PERFORMANCE ANALYSIS OF ANTENNA TECHNIQUES ON WIRELESS COMMUNICATION SYSTEMS

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ABSTRACT

Performance analysis of antenna techniques on wireless communication systems was the focus of this work. This was brought about as a result of the ever-increasing demand for higher communication channel capacity and baud rates resulting from the global technological revolution informed by increased number of users. Hence, there is urgent need to device technique(s) to effectively combat these and other related challenges. Measurement data was sourced from one of the network service providers in Lagos, Nigeria. Four channel capacity enhancement of transmission schemes: Single Input Single Output(SISO), Single Input Multiple Output (SIMO), Multiple Input Single Output (MISO) and Multiple Input Multiple Output (MIMO) were investigated. Their performances in terms of capacity and bit error rates at the receivers' outputs were compared using a binary phase shift keying for Rayleigh fading channel. The results showed that MIMO antenna system have more capacity and higher reliability compared to other antenna systems. This is made possible owing to the larger number of antennas in its design. Also, the BER values for the MIMO are much lower than that of the other three antenna schemes, inferring better performances. Furthermore, better performance is observed as the number of antenna configuration increases on MIMO. Again, as the number of antennas at both ends increased, the channel capacity increased while the Bit Error Rate (BER) decreased, leading to improved reliability over and above the use of a single antenna channel. The findings of this work will be useful for network channel designers and mobile network service providers for 4G, 5G and Long Term Evolution (LTE) systems.

Keywords: BER, BPSK, Channel Capacity, CSI, MIMO, MISO, Rayleigh SISO, SIMO

INTRODUCTION

There ever-increasing demand for communication channel capacity and baud rate, which is a direct consequenceof various research works going on globally. Thishas resulted inurgent need to develop technique(s) to effectively encounter these and other related challenges.

MIMO (multiple input multiple output), wireless technology is one method through which channel capacity can be increased, higher data rate achieved;while also accomplishing increased transmit range and transmit power. Again, technical considerations such as cost, scalability and power has led to the implementation of Bi-antennas on 802.11n devices; hence MIMO technology have become one of the recent wireless methods that allows higher spectral resulting from scarcity of resources while also making better effective use of the available bandwidth (Bakare and Esther,2018).

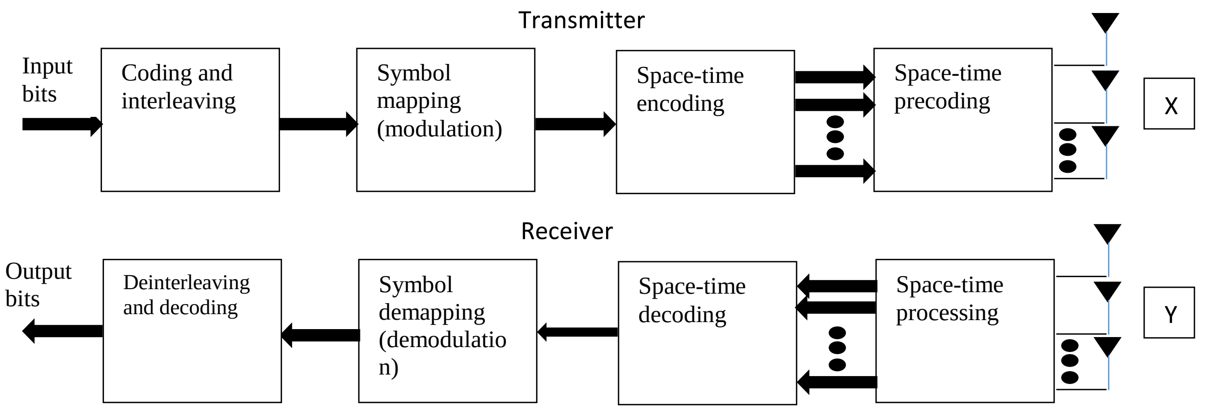

Fig 1: Block Diagram of Wireless Digital Communication Systems.
Source: Bakare and Esther (2018).

The quality of a wireless communication channel is determined by its availability, data rate, or itstechnologicalcapacity. According to Kumar et al. (2018), increasing the quality of the channel capacity increases the data rate and spectral efficiency of the radio wireless communication. The deployment of more than one transmit and receive antennas in the wireless system enhances the system throughput. With MIMO, channel capacity can be increased without additional requirement of transmit power and spectral efficiency bandwidth over SISO (single input single output) antenna system (Rayi and Chandra,2018). MIMO is an IEEE 802.11n standard, which according toMunshiet al. (2018), canachieve throughputs as high as 600Mps. Multi-antenna systems using MIMO technology would facilitatetherealization ofa potential data rate of 1Gbps target with high spectrum efficiency. Ando et al.(2018), reported thatMIMO technology performs pre-coding (multi-layer beam forming), diversity coding (space-time coding) and spatial-multiplexing, and that MIMO possess the ability to allocate the same total transmit power to multiple antennas in order to obtain a multiplexing gain that enhances the spectral efficiency and to achieve a diversity gain that improves the link reliability, in terms of quality of service (QoS). Other factors that could result in the enhancement of the channel performance include, the use of water filling algorithm, the availability of channel state information (CSI) at the transmitter and the receiver ends, as well as combining the system with orthogonal frequency modulation multiplexing (OFDM) to createa MIMO-OFDM technology, which is an air interface system for 4G and 5G technologies(Kennedu et al; 2018).

OVERVIEW OF EXISTING TRANSMISSION SCHEMES FOR SOMEANTENNA TYPES

Giiand Sahoo (2017), listed some of the commonwireless communication transmission schemes to include SISO, SIMO (single input multiple output), MISO (multiple input single output), and MIMO.

A. Capacityof SISOChannel

There is only one transmittingand receiving antennas each at both the transmitter and receiver ends, making it the easiest to design among all the four types. The block diagram of SISO system is shown in Figure 2.
S is input; Y is output;X_T: is Transmitting antenna;$Y_R$is Receiving antenna. The noise is introduced into the system when the signal is processing from X_T toY_R.

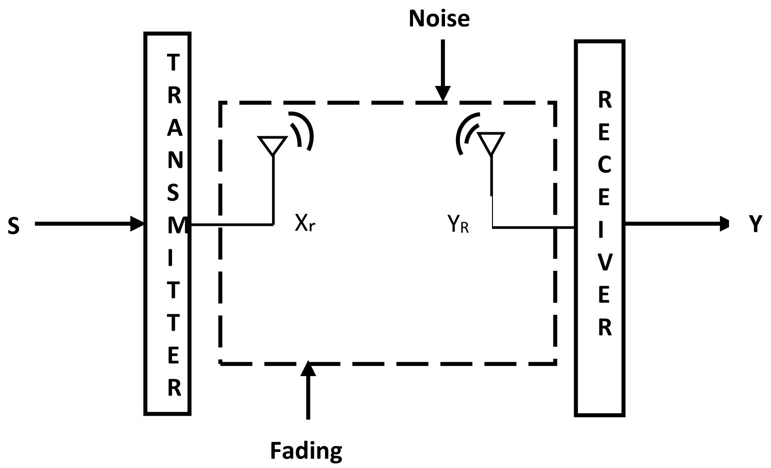

Fig.2**:** SISO Model
Source: Kumar et al. (2018).

According to Shannon’s law, the channel bandwidth of SISO is inadequate. Shannon’s law states that theoretical maximum rate at which error-free digits can be transmitted over a bandwidth-limited channel in the presence of noise, for SISO system is given as (Patil and Allen; 2017):

$$C_{SISO} = B log_2 (1 + SNR) \quad (1)$$

where C_{SISO} is capacity for the SISO channel, B is Bandwidth of the signal and SNR is the signal to noise ratio.

B. Capacity of SIMO Channel

A SIMO channel is a multi-antenna system with one transmitting antenna and several receiving antennas. This techniqueenhances the diversity at the receiving antennas(Shah; 2017).

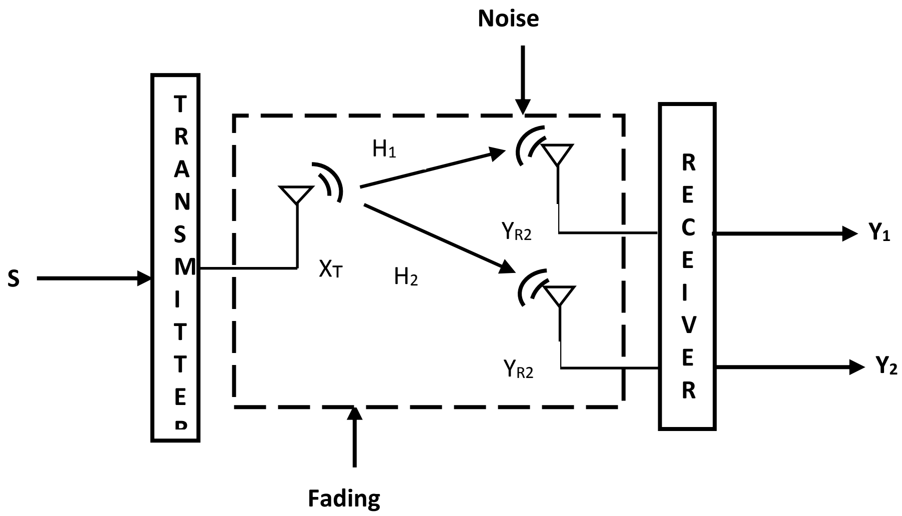

Fig. 3:SIMO Model
Source: Rayi and Chandra (2018).

As shown in Figure 3,S is the input,Y_1andY_2 are the outputs from two receiving antennas, $X_T$is the transmitting antenna, Y_{R1}andY_{R2} are the two receiving antennas;with diverse fading constants. In the receiving scheme, since there are numerous receiving antennas many kinds of signal receiving methods can be used like RAKE receiver. SIMO helps in refining the receiving diversity of the antenna because it gives stronger diversity than SISO, but there is no observed increase in channel capacity (Ella; 2017). The channel capacity of the SIMO system is given as (Sengaret al.; 2014):

$$C_{SIMO} = M_r B \log_2(1 + SNR) \qquad (2)$$

whereCis the capacity, M_r is the number of antennas used at receiver end, B is Bandwidth of the signal and $SNR$is the signal to noise ratio.

C. Capacity of MISO Channel

This system comprises several transmitting antennas with only one receiving antenna. Figure 4 depicts a MISO system with two transmitting antennas and one receiving antenna.

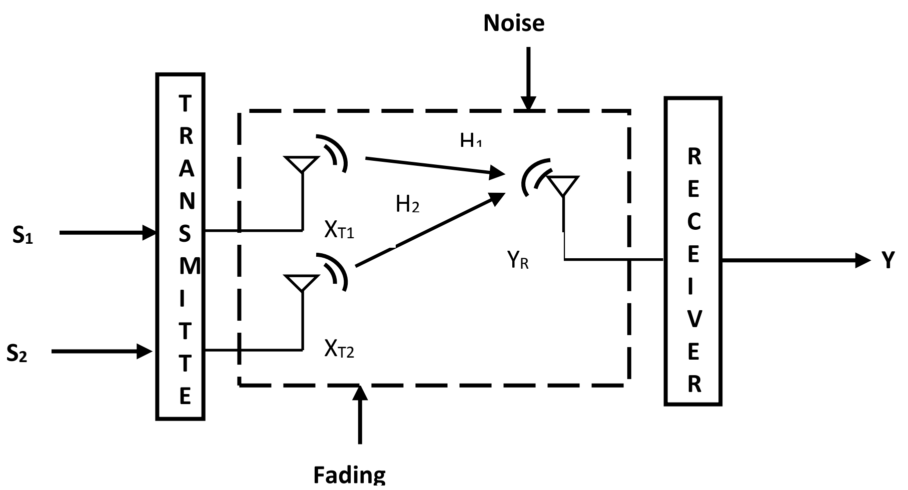

Fig 4: MISO Model
Source: Munshi et al. (2018).

S_1 and$S_1$are inputs from two transmitting antennas, Y_1 and Y_2 are outputs from the receiving antennas, Y_{T1} and Y_{T2} are two transmitting antennas andY_{R1} and Y_{R2}two receiving antennas. This configurationfacilitates therestoring of the original signal at receiving end with reduced path loss compared to SISO and SIMO. Furthermore, the effect of multipath fading is reducedcomparedSISO and SIMO, because there are two antennas at the transmission end (Tarunaand Suma; 2016). Again, since two signals needs to be transmitted, there is visible improvement in the channel capacity compared to SISO and SIMO. The channel capacity of the SISO system is given as (Veeranna and Raghav; 2012).

$$C_{MISO} = Blog2(1 + SNR/M_t) \quad (3)$$

where C_{MISO} is the capacity of the MISO system, M_t is the number of antennas used at transmitter side, B is Bandwidth of the signal and SNR is the signal to noise ratio.

D. **Capacity of MIMO Channel.**

Multiple antennas are utilized atboth the transmitter and receiver ends.The incorporation of multiple antennas at the transmitter joint by means of advanced signal processing algorithms at both transmitter and receiver ends providesimproved performance in terms of capacity and diversity (Veeranna and Raghav; 2012). A MIMO channel with Ntransmit antennas and M receive antennas involves NM elements that make up the MIMO channel coefficients. The multiple transmit and receive antennas could fit to a single user modem or it could be distributed among different contending users(Rao and Malavika; 2014). For a MIMO channel with N transmit antennas and M receive antennas, the channel matrix is represented byH, and it is of sizeN X M.

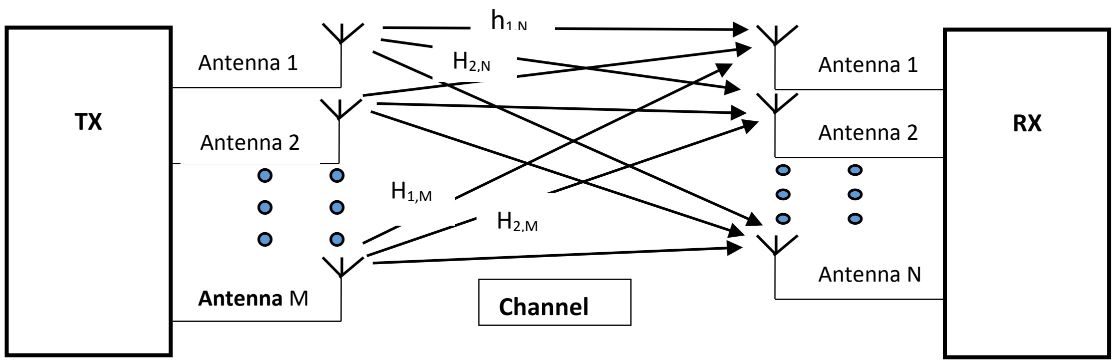

FIG .5: MIMO Model
Source: Ando et al. (2018).

That is,

$$H = \begin{bmatrix} h_{11} & \cdots & h_{1N} \\ \vdots & \ddots & \vdots \\ h_{M1} & \cdots & h_{MN} \end{bmatrix} \quad (4)$$

Where h_{ij} Is the complex channel gain between the i^{th} transmit antenna and the i^{th} receiving antenna: Consequently, the capacity of MIMO system is given as:

$$C_{MIMO} = N_t M_r Blog_2\,(1 + SNR) \quad (5)$$

where, again, $C_{MIMO}$is the capacity of MIMO system, N_t is the number of transmitting antennas, M_r is the number of receiving antennas and SNR is the signal to noise ratio.

For an unknown transmitter channel, uniform power allocation is recommended. However, this may result in highersignal probability outage since the transmitter cannot determine the requisitedata transmit rate to guarantee batter data delivery or QoS.MIMO systems were observed to offer the best capacity amongst these four systems under consideration (SISO, SIMO, MISO and MIMO) due to to the large number of antennas utilized (Rao and Malavika; 2014). More so, MIMO has a wide-ranging application, such as ability to transmit signals through diverse spatial domains by employing Spatial Multiplexing technique.

2. RESEARCH METHODOLOGY

I. Bit error rate in Rayleigh Channel MIMO model

For Rayleigh channel, in theory BER (bit error rate) for a Binary Phase Shift Keying (BPSK) modulated transmission for SISO is:

$$BER_{SISO} = \frac{1}{2}\left(1 - \sqrt{\frac{SNR}{2+SNR}}\right) \quad (6)$$

where BER_{SISO}it the bit error rate for the SISO system, and$SNR$is signal to noise ratio.

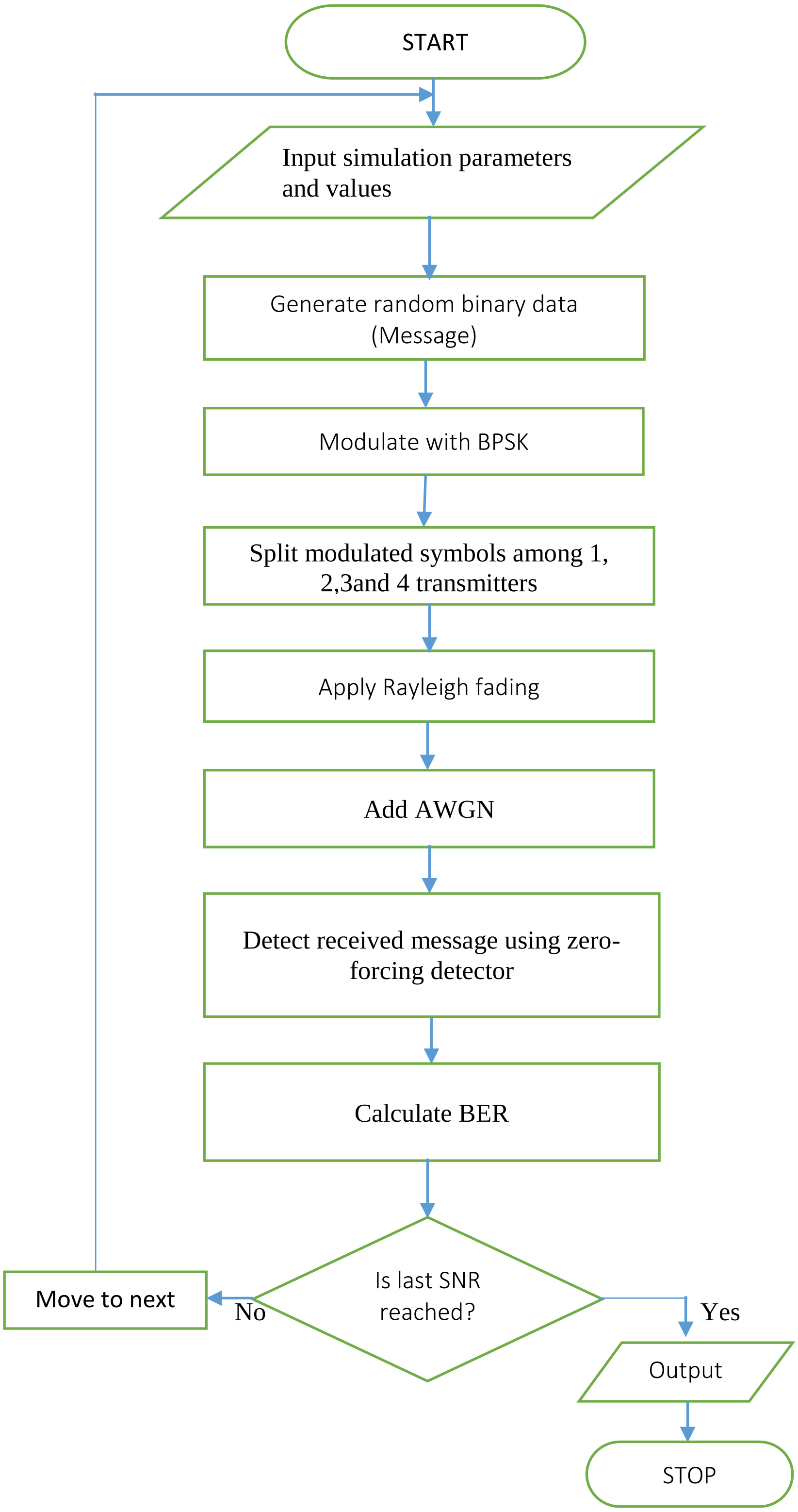

Fig. 6: Flowchart of MIMO Over Rayleigh Channel

In practice, the BER is calculated as:

$$\text{BER}_{\text{Approx}} = e^{2\text{L}-1}\text{c}1\ (1/\text{SNR})^{\text{L}} \quad (8)$$

where $L = r - t + 1$, $\text{BER}_{\text{Approx}}$ is the approximate or theoretical bit error rate, SNR is the signal to noise ratio, and L is area of coverage in meters. C is the channel capacity.

$$\text{BER}_{\text{Pract}} = \frac{Number\ of\ Errors}{Total\ number\ of\ bits} \quad (9)$$

where, $\text{BER}_{\text{Pract}}$ is the practical bit error rate.

The BER is calculated and the transmitted data is subsequently compared with the received data**.**

II. Comparison of Characteristics of SISO, SIMO, MISO and MIMO SCHEMES

Table 1. Comparison of SISO, SIMO, MISO and MIMOSystems

PARAMETERS	SISO	SIMO	MISO	MIMO
1. *Number ofTx and Rx antennas*	Single Tx and Rx	Single Tx and Multiple Rx	Multiple Tx and Single Rx	Multiple Tx and Rx
2. *BER*	Gives lowest BER value due to only one antenna.	Better than SISO due to multiple antennas at receiving end (Veeranna and Raghav; 2012).	Better than SIMO since loss of signal is less.	Optimized value of BER is observed due to multiple antennas at both ends (Veeranna and Raghav; 2012).
3. *Throughput*	Observed to be much less than all the others	Better than of MISO system because of higher number of receiver antennas(Rao and Malavika; 2014).	Slightly better than SISO because there is only one receiving antenna. But less than SIMO for same reason.	Observed to have the best capacity, which allows for wide range of applications.
4. *Transmittingof signals from Tx to Rx.*	Since there is only one antenna at Tx and Rx end, only point-to-point transmission occurs.	Signals are received by multiple antennas and are then combined by Maximum RatioCombining(MRC) and Equal Gain Combining technique (Rao and Malavika; 2014).	The signals transmitted using transmit beam forming and space time coding; there is only onereceiving and multipletransmitting antennas(Rao and Malavika; 2014).	The transmit/ receive diversity is used where multiple antennas are present at both Tx and Rx ends.
5. *Quality of signals received at the output.*	Quality is weak because only one transmitting and receiving antennas are involved.	Uses concept of switched diversity for implementation, where the receiver can choose the stronger antenna for receiving the signal.	Implemented bySpace Time Coding (STC)technique, where signals are transmitted spatial-temporally i.e. data can betransmitted by multiple antennas; therebyenhancing gain and signal quality (Rao and Malavika; 2014).	Signalstransmitted usingSpatial Multiplexing which allowstransmission acrossdifferent spatialdomains;it therefore gives the best signalquality and diversitygain(Rao and Malavika; 2014).
6. *Channel capacity and coverage.*	Least of the four.	Greater than SISO and MISO.	Greater than SISO.	Greatest among the Four.
7. *Applications.*	WI-FI, television, radio broadcasting.	In encountering the effects of ionosphere fading for listening and receiving of short waves and in mobile phones (Pytell; 2016).	Digital television, WLANS.	Used in all advanced wireless communication systems such as LAN, WLANS, WiMAXs MAN,

				3G, 4G, LTE, and 5G.
8. *Overall advantage.*	Simple in design Andcheap compared to others.	Provides increased in diversity beyond SISO and gives better BER than SISO.	High diversity gain; with redundancy at receivers.	Gives best results; offers the best throughputs and efficiency of signal transmissions.

Note: - Tx = Transmitter; Rx = Receiver

RESULTS AND DISCUSSION

The results of simulations in determining the channel capacity (bits/sec/Hz) against SNR (dB)were investigated for SISO, SIMO, MISOand MIMO. Also, simulations over a range of SNR for various corresponding channelcapacities, along withvarying number of transmitter and receiver antennas werepresented. From Figure 7, it is observed that the channel capacity of MIMO systems is highest among the four systems under investigation. This was followed by SIMO and MISO respectively. SISO systems presented the least capacity; this was corroborated by the results obtained by(Pytell; 2016).

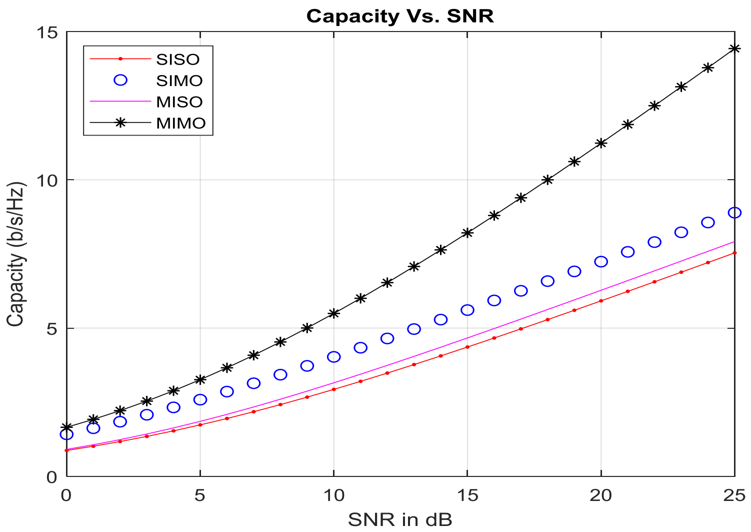

Fig.7: Channel Capacities of Against SNR for SISO, SIMO, MISO and MIMO Systems

The channel capacities were reported to increaseas the number of antennas at transmitter and receiver ends increase by Pytell (2016).It was also observed that MIMO capacity grows exponentially as the number of antennas; and approximately M times larger than SISO capacity (where M is an arbitrary number of antennas). For these systems, improved capacity is more pronounced at high SNR. The advantage (in terms of capacity) of MIMO may be due to exploitation of multipath technique in MIMO technology.Furthermore, BER against SNR for the four configurations was studied. The SNR is the ratio of the received signal power over the noise power in the frequency range of the process. Again, SNR is inversely related to BER. That is, high BER results in low SNR. However, high BER results in increased packet loss,higherprocessing delay andreduced system throughput.

From Figure 8, it is easily seen that as the SNR rises the value of BER is decreasing, which means that SISO systems are largely impaired by noise, which leads to signal fading. For SIMOthe BER value is lower when compared withthat of SISO (see Figure 9), and equally is the SNR. This isbecause there are numerous receiving antennas,in addition to employing beam forming and spatio-temporal coding for signal transmissions.

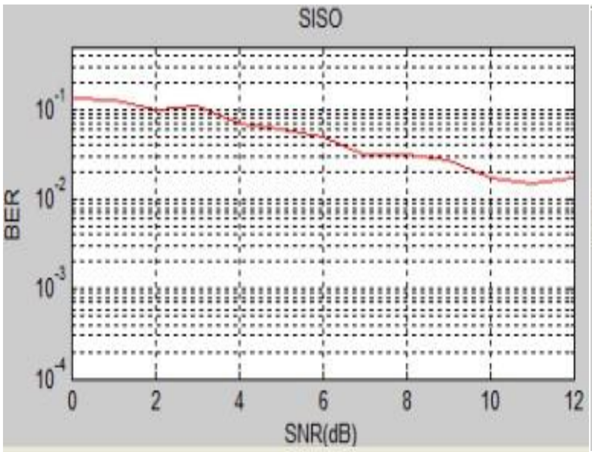

Fig.8: Plot ofBER versus SNR for SISO System

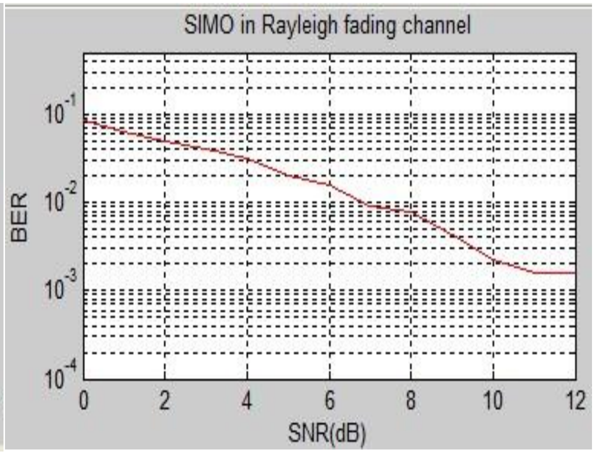

Fig. 9: Plot of BER versus SNR for SIMO System

Again, in Figure 10, the BER value for MISO is lower than that of SIMO, which is desirable, because the smaller the BER the more reliable the link becomes. Hence, MISO is more reliable than SIMO in terms of QoS but SIMO is better in terms of capacity and throughput. More so, MISO employs RAKE receivers at the receivers in combination with the multiple signals received. MIMO provides the best performances both in relation to QoS and channel capacity, as shown in Figure 11.

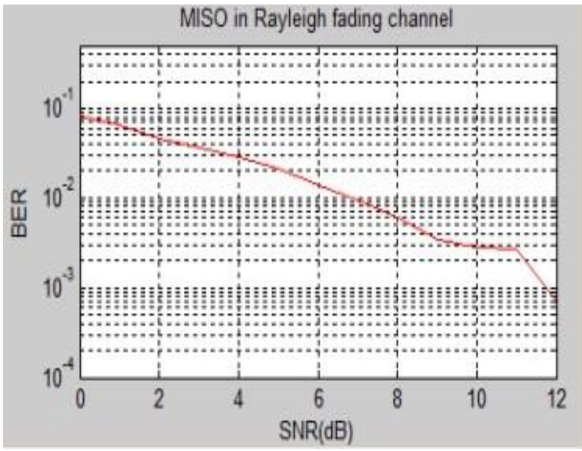

Fig. 10: Plot of BER versus SNR for MISO System

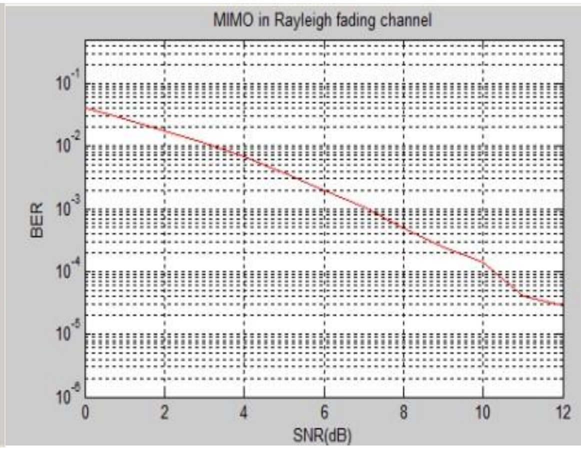

Fig. 11: Plot of BER versus SNR for MIMO System

Table 2 gives the comparative analysis of BER results found for all the above four types of antennas. The practical analysis obtained in Table 2 also matches the theoretical analysis of for all the four antennas. Furthermore,it can be observed that MIMO gives the best overallperformances when compared with the others since it exhibited the least number of errors/bits for all the SNR considered.

Table 2: Comparison of PracticalBER (BER_{Pract})for SISO, SIMO, MISOand MIMO

SNR (dB)	**SISO**(errors/bit)	**SIMO** (errors/bit)	**MISO** (errors/bit)	**MIMO** (errors/bit)
0	0.147	0.0844	0.081	0.04048
2	0.112	0.0499	0.0469	0.01787
4	0.077	0.0308	0.0252	0.006693
6	0.063	0.0154	0.0136	0.001984
8	0.03	0.008	0.006	0.000138

CONCLUSION

This workprobed into the performances of SISO, SIMO, MISO and MIMO antenna technologies on 4G network using locally sourced data from, Lagos, Nigeria. MIMO antenna system have more capacity and higher reliability compared to other antenna systems on 4G network. The results obtained from this work also showed that the BER for MIMO is the smallest for SNRs (0 to 8 dB) investigated at 0.04048 and 0.000138errors/bit for 0 and 8 dB respectively. This is made possible owing tolarger number of antennas in its design.Which also indicates better performances on LTE. Furthermore, better performance is observed as the number of antenna configuration increases on MIMO. MISO and SIMO occupied the second and third positionswith 0.081 and 0.006errors/bit for MISO; and 0.0844, 0.008errors/bit for SIMO. SISO exhibited the least perfomance with 0.147 and 0.03errors/bit for 0 and 8 dB respectively. To sum up, MIMO systems offers the bestthroughputs, signal quality andefficiency of digital signal transmissions, while at the same time providering the widestarea of signal coverage.

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