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Performance of A MIMO-OFDM System to Different Modulation Schemes in AWGN and Rayleigh Channels using Simulink

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***Abstract*— This paper studies and gives emphasis on the effectiveness of both MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency Division Multiplexing) in communications system. The performance comparison of various modulation schemes in both OFDM only and MIMO-OFDM systems in terms of BER (Bit Error Rate) is carried out. This is done for both AWGN (additive White Gaussian Noise) channel and Rayleigh Fading channel where channel noise is considered as the channel condition. The performance analysis of the entire system is done using designs modelled with Simulink tool in MATLAB.**

Keywords*— *OFDM; MIMO; Modulation; BER; SNR; Fading; AWGN;

I. INTRODUCTION

The cellular mobile communications industry has recently been one of the fastest growing industries of all time, with the number of users increasing incredibly rapidly [1]. However, Multipath fading is very much influencing the performance of wireless communication link [2]. The term fading is applied to signal loss that changes fairly slowly relative to the signal bandwidth. This term is usually applied to atmospheric phenomena, however [3]. The fading may vary with time, geographical position or radio frequency, and is often modelled as a random process. Fading may either be due to multipath propagation and/or Doppler shift from changes in velocity or the channel, referred to as small scale fading, or due to shadowing (Large scale fading) from obstacles affecting [3],[4].

Most communications systems designed aimed at providing one or combinations of these: bandwidth efficiency, power efficiency, or cost efficiency. Bandwidth efficiency describes the ability of a modulation scheme to accommodate data within a limited bandwidth with low bit-error-rate. Power efficiency describes the ability of the system to reliably send information at the lowest practical power level [5].

With the increasing traffic for the wireless communication the need for the more efficient use of the spectrum available becomes highly important. Considering a desire for even higher data rates the long-term 3GPP evolutionary trends include support towards wider transmission [6].

Obviously as the generation is advancing higher data rates as well as high spectral efficiency are expected. Of course achieving these data rates requires careful selection of multicarrier modulation scheme available. OFDM is one of the emerging techniques for transmitting at higher data rates [7]. Orthogonal Frequency Division Multiplexing (OFDM) is a multi carrier modulation technique that provides high bandwidth efficiency because the carriers are orthogonal to each other and multiple carriers share the data among themselves. The main advantage of this transmission technique is its robustness to channel fading in wireless communication environment. OFDM can be seen as either a modulation technique or a multiplexing technique [8].

Consequently this necessitates the study focusing on the performance of the MIMO-OFDM system under different channel conditions in various modulation schemes. The analysis is done based on simulations using Simulink simulation tool in MATLAB.

II. OFDM

OFDM is a transmission technique based on the idea of FDM (Frequency Division Multiplexing). In OFDM, the transmitter transmits a single data stream over a number of lower rate orthogonal sub-carriers which made use of the advanced modulation techniques on each component. This results in a signal with high resistance to interference. OFDM can be simply define as a multi-carrier modulation where its carrier spacing is carefully selected so that each sub-carrier is orthogonal to the other sub-carrier [9]

A. Functional block of an OFDM System

A simple block diagram of an OFDM System is shown in fig.1 below.

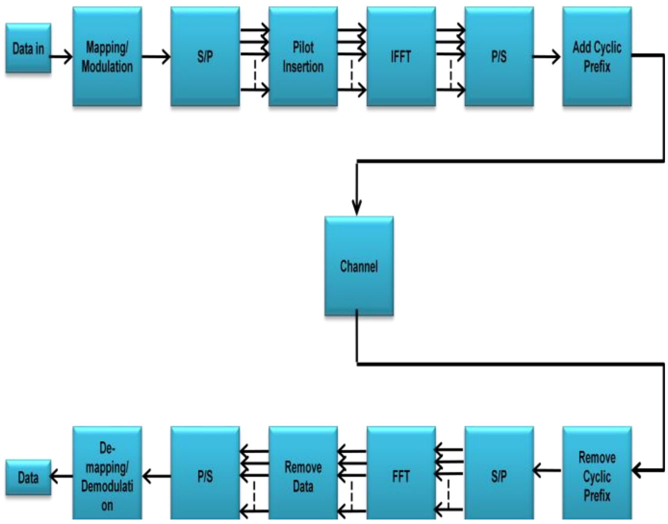

Fig. 1. Simple block digram of an OFDM system

The functions of the blocks making up the system are described below.

1) MAPPING of SYMBOLS

Bits are grouped based on the modulation method selected by the user to form symbols ready for modulation. For Multicarrier transmission signal bits are sometimes padded with zeros to make it a multiple of sub- carriers.

2) MODULATION

After mapping is done the symbols are modulated using any of the different modulation schemes such as M-ary PSK and M-ary QAM. The major M-ary PSK modulation schemes include but not limited to BPSK, QPSK and 16PSK. Among the M-ary QAM are 16QAM, 64QAM and 256QAM.

3) OFDM TRANSMITTER

A serial to parallel conversion on the stream of symbols is carried out and placing them at the positions of the carriers along with pilot symbols next to them. An IFFT is then performed to get the OFDM time signal per block of symbols. Next is the insertion of guard time (cyclic prefix) to prevent inter-channel interference.

4) CHANNEL

The channel adds noise to the data output from the OFDM transmitter.

5) OFDM RECEIVER

The removal of the Guard Band is done. Next is the division of the time signal into the OFDM blocks. For Each Block FFT is performed and the symbols of interest is extracted to exclude the pilot symbols.

6) DEMODULATION

This performs the reverse of modulation process.

7) RECOVERING of SYMBOLS

The bits are recovered from the symbols by unpacking the symbols.

B. Mathematical Description of an OFDM

Mathematically, the modulated sub-carriers can be represented as a real part of the complex signal below (1).

$$S_c(t) = A_c(t)e^{j[\omega_c t + \emptyset_c(t)]}, \quad (1)$$

Where; ω_c is the sub-carrier angular frequency

$A_c(t)$ is the amplitude on the sub-carrier

$\emptyset_c(t)$ is the phase modulation on the sub-carrier [9].

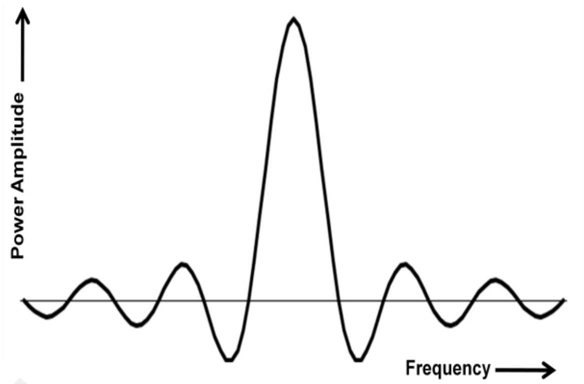

Fig. 2. OFDM Sub-channel Spectrum

OFDM consists of many sub-carriers. Therefore, the complex OFDM signal $S_s(t)$ with N sub-carriers can be written as;

$$S_s(t) = \frac{1}{N} A_n \sum_{n=0}^{N-1} A_n(t)e^{j[\omega_n t + \emptyset_n(t)]} \quad (2)$$

Note,

$$\omega_n = \omega_0 + n\Delta\omega \quad (3)$$

Where $\Delta\omega$ is the sub-carrier spacing in angular frequency.

The amplitude and phase modulation do not change within an OFDM symbol, hence $A_n(t)$ and $\emptyset_n(t)$ can be rewritten as A_n and $\emptyset_n$ [9].

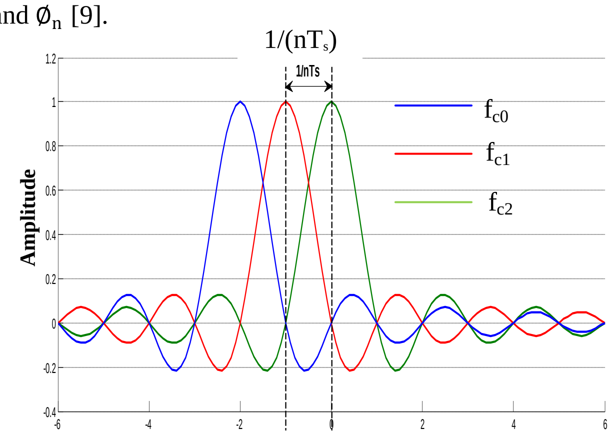

Fig. 3. OFDM System Spectrum

Where; f_c is the sub-carrier frequency

T_s is the symbol period.

III. INTER-SYMBOL INTERFERENCE

In a single carrier system, a single fade or interference can cause the entire link to fail, but in a multi-carrier system, only small percentage of the sub-carriers will be affected. The efficiency of OFDM is brought by the use of parallel data and OFD with overlapping sub-channels to avoid the use of high speed equalization and to combat impulsive noise, and multi-path noise as well as to fully utilize the available bandwidth [9].

To avoid ISI due to multi-path, successive OFDM symbols are separated by guard band. This makes the OFDM system resistant to multi-path effects. OFDM is a widely used because of its high bandwidth efficiency and robustness against frequency fading due to multipath propagation [10].

Hence orthogonal frequency division multiplexing (OFDM) can be used to combat fast fading and frequency-selective fading. OFDM uses multiple carriers, each operating at a reduced symbol rate to mitigate the effects of delay spread and selective fading. The longer symbol times make fast fading less of an issue, and redundancy over the carrier frequency reduces the effect of any frequency dropouts [11].

IV. CYCLIC PREFIX AND CYCLIC PREFIX REMOVAL

Theoretically, the orthogonal of sub-channels in OFDM can be maintained and individual sub-channels can be completely separated by the FFT at the receiver. However, these conditions cannot be obtained in practice due inter-symbol interference (ISI) and inter-carrier interference (ICI) introduced by transmission channel distortion.

In order to prevent multi-path components interfering from one symbol with the next symbol, a cyclically extended guard interval known as Cyclic Prefix. The cyclic prefix is a replica of the last samples of the OFDM symbol. This is achieved by adding partial symbol information of each cycle to the beginning of the symbol [10], [12]. The ratio of the guard interval to the useful symbol duration depends on different systems. Since the insertion of guard interval will reduce data throughput, T_g is usually less than $T_s/4$ [10].

The total symbol duration, Td, is given as

$$T_d = T_g + T_s \tag{4}$$

Where; T_g is the duration of guard interval.

T_s is the duration of useful symbol.

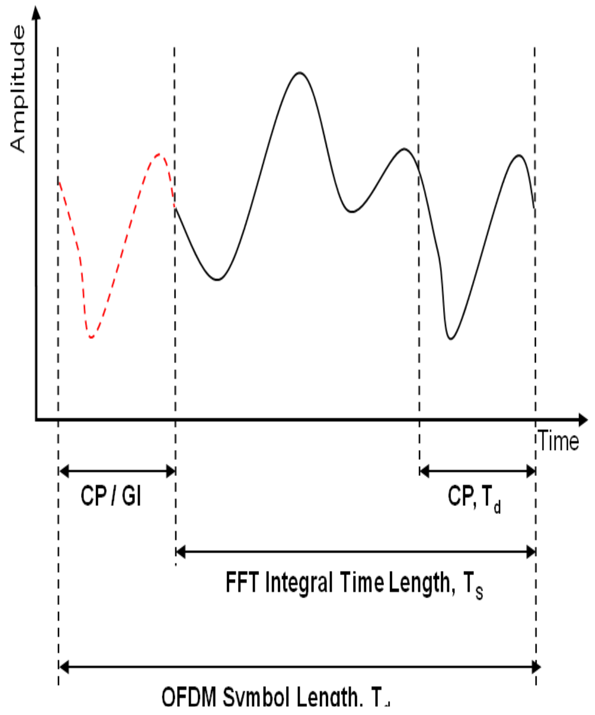

Fig. 4. Cyclic Prefix Insertion illustration

Fig. 5.

V. MULTIPLE ANTENNA

Multiple-antenna systems, called MIMO systems (Multiple Input Multiple Output). "In" and "out" always refer to the transmission channel. MI stands for multiple sending antennas and MO accordingly for multiple receiving antennas [13].

In essence MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used [14].

There are also the classic SISO systems (Single In Single Out) with one sending and one receiving antenna respectively, as well as combinations such as SIMO and MISO [13].

MIMO system consists of three components, mainly transmitter, channel and receiver. Transmitter sends a multiple data such as X_1, X_2, X_3…….X_N from different transmit antenna and signal is received by each receive antenna R_1, R_2, R_3……R_M simultaneously. The relation between transmit data and receive data is given by

$$R_1 = H_{11}X_1 + H_{12}X_2 + \ldots\ H_{1M}X_M \tag{5}$$

$$R_2 = H_{21}X_1 + H_{22}X_2 + \ldots\ H_{2M}X_M \tag{6}$$

……

$$R_M = H_{N1}X_1 + H_{N2}X_2 + \ldots\ H_{NM}X_M \tag{7}$$

Where, X = transmitted Signal Vector;

R = Received Signal Vector;

H = Channel Matrix;

N = Number of transmitting antenna

M = Number of receiving antenna [14].

Fig. 5 below shows the MIMO transceiver system.

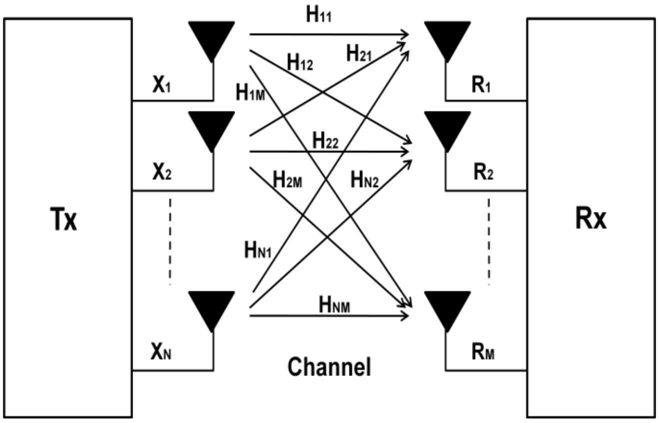

Fig. 6. MIMO transceiver

VI. MODULATION

Modulation is the process of facilitating the transfer of information over a medium. It is the process by which information is mapped on to a carrier [15]. In the process a carrier signal is altered according to information in a message signal. The carrier frequency, denoted by f_c, is the frequency of the carrier signal.

In digital communications, the modulating wave consists of binary data or an M-ary encoded version of it and the carrier is sinusoidal wave.

The major classes of digital modulation techniques used for transmission of digitally represented data include (i) Amplitude Shift Keying (ASK), (ii) Frequency Shift Keying (FSK), (iii) Phase Shift Keying (PSK) and (iv) QAM [16], [17]. The "shift Keying" the second two terms in the name of these modulations imply that they are digital modulations, i.e. the information is digital [15].

A. Quadrature Phase Shift Keying

Quadrature (or Quartenary) Phase Shift Keying (QPSK) is a form of Phase Shift Keying in which two bits are modulated per one symbol, selecting one of four possible carrier phase shifts (π/4, 3π/4, 5π/4 and 7π/4) [2]. QPSK perform by changing the phase of the In-phase (I) carrier from 0° to 180° and the Quadrature-phase (Q) carrier between 90° and 270°. This is used to indicate the four states of a 2-bit binary code. Each state of these carriers is referred to as a Symbol. Quadrature Phase-shift Keying (QPSK) is a widely used method of transferring digital data by changing or modulating the phase of a carrier signal. In QPSK, digital data is represented by 4 points around a circle which correspond to 4 phases of the carrier signal. These points are called symbols.

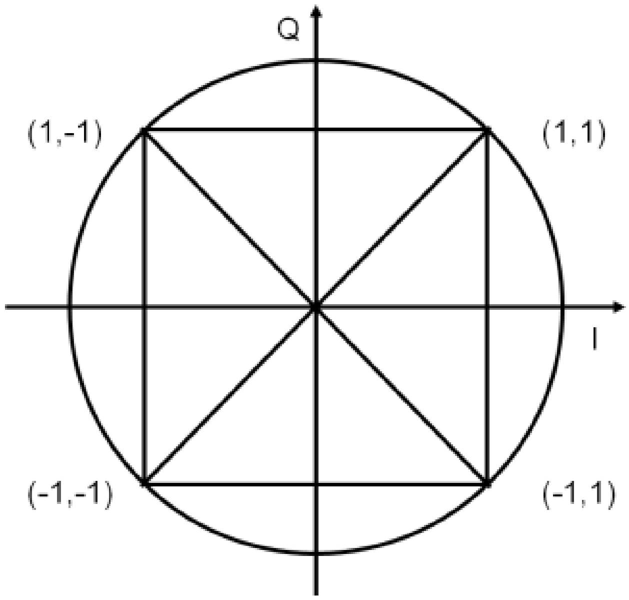

Fig. 7. Constellation Diagram of a QPSK System

With four phases, QPSK can encode two bits per symbol, with gray coding to minimize the BER. The QPSK signal consists of two parts In-phase and Quadrature phase. In-phase gives the real part of the signal and quadrature gives the imaginary part of the signal. The implementation of QPSK is more general than that of BPSK and also indicates the implementation of higher order PSK.

The QPSK formula is mathematically represented as follows:

$$s(t) = A\cos(2\pi f_c t + \varnothing(t)) \quad (8)$$

Where $\varnothing(t)$ = 135°, 45°, 45°, -135.

$$s(t)=A\cos\varnothing(t)\cos(2\pi f_c t)-A\sin\varnothing(t)\sin(2\pi f_c t) \quad (9)$$

The probability of bit error rate (BER) in QPSK is given by:

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^\infty \exp\left(\frac{-t^2}{2}\right)dt,\ x\geq 0 \quad (10)$$

$$Q(x)=\frac{1}{2}\operatorname{erfc}\left(\frac{x}{\sqrt{2}}\right) \quad (11)$$

Where $x^2 = E_b/N_o$, is the bit energy to noise density ratio denoting the SNR per bit.

$Q(x)$ gives the probability that a single sample taken from a random process with zero-mean and unit-variance Gaussian probability density function will be greater or equal to x.

The symbol error probability of QPSK is given by:

$$P_s = \left[1-Q\left(\sqrt{\frac{2E_b}{N_0}}\right)\right]^2 \quad (12)$$

B. Quadrature Amplitude Modulation

Quadrature Amplitude Modulation (QAM) has fast become the dominant modulation mechanism for high speed digital signals. From the wireless 802.11 protocols to ADSL modems to personal communicators for the military, QAM has become a necessary part of our daily lives.QAM is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. In a QAM signal, there are two carriers, each having the same frequency but differing in phase by 90 degrees (one quarter of a cycle, from which the term quadrature arises). One signal is called the In-phase signal, and the other is called the Quardrature signal. Mathematically, one of the signals can be represented by a sine wave, and the other by a cosine wave. The two modulated carriers are combined at the source for transmission. At the destination, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating information. The QAM signal is mathematically represented as follows:

$$s(t)= m_1 (t) \cos(2\pi f_c t)-m_2(t)\sin(2\pi f_c t) \qquad (13)$$

Where $m_1(t)$ and $m_2(t)$ are the two message signals. One of them is sent in phase i.e. by multiplying it with $\cos(2\pi f_c t)$ and the other one is sent in quadrature by multiplying it with $\sin(2\pi f_c t)$. Finally, the two signals are added to obtain the QAM signal. [18]

The symbol error probability of M-ary QAM is given by

$$P_b \le 4 erfc\left(\sqrt{\frac{3kE_b}{(M-1)N_o}}\right) \ (for\ M = 2^k) \qquad (14)$$

Where k is the number of bits transmitted by each symbol.

VII. NOISE AND INTERFERENCE

In wireless communication, radio propagation refers to the behaviour of radio waves when they are propagated from transmitter to receiver [1]. Data are transmitting through the wireless channel with respective bandwidth to achieve higher data rate and maintain quality of service. The transmitting data has to take environmental challenge when it is on air with against unexpected noise [19]. In the course of propagation, radio waves are mainly affected by three different modes of physical phenomena: reflection, diffraction, and scattering [14].

A. Additive white Gaussian noise

AWGN is often used as a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude.

The PDF for the AWGN channel is given in (15)

$$\frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \qquad (15)$$

Where μ is the mean and σ is the standard deviation.

The model does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. However, it produces simple and tractable mathematical models which are useful for gaining insight into the underlying behaviour of a system before these other phenomena are considered.

The AWGN channel is a good model for many satellite and deep space communication links. It is not a good model for most terrestrial links because of multipath, terrain blocking, interference, etc. However, for terrestrial path modeling, AWGN is commonly used to simulate background noise of the channel under study, in addition to multipath, terrain blocking, interference, ground clutter and self interference that modern radio systems encounter in terrestrial operation [4].

B. Multipath Fading

A unique characteristic in a wireless channel is a phenomenon called ‘fading’ which is the variation of the signal amplitude over time and frequency. In contrast with the additive noise as the most fading common source of signal degradation, fading is another source of signal degradation that is non-additive signal disturbance in the wireless channel. Fading may either be due to multipath propagation, referred to as multi-path (induced) fading, or to shadowing from obstacles that affect the propagation of a radio wave, referred to as shadow fading [17], [20].

Rayleigh and Rician fading channels are useful models of real-world phenomena in wireless communications. These phenomena include multipath scattering effects, time dispersion, and Doppler shifts that arise from relative motion between the transmitter and receiver.

Some wireless applications, such as standard GSM (Global System for Mobile Communication) systems, prefer to specify Doppler shifts in terms of the speed of the mobile. If the mobile moves at speed v making an angle of θ with the direction of wave motion, then the Doppler shift is

$$f_d = (vf/c)\cos\theta \qquad (16)$$

Where; f is the transmission carrier frequency

c is the speed of light.

The Doppler frequency represents the maximum Doppler shift arising from motion of the mobile.

If the value of θ is zero then maximum Doppler shift results and from (16),

$$f_d = (vf/c) \qquad (17)$$

Fig. 7 below depicts direct and major reflected paths between a stationary radio transmitter and a moving receiver.

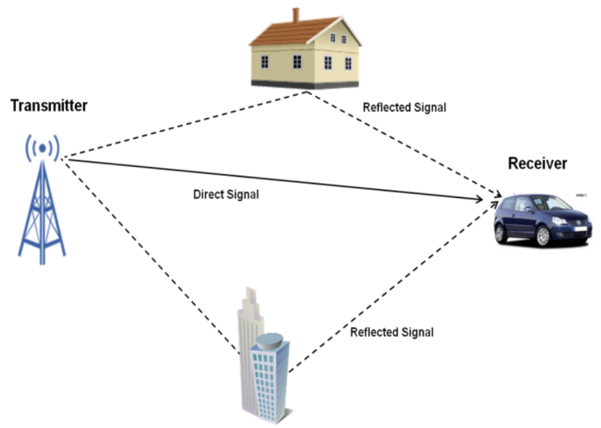

Fig. 8. Direct and major reflected paths between transmitter and a moving receiver

Typically, the fading process is characterized by a Rayleigh distribution for a nonline-of-sight path and a Rician distribution for a line-of-sight path.

The Rayleigh distribution has a probability density function (PDF) given by,

$$p(r)=\begin{cases}\frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) & r\geq 0\\ 0 & r<0\end{cases} \tag{18}$$

where σ^2 is known as the fading envelope of the Rayleigh distribution [17].

VIII. SIMULINK MODEL OF AN MIMO-OFDM SYSTEM

The MIMO-OFDM model design consists of various blocks which shall be discussed in brief:

1) Random Integer Generator

The Random Integer Generator block generates uniformly distributed random integers in the range [0, M-1], where M is the M-ary number

2) Digital modulator

The modulator block is used to modulate the input data stream using. In this research, various blocks were used which include QPSK, 16-QAM, 64-QAM and 256-QAM.

3) OFDM Transmitter sub-system

This subsystem is made up of the various blocks which shall be discussed in the subsequent sections.

a) Pilots Insert Subsystem

- This subsystem includes blocks such as PN Sequence Noise generator, Row Selector, Input Packing, Constant, Serial-Parallel and Gain.
- The Serial – Parallel block is used to convert a serial stream of data to parallel data.
- Sub-channel selector block is used to select the rows from the S/P block and then unit data samples from the Pilot Generator block are inserted in between to maintain uniformity.
- The constant block adds zeros to act as pads.
- Finally, the resulting data samples are concatenated vertically by input packing block to get the data in which number of input samples are a power of 2 as is required by the IFFT block.
- PN Sequence Noise generator is used to add extra pilot samples to the unit data samples.

b) IFFT

The IFFT block computes the inverse fast Fourier transform (IFFT) of each row of a sample based 1-by-P input vector.

The IFFT operation is mathematically identical to OFDM operation. Hence it could be said that this is the block that actually implements OFDM. Before feeding the data samples to the IFFT block, the input data stream should be formatted so that the total number of input samples is a power of 2 as is required by the IFFT block.

c) Parallel- Serial

This block performs the opposite of Serial – Parallel bock in function.

d) Add Prefix Cyclic

This block add cyclic prefix to the output from the IFFT.

4) OSTBC Encoder

The OSTBC Encoder block encodes an input symbol sequence using orthogonal space-time block code (OSTBC). The block maps the input symbols block-wise and concatenates the output codeword matrices in the time domain

5) Channel

The channel consists of two blocks connected in series namely the AWGN Channel block and the Multipath Rayleigh Fading Channel block. The AWGN Channel block adds white Gaussian noise to a real or complex input signal while the Multipath Rayleigh Fading Channel block implements a baseband simulation of a multipath Rayleigh fading propagation channel.

6) OSTBC Combiner

The OSTBC Combiner block combines the input signal (from all of the receive antennas) and the channel estimate signal to extract the soft information of the symbols encoded by an OSTBC. A symbol demodulator or decoder would follow the Combiner block in a MIMO communications system. The block conducts the combining operation for each symbol independently

7) OFDM Receiver Sub-system

This subsystem consists of the following blocks:

- The Serial – Parallel
- FFT
- Remove Cyclic Prefix
- Extract data carrier
- Frame conversion
- Receiver Power Scale

Basically, the function of this sub-system is directly opposite to that of the OFDM transmitter.

8) Digital Demodulator

The function of this block is opposite to that of the modulator.

9) Error rate Calculation

The Error Rate Calculation block compares input data from a transmitter with input data from a receiver. It calculates the error rate as a running statistic, by dividing the total number of unequal pairs of data elements by the total number of input data elements from one source.

10) Display

This unit gives the total number of bits transmitted, the number of errors and finally displays the Bit Error Rate.

B. Model of an MIMO-OFDM System

The following figures depict the various blocks that make up the entire model and subsystems

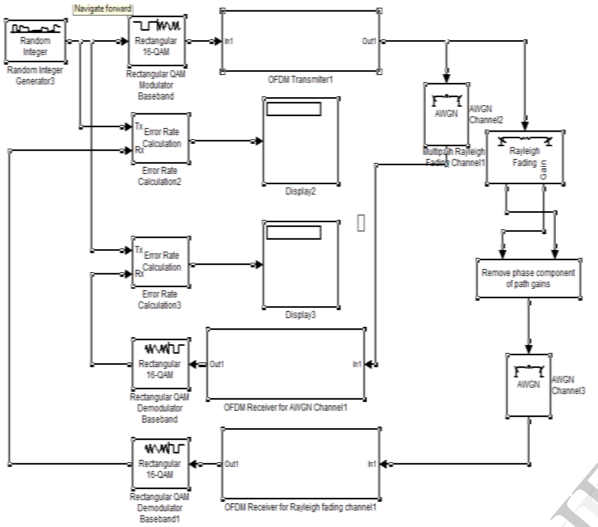

Fig. 9. Model of OFDM subsystem without OSTBC using SIMULINK

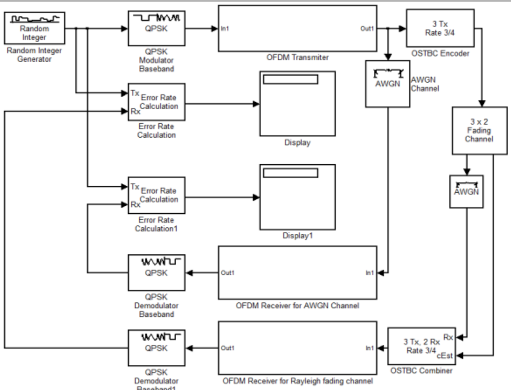

Fig. 10. Model of MIMO-OFDM subsystem using SIMULINK

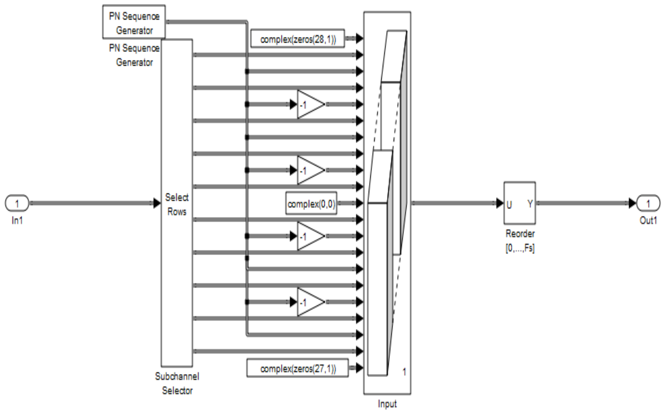

Fig. 11. Pilots sub-system

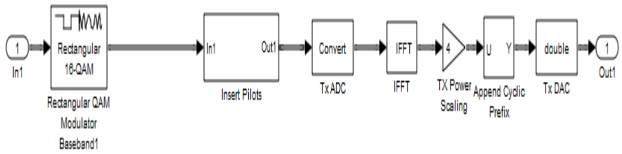

Fig. 12. OFDM Receiver Sub-system

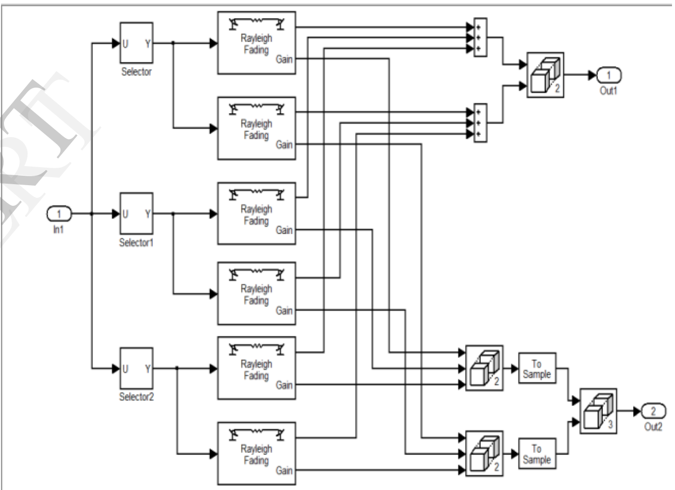

Fig. 13. 3x2 MIMO in Rayleigh fading channel sub-system

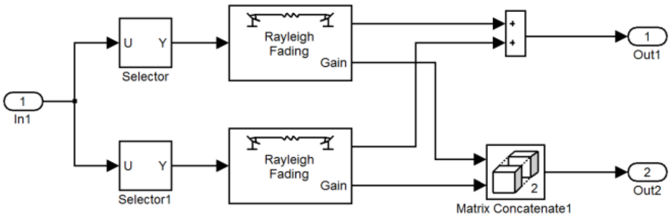

Fig. 14. 2x1 MIMO in Rayleigh fading channel sub-system

C. Simulation Environment

The following are the parameters of the Modelled OFDM system.

TABLE I. PARAMETERS OF THE MODELLED MIMO-OFDM SYSTEM

Parameters	Values
Data Rates	1 Mbps
Modulation	QPSK, 16 QAM and 64 QAM
FFT Size	256 with 200 sub-carriers uses, 192 for data and 8 pilots
FFT Period	Also called symbol period, 256 µs
Guard Duration	1/16 of symbol time, 16 µs
Symbol Time	192 µs
Channel	AWGN and Rayleigh Fading
Maximum Doppler frequency	0.01Hz
Channel input signal power	1W

D. Simulation Steps

- Various blocks and sub-systems that make up the whole MIMO-OFDM system were connected as shown in figs. 8 - 13.
- First the model of fig. 8 was implemented.
- The functional block parameters for the constituting blocks were set.
- For a given modulation/demodulation blocks pair the SNR was set to 0 from AWGN channel functional parameter blocks.
- The simulation was run for 1 second.
- The total bit transferred, numbers of bits in error as well as the BER were taken from the display block of the entire model.
- For the same modulation/demodulation blocks pair the SNR was varied from 0 to 30 in step of 2, run for I second each time and the result from the display taken for each step.
- The steps described above were repeated for the two other modulation/demodulation blocks pair.
- The implementation of the MIMO-OFDM (fig. 9) is similar to that of fig. 8

IX. RESULTS OF THE SIMULATION

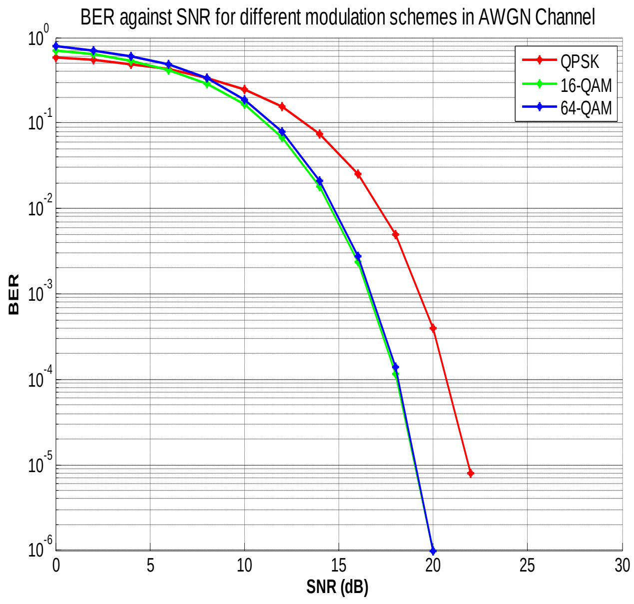

Fig. 15. BER against SNR in AWGN channel

Fig. 14 reveals that the performance of the OFDM system in AWGN channel improves (in terms of BER) with increasing SNR. From the figure it is clear that QPSK has the best performance when the SNR is less 6dB in comparison to 16-QAM and 64-QAM beyond which 16-QAM performs best. Also the BER for both 16-QAM and 64- QAM is very close and becomes even closer as the SNR increases and approaching 0 value for SNR level of close to 20dB. This is somewhere around 22dB for QPSK.

To achieve a BER of 0.001, the SNR value attained shall be close to 17dB for both 16-QAM and 64-QAM and around19dB for QPSK.

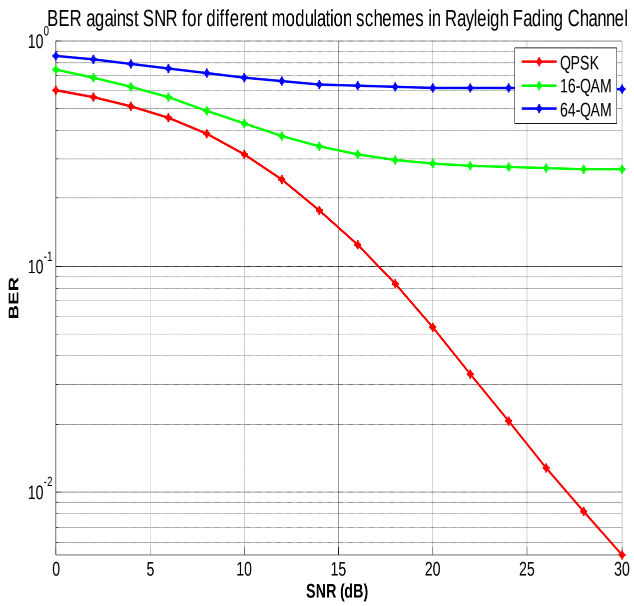

Fig. 16. BER against SNR in Rayleigh fading channel

From fig. 15 above the performance of the system in Rayleigh fading channel is low when compared to that of fig. 14. QPSK performs best in this channel at all SNR levels and improves (in terms of BER) with increasing SNR and approaching 0 for SNR greater than 0dB. 64-QAM has the poorest performance. As the SNR level increases the tendency that the BER for both 16-QAM and 64-QAM remains constant increases. It is observed from fig. 15 that the BER for 64-QAM is likely not falling below 0.6 (the value of BER for QPSK at SNR of 0dB) even at a high SNR.

A BER of 0.001, as noticed from the figure is un-attainable at SNR values less than or equal 30dB for QPSK modulation scheme. It is also obvious from fig. 15 that a BER of 0.1 cannot be achieved with both 16-QAM and 64-QAM.

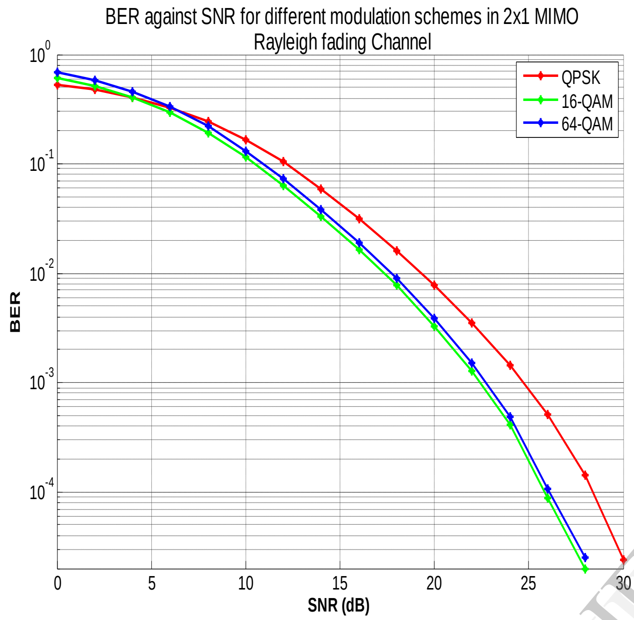

Fig. 17. BER against SNR in 2x1 MIMO in Rayleigh Fading channel

Fig. 16 above bears greater similarity between that of fig. 14. The figure depicts better performance than that of figure 14 at lower SNR values. As the SNR increases, the BER increases relative to that of fig. 14 for all the modulation schemes. QPSK shows the best performance up to SNR of around 4dB in comparison to 16-QAM and 64-QAM beyond which 16-QAM performs best. Also the BER for both 16-QAM and 64-QAM becomes closer as the SNR increases and approaching 0dB for SNR level of above 28dB.

To achieve a BER of 0.001 the SNR values for QPSK shall be less than 25dB. Similarly the value shall be less than 23dB 16-QAM and 64-QAM.

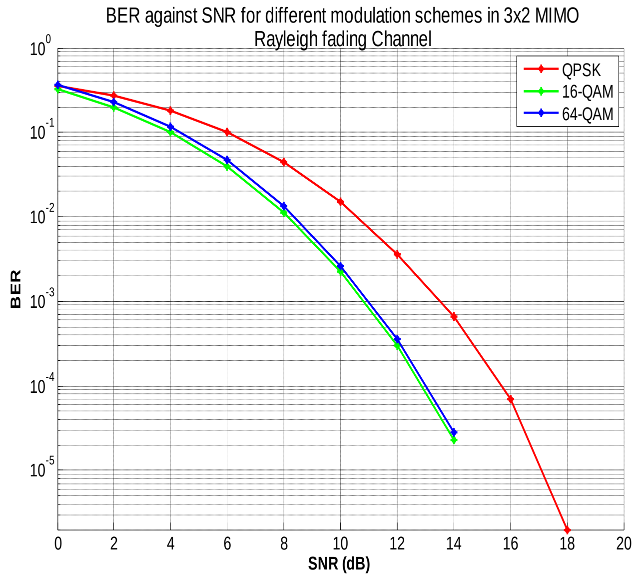

Fig. 18. BER against SNR in using 3x2 MIMO in Rayleigh Fading channel

The characteristics of fig. 17 are similar to those of fig. 16 but with better performance. 16-QAM shows the best performance for all the SNR levels in comparison to QPSK and 64-QAM. 64-QAM has a better performance in terms of BER compared to QPSK from SNR of about 0.5dB. Also the BER for both 16-QAM and 64-QAM becomes closer as the SNR increases and approaching 0 for SNR level of about 14dB.

To achieve a BER of 0.001 the SNR values for QPSK shall be less than 14dB. Similarly the value shall be less than 11dB 16-QAM and 64-QAM.

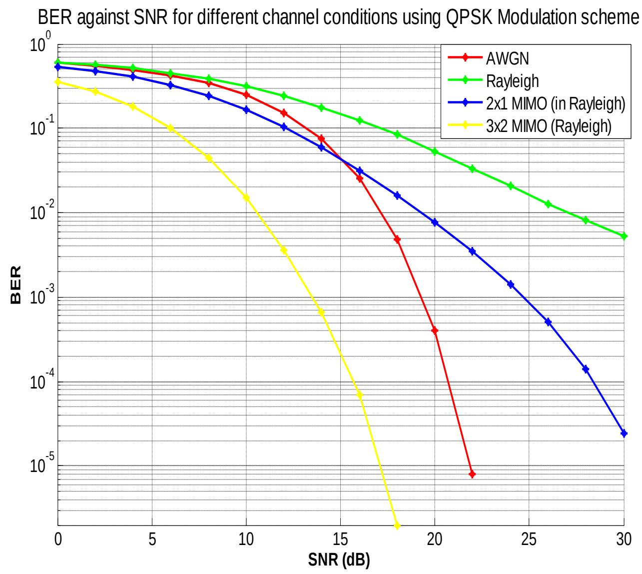

Fig. 19. BER against for QPSK under different channel conditions compared

From fig. 18 above 3x2 MIMO in Rayleigh fading channel favours QPSK modulation best with the poorest performance noticed in the Rayleigh fading channel for all SNR levels. Similarly QPSK shows a better performance up to SNR of about 16dB for 2x1 MIMO in Rayleigh fading channel in comparison to AWGN channel.

0.001 BER is achievable in all the channel conditions except in the Rayleigh fading channel. It takes QPSK modulation schemes to attain this value at SNR values of 19dB, 25dB and 13.5dB in AWGN, 2x1MIMO in Rayleigh and 3x2 MIMO In Rayleigh channels respectively.

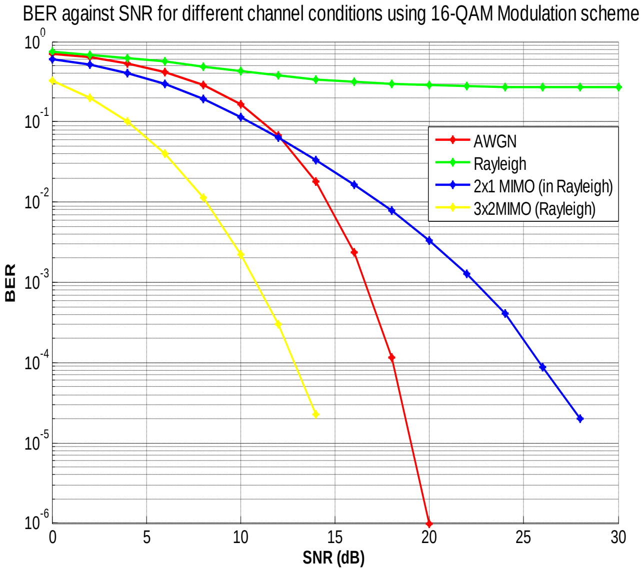

Fig. 20. BER against for 16-QAM under different channel conditions compared

Fig. 19 above bears close similarity to that of fig. 18. Here also, 3x2 MIMO in Rayleigh fading channel favours 16-QAM modulation best with the poorest performance noticed in the Rayleigh fading channel for all SNR levels. Similarly 16-QAM shows a better performance up to SNR of about 12dB for 2x1 MIMO in Rayleigh fading channel in comparison to AWGN channel.

Using 16-QAM modulation schemes 0.001 BER appeared attainable at SNR values of 17dB, 22.5dB and 11dB in AWGN, 2x1MIMO in Rayleigh and 3x2 MIMO in Rayleigh channels respectively. This value remain not achievable in Rayleigh fading channel for 16-QAM.

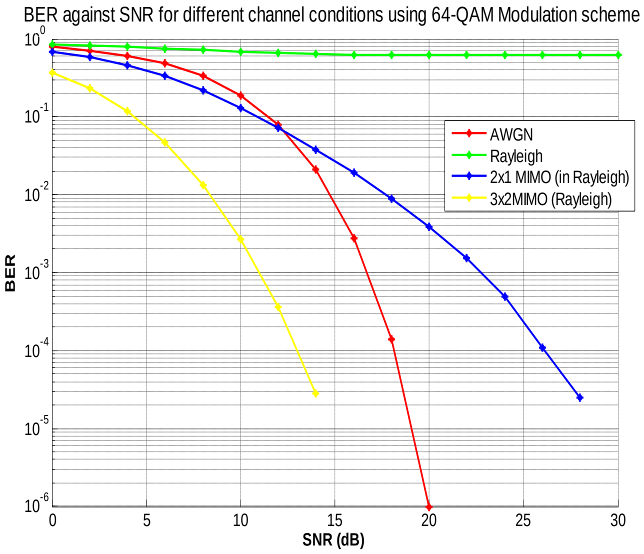

Fig. 21. BER against for 64-QAM under different channel conditions compared

The figure above also shows close characteristics to that of figure 18. Here also, 3x2 MIMO in Rayleigh fading channel favours 16-QAM modulation best with the poorest performance noticed in the Rayleigh fading channel for all SNR levels. Similarly 16-QAM shows a better performance up to SNR of about 12dB for 2x1 MIMO in Rayleigh fading channel in comparison to AWGN channel.

Similarly using 64-QAM modulation schemes 0.001 BER appeared attainable at SNR values of 16dB, 20dB and 10dB in AWGN, 2x1MIMO in Rayleigh and 3x2 MIMO in Rayleigh channels respectively. This value remain not achievable in Rayleigh fading channel for 64-QAM.

X. CONCLUSION

The observation shows the rate of change of BER with SNR in both AWGN and Rayleigh fading channels. Considering the OFDM system all the modulation schemes show better performance in AWGN than Rayleigh fading channel. QPSK has a better performance compare to 16-QAM and 64-QAM in Rayleigh Fading channel. However, the performance of QPSK is better off at lower SNR than 16-QAM in AWGN channel.

The performance of all the modulation schemes is improves in the MIMO-OFDM system in the Rayleigh fading channel. Comparing to the performance in the AWGN channel using the OFDM system, these modulation schemes as seen in the Rayleigh fading using MIMO-OFDM system is better at higher SNR. The higher the number of the Input and Output antennas, the better the performance.

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