both TDD and FDD techniques so can be used with earlier versions 802.11x to increase the data rate.
- 4) MIMO provides a high-speed wireless communication link to support a wide range of applications without increasing bandwidth or transmitted power.

**Figure 8.** Combined advantages of MIMO [27].

4.2. Disadvantages of MIMO systems

- 1) The disadvantages of the MIMO system are mostly the need for multiple antennae the cost of the equipment compared to existing equipment available and limited open driver support.
- 2) The main disadvantage is that its more complex
- 3) Requires more hardware

**Figure 9.** Smart antenna technology—SDMA.

MIMO refers to a link for which the transmitting end, as well as the receiving end, is equipped with multiple antenna elements, as illustrated in Figure 11 and Figure 12. The idea behind MIMO is that the signals on the transmit antennas on one end and that of the receive antennas on the other end are "combined" in such a way that the quality (Bit Error Rate) or the data rate (Bit/Sec) of the communication will be improved [14].

MIMO systems use space-time processing techniques that the time dimension (natural dimension of transmission signals) is joined with the spatial dimension brought by "smart antennas," a popular technology for improving wireless transmission. However, the underlying mathematical nature of MIMO environments can give a performance that goes well beyond that of conventional smart antennas. In particular, MIMO systems can turn multipath propagation, usually a

pitfall of wireless transmission, into an advantage for increasing the user's data rate and simultaneously improving the robustness of wireless links as shown in Figure 12.

In Figure 10, the data stream to be transmitted is distributed among different sub-channels, then goes through modulation and mapping, and is transmitted by corresponding antennas. Upon receipt, each receiving antenna receives three signals from the transmit antennas, then the entire received signal goes through signal processing to receive the desired signal [5]. The promise of MIMO techniques and the mechanisms to achieve it are on the horizon. The practical design of MIMO solutions involves both transmission algorithms and channel modeling to measure their performance as well as the radio network-level considerations and to evaluate the overall benefits of MIMO [15].

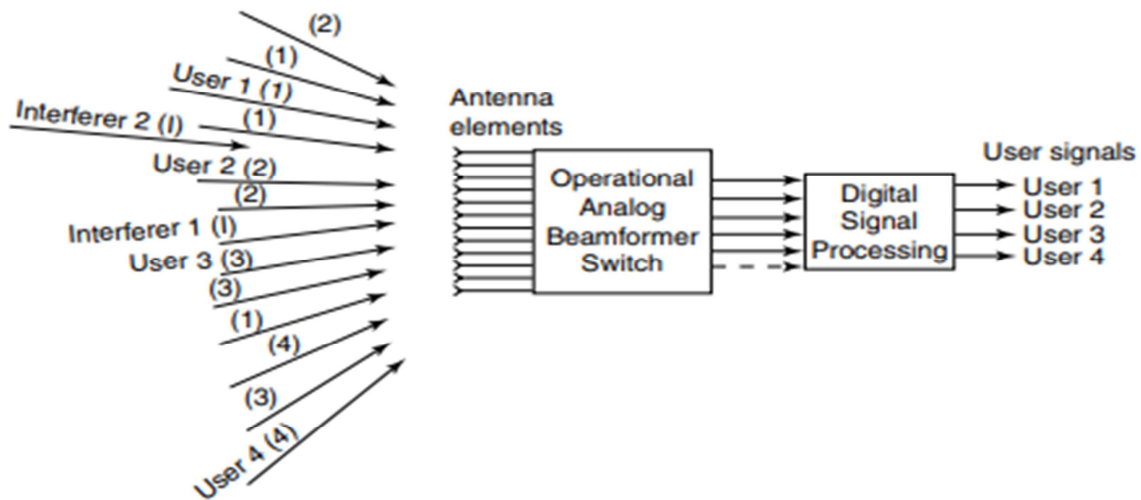


Figure 10. Smart antenna system.

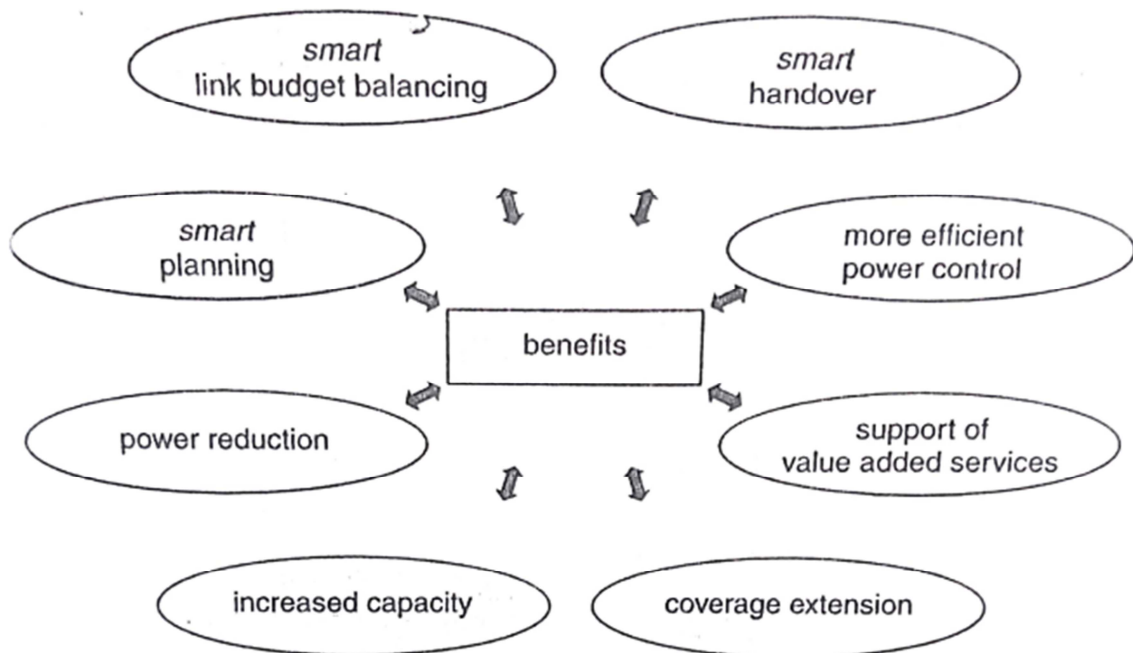


Figure 11. Benefits achieved with a smart antenna.

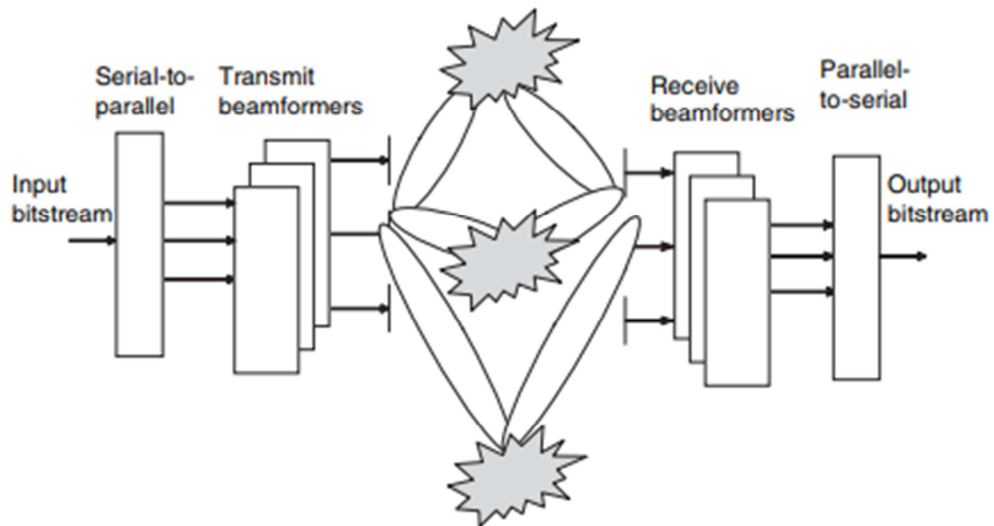


Figure 12. Basic MIMO.

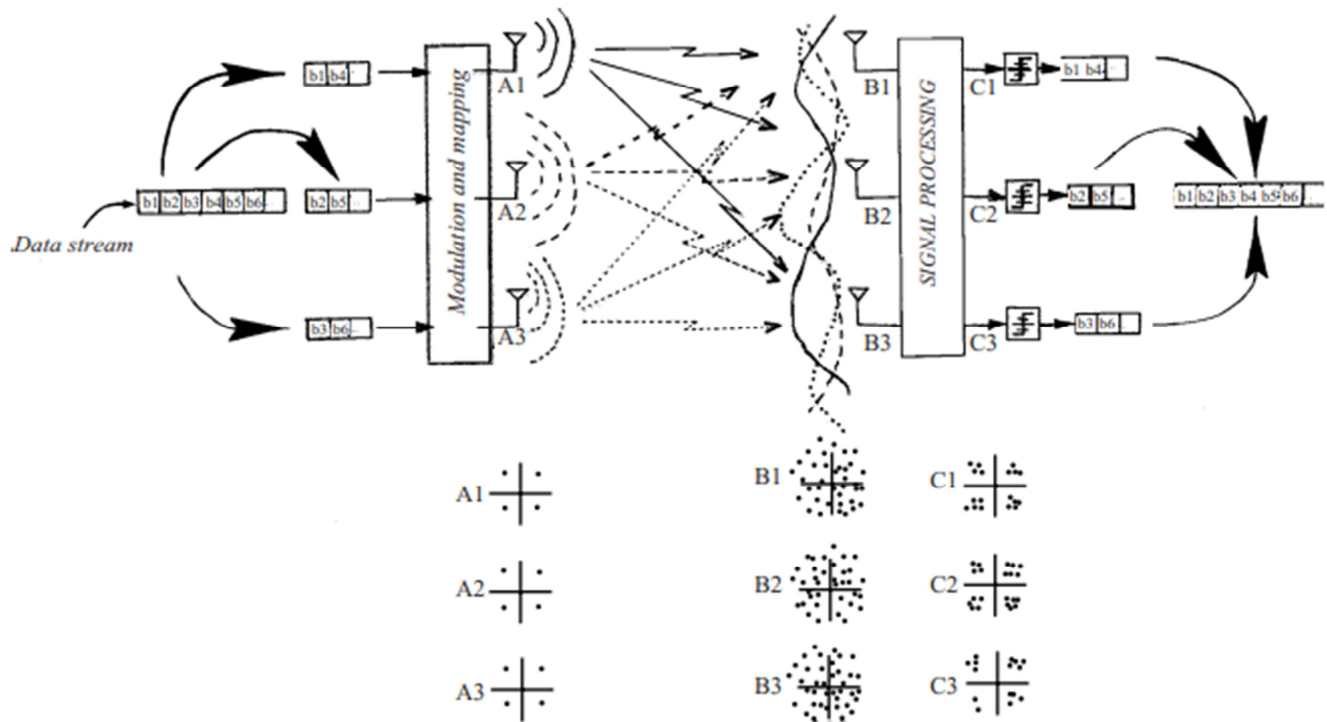
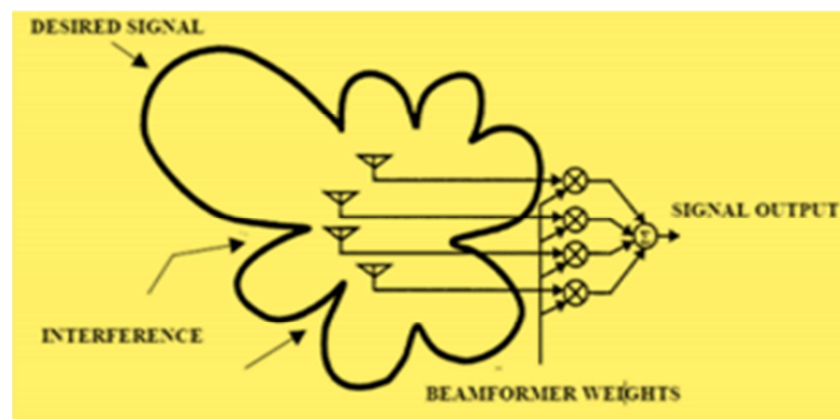


Figure 13. MIMO system.



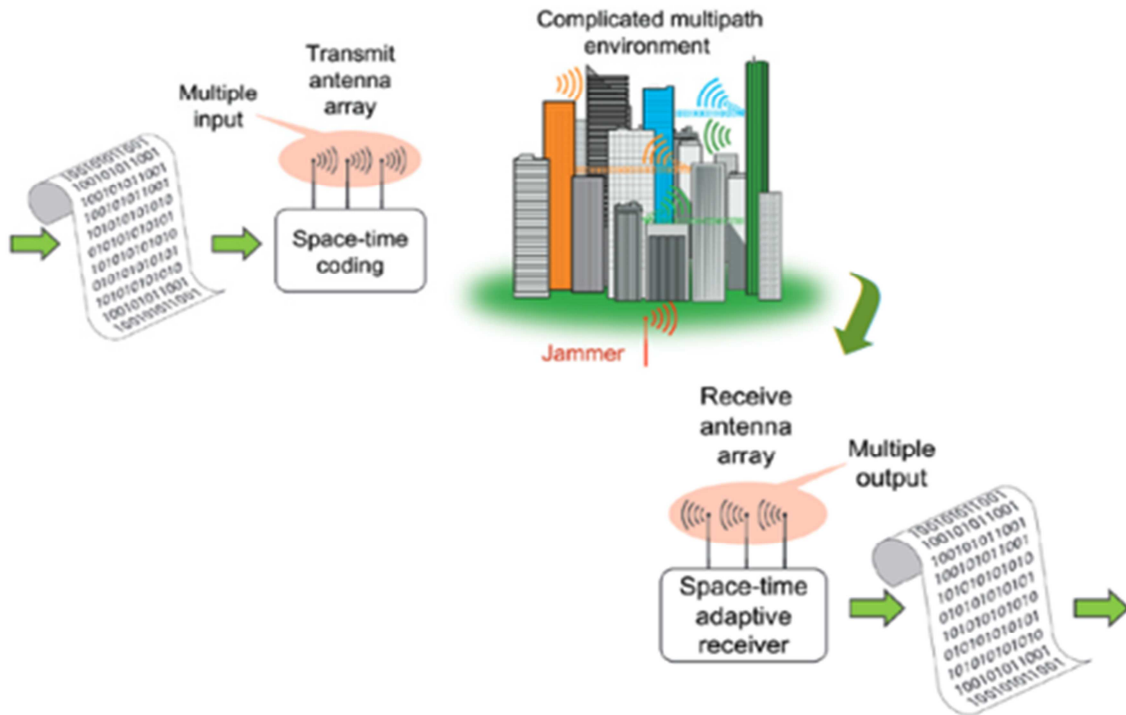


Figure 14. Multiple-input multiple-output communications links enable accurate data to be received despite a complicated multipath environment with jamming [18, 19].

5. Result, Analysis, and Discussion

BER (Bit Error Rate): The BER of any system is defined as the ratio of several error bits received to the total number of bits transmitted [3]. The error may get introduced by the fading effect while using different types of antennas. Mathematically, BER is given as:

$$\text{BER} = \text{No. of errors} / \text{Total number of bits} [28, 29].$$

Table 3 gives the comparative analysis of BER results obtained for SISO and MIMO types of antennas and the

practical analysis obtained also matches the theoretical analysis of the antennas.

Table 3. Practical Comparison of SISO and MIMO.

SNR (dB)\BER	SISO	MIMO
0	0.15	0.0405
2	0.11	0.0179
4	0.08	0.0067
6	0.06	0.00198
8	0.03	0.0005
10	0.02	0.00014

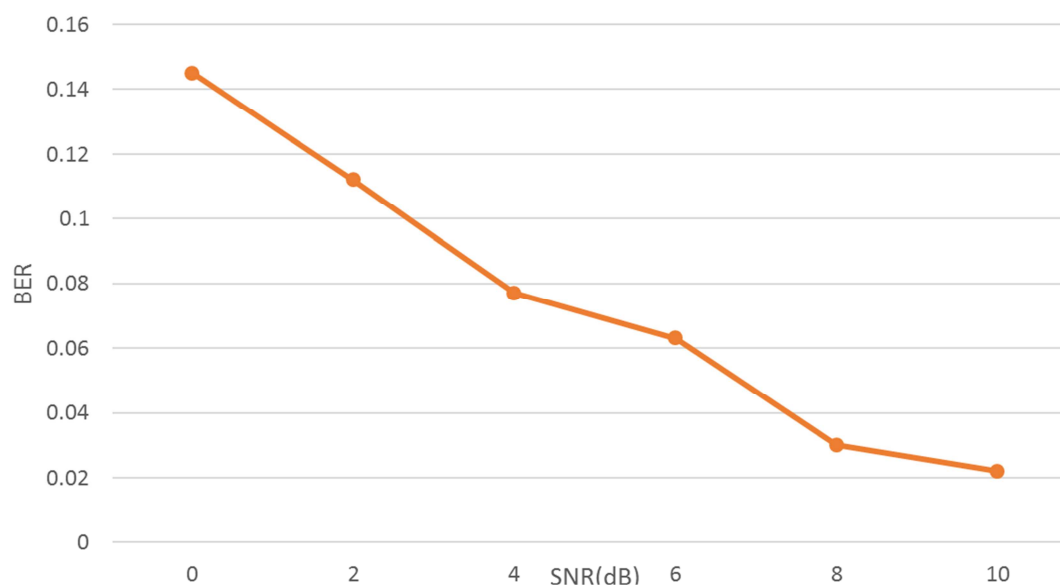


Figure 15. BER response of SISO System.

In Figure 15, we can observe that, as the SNR increases the value of BER is decreasing, which shows that the SISO system channel is limited in its quality as interference and fading is present.

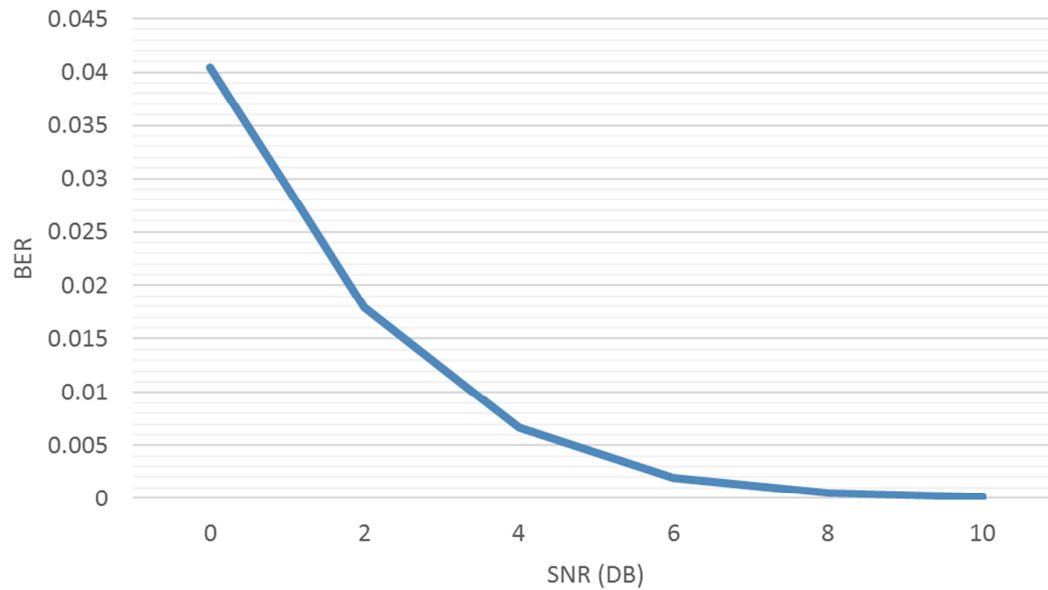


Figure 16. BER response of MIMO System.

The curve of MIMO gives the optimum result observed from the graph in Figure 16.

6. Conclusion

The economic and systems performance benefits overwhelmingly support the deployment of smart antenna systems in new, emerging networks to increase capacity and improve the QoS. The next generation of smart antennas allows for even greater benefits as it provides substantial leverages in making 1-Gb/s wireless links a reality. In this study, we analyze SIMO and MIMO types of antennas theoretically and practically (concerning OFDM) to have a clear view of how the signals are processed which makes the MIMO technique the most suitable. Also, in comparison parameter, practically using BER to support the theoretical analysis. Based on the analysis obtained we have deduced that MIMO is the best suitable for future wireless communication for transmitting the signals with the least fading, within optimized time with the best throughput and this will have led to the transformation in advanced wireless communication giving maximum data rate to all the users.

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