Performance Evaluation of New MIMO-OFDM Model for Modern Wireless Application

Yousif Ibrahim Hammadi

Abstract— In this paper, a new MIMO-OFDM model has been introduced. The performance of this model using PSK and QAM digital modulations for different antenna configurations is analyzed and evaluated under Rayleigh fading channel. The proposed MIMO-OFDM system can be implemented using higher order modulatiosns to achieve large data capacity and remarkable enhanced performance.The main purpose of using high order antenna configurations is to increase the space diversity, which will further decrease the BER at given Eb/N0 as compared to lower order Antenna configurations. It is found effectively the diversity order increases as number of receiving antenna increases regardless the number of transmitting antennas , also the lowest BER can be obtained at highest number of transmitting and receiving antenna configurations. Moreover, the effect of the channel order on proposed MIMO - OFDM system has been also reported in this paper.

Keywords — OFDM , MIMO, Rayleigh Fading Channel, BER

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1 INTRODUCTION

ORTHOGONAL frequency division multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels. OFDM has been utilized in many applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G mobile communications [1].

OFDM is a modulation method known for its capability to suppress frequency selective fading due to multipath and narrow band interference. In OFDM ,the total transmission bandwidth is divided into a number of orthogonal subcarriers so that a wideband signal is transformed in a parallel arrangement of narrowband orthogonal signals , for example , one OFDM symbol consists of *N* symbols modulated for example by QAM or PSK. The symbol duration is made even longer by adding a cyclic prefix (CP) to each symbol. As long as CP is longer than the channel delay spread ,OFDM offers inter-symbol interference (ISI) free transmission. Another key advantage of OFDM is that it dramatically reduces equalization complexity by enabling equalization in the frequency domain.

OFDM, implemented with IFFT at the transmitter and FFT at the receiver, converts the wideband signal, affected by frequency selective fading, into *N* narrowband flat fading signals thus the equalization can be performed in the frequency domain by a scalar division carrier-wise with the subcarrier related channel coefficients [2,3].

Various schemes that employ multiple antennas at the transmitter and receiver are being considered to improve the range and performance of communication systems. By far the most promising multiple antenna technology today happens to be multiple-input multiple-output (MIMO) system. MIMO systems employ multiple antennas at both the transmitter and receiver [4].

MIMO-OFDM combines OFDM and MIMO techniques thereby achieving spectral efficiency and increased throughput. A MIMO-OFDM system transmits independent OFDM modulated data from multiple antennas simultaneously. At the receiver, after OFDM demodulation, MIMO decoding on each of the subchannels extracts the data from all the transmit antennas on all the subchannels .With the initiation of next generation (4G) broadband wireless communications, the combination of MIMO wireless technology with OFDM has been recognized as one of the most promising techniques to support high data rate and high performance.

- *Yousif Ibrahim Hammadi is currently pursuing masters degree program in ECE in Cankaya University, Turkey .E-mail: yousif_com88@yahoo.com*

The MIMO-OFDM has a great potential to meet up the rigorous requirement for enhancing the transmit diversity and mitigation of the detrimental effects due to multipath fading. With the advancement of various time and frequency-selective channel coding techniques, the MIMO-OFDM will enable a much more reliable and robust transmission over the harsh wireless environment [5].

In 1998, S. M. Alamouti [6] developed diversity scheme using two transmit antennas and one receive antenna, the scheme gives the same diversity order as a maximal - ratio combining (MRC) at the receiver side, with one transmit antenna, and dual antennas. There is no need for any bandwidth expansion in this scheme, all feedbacks from the receive to the transmit antennas, and its degree of computation complexity is same as MRC.

D. Q. Truing, N. Prayongpun, and K. Roof [7] considered new two models of antenna selection in Rayleigh channels such the Maximal Ratio Transmission (MRT) and Orthogonal Space-Time Block Code technique (OSTBC). The simulated results show that proposed antenna selection scheme may get a performance near by the optimum selection with low level of complexity.

A. Lozano, and N. Jindal [8] provided principals on the tradeoff property between transmit antenna diversity and spatial multiplexing . They showed the difference between the techniques of transmission that are using full spatial multiplexing and MIMO communication techniques for diversity purposes.

J. Jayakumari [9] analyzed her suggested MIMO-OFDM system using Quadrature Amplitude Modulation (QAM) in Rayleigh channel for next generation and promising wireless communication systems.

P. Bhatnagar,et.al [10] , submitted an improvement for MIMO-OFDM system employing Space Time Block Coding(STBC) over Rayleigh channels using BPSK and QPSK digital modulation techniques to overcome subchannel interference. Results showed that SNR increases with decrease in bit error rate magnitudes while it is decremented by increasing throughput of the system.

N. Sreekanth and M. N. Giriprasad [11], introduced new evaluations of MIMO-OFDM performance using Minimum Mean Square Error (MMSE) equalization . Maximum likelihood methods are proposed and iterative solutions are developed. BER study and analysis for BPSK digital modulation in Rayleigh fading channel with (2 x1) transceiver antennas as well as (2 x2) transceiver antennas for Alamouti STBC are presented. The used maximum likelihood is related on least squares iterations and projection .

The main goal of this paper is to show the analysis and impact of using different antenna lengths on the performance of bit error rate in new proposed model of MIMO-OFDM system employing different levels of PSK and QAM modulation techniques. Also, the effect of the channel order on suggested MIMO - OFDM system has been introduced and analyzed by using Matlab simulator.

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2 ALAMOUTI SCHEME

The easiest format of space time block codes was developed by Alamouti in 1998. He proposed this technique for dual sending antennas and one receive antenna .In the Alamouti encoder, dual consecutive symbols x_1 and x_2 are encoded , and the code matrix is given as in [6]:

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \quad (1)$$

In equation (1), the column in the beginning stands for the first transmission period (T) and the 2nd column the 2nd transmission period (2T). The 1st row related to the symbols sent from the 1st antenna and the 2nd row related to the symbols sent from the 2nd antenna . Namely, the encoding is done in both the space(across dual antennas) and time (dual sending durations) domains. This represents as space-time coding.

The encoder outputs are sent in two consecutive transmission periods from dual transmit antennas as shown in **Figure.1**. During 1st transmission period, dual signals x_1 and x_2 are sent at same time from 1st and 2nd antenna, respectively. In the 2nd transmission period, two signals $-x_2^*$ and x_1^* are sent on time from 1st and 2nd antenna, respectively, where $*$ denotes the complex conjugate .

$$X^1 = [x_1, -x_2^*] \text{ and } X^2 = [x_2, x_1^*] \quad (2)$$

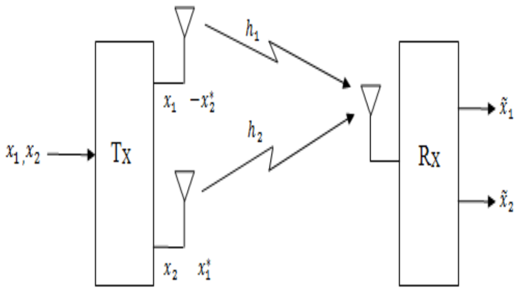

Figure.1. Alamouti encoder

Where X^1 and X^2 are the data sequences from 1st antenna and 2nd antenna, respectively .The basic property of the Alamouti scheme is the sent sequences from the dual sending antennas are orthogonal, because of zero inner product value of the sequences X^1 and X^2, This inner product is given by :

$$X^1.X^2 = x_1 x_2^* - x_2^* x_1 = 0 \qquad (3)$$

The code matrix in Equation (1) is a complex-orthogonal matrix, that is

$$X.X^H = \begin{bmatrix} |x_1|^2 + |x_2|^2 & 0 \\ 0 & |x_1|^2 + |x_2|^2 \end{bmatrix} = (|x_1|^2 + |x_2|^2)I_2 \qquad (4)$$

where I_2 is a 2 × 2 identity matrix.
At the receiving side, single receive antenna is used and the diversity analysis is based on Maximum likelihood (ML) signal detection. **Figure.2** explains the block diagram of the receiver for the Alamouti scheme. The fading channel parameters from 1st and 2nd sending antennas to the receive antenna at time t are symboled by $h_1(t)$ and $h_2(t)$, respectively.

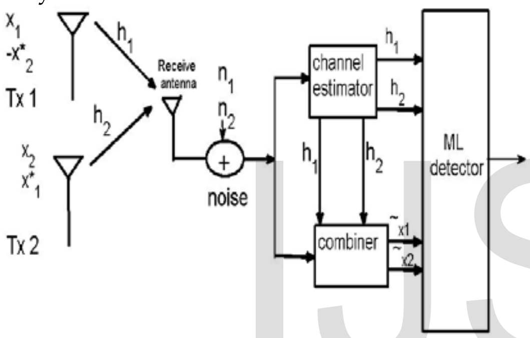

Figure.2.The Alamouti scheme receiver

Consider two sent consecutive symbols for fading coefficient are fixed, they can be written as :

$$h_1(t) = h_1(t+T) = h_1 = |h_1|e^{j\theta_1} \qquad (5)$$
$$h_2(t) = h_2(t+T) = h_2 = |h_2|e^{j\theta_2} \qquad (6)$$

Where $|h_i|$and θ_i ,i = 0, 1, are the amplitude gain and phase shift for the path from sending antenna i to the receiving antenna, and T is the symbol duration. The receiver receives y_1 and y_2 denoting the two received signals across two consecutive symbol intervals for time t and $t+T$, respectively .The received signals may be written as :

$$y_1 = h_1 x_1 + h_2 x_2 + n_1 \qquad (7)$$

$$y_2 = h_1 x_2^* + h_2 x_1^* + n_2 \qquad (8)$$

Where n_1 and n_2 are independent complex variables with zero mean and unity variance, representing AWGN samples at time t and $t+T$, respectively. In the combiner-aided by the channel estimator, which provides perfect estimation in which the channel coefficients, h_1 and h_2 , are sufficiently familiar to the receiver.

For this instance ,easy signal processing is performed so as to separate the signals x1 and x2. Specifically, the maximum likelihood detector reduces highly the decision metric:

$$|y_1 - h_1\check{x}_1 - h_2\check{x}_2|^2 + |y_2 + h_1\check{x}_2^* - h_2\check{x}_1^*|^2 \qquad (9)$$

By whole possible magnitudes of $\check{x}_1$ and $\check{x}_2$. Substituting (7) and (8) into (9), the maximum likelihood decoding can be stood for :

$$(\check{x}_1, \check{x}_2) = arg_{(\check{x}_1,\check{x}_2)\in C}^{min}(|h_1|^2 + |h_2|^2 - 1)(|\check{x}_1|^2 + |\check{x}_2|^2) + d^2(\tilde{x}_1, \check{x}_1) + d^2(\tilde{x}_2, \check{x}_2) \qquad (10)$$

C stands for all possible groups for modulated symbol pairs$(\check{x}_1, \check{x}_2)$, $\tilde{x}_1$ and $\tilde{x}_2$ are two decision statistics built by emerged received signals with channel state information.

The following statistics are used for decision and they can be calculated by:

$$\tilde{x}_1 = h_1^* y_1 + h_2 y_2^* \qquad (11)$$
$$\tilde{x}_2 = h_2^* y_1 - h_1 y_2^* \qquad (12)$$

h_1 and h_2 are channel realization, the decision statistics $\tilde{x}_i$, i = 1, 2, is only a function of x_i, i = 1, 2. By the way, the maximum likelihood decoding principle may be composed of dual independent decoding equations for x_1 and x_2, by :

$$\check{x}_1 = arg_{\check{x}_1\in S}^{min}(|h_1|^2 + |h_2|^2 - 1)|\check{x}_1|^2 + d^2(\tilde{x}_1, \check{x}_1) \qquad (13)$$
$$\check{x}_2 = arg_{\check{x}_2\in S}^{min}(|h_1|^2 + |h_2|^2 - 1)|\check{x}_2|^2 + d^2(\tilde{x}_2, \check{x}_2) \qquad (14)$$

Alamouti STBC have been used in multiple wireless standards such as WCDMA and CDMA2000 because of the following features. Firstly, it implements the full diversity of any signal(real or complex) constellation in the full transfer rate. Secondly, it does not require channel state information (CSI) at sender. Thirdly, the maximum likelihood decoding at the receiver includes just linear processing because of orthogonal code nature .

2.1 THE ALAMOUTI SCHEME WITH MULTIPLE TRANSMIT ANTENNAS

The Alamouti scheme brought in a revolution of sorts in multi antenna systems by providing full diversity of two without (CSI) at the sender and a very simple maximum likelihood decoding system at the receiver may be performed by simple linear processing. Maximum likelihood (ML) decoders provide full diversity gain of N_R receive antennas. Hence, such a system provides a guaranteed overall diversity gain of 2N_R, in the case of not using CSI at the sender. This is achieved by orthogonality feature among the sequences produced by two sending antennas. Due to these reasons, the approach was used generally to an arbitrary number of sending antennas using the orthogonal designs theory. This approach is known as space-time block codes (STBCs) [12,13] .

Generally, the resultant space time block encoder , as in **Figure.3,** is a code word matrix **x** with dimension of $N_T \times T$. Here N_T is the number of sending antenna and T represents the number of symbols for each block. The matrix **x** is based on orthogonality designs such that :

$$\mathbf{x}.\mathbf{x}^H = c(|x_1|^2 + |x_2|^2 + \cdots + |x_i|^2) I_{N_T} \qquad (15)$$

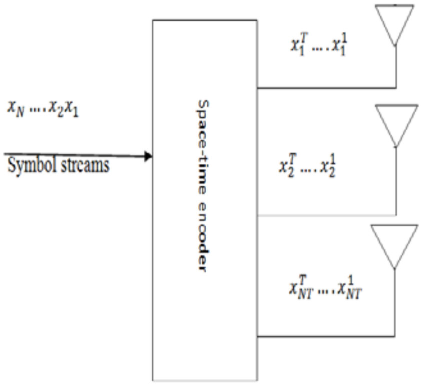

Figure .3. Space-time block encoder

Where c is a constant,$N_T$represents sending antennas number, $\mathbf{x}^H$ is the Hermitian of $\mathbf{x}$, and I_{N_T} is $N_T \times N_T$unity matrix. The ith row of x stands for the symbols sent from the ith sending antenna respectively in T transmission intervals, whereas the jth column of **x** stands for the symbols sent at same time by N_T sending antennas at time j. The jth column of x is related as a space-time symbol sent at time j. The elements of **x** in the ith row and jth column, $x_{i,j}$, $i = 1, 2, \dots, N_T$ & $j = 1, 2, \dots, T$, represent the signal sent from the antenna i at time j. The property in equation (16) indicates that the transmission matrix row vectors **x** are orthogonal to each other, which is

$$\mathbf{x}_i.\mathbf{x}_j = \sum_{t=1}^{T} x_{i,t}.x_{j,t}^* = 0\,, i \neq j\,, \quad i,j \in \{1,2,\dots,N_T\} \qquad (16)$$

Where $\mathbf{x}_i.\mathbf{x}_j$ stands for the inner product of the sequences $\mathbf{x}_i$ and $\mathbf{x}_i$.The orthogonality activates to implement the complete sending diversity for specified sending antennas. In addition, it permits the receiver to separate the sent signals from various antennas and hence, a casual maximum likelihood decoding which is relied on linear processing of the received signals .

2.2 THE ALAMOUTI SCHEME WITH MULTIPLE RECEIVE ANTENNAS

The Alamouti scheme may be used for a system with dual sending and N_R receive antennas. The encoding sending process for this scheme is similar to the case of one receive antenna. It is considered that r_1^i and r_2^i are the received signals at the i^h receive antenna at 1st and 2nd symbol period ,consecutively [13,14].

$$r_1^i = h_{i,1}x_1 + h_{i,2}x_2 + n_1^i \qquad (17)$$

$$r_2^i = -h_{i,1}x_2^* + h_{i,2}x_1^* + n_2^i \qquad (18)$$

Where $h_{i,j}$ ($j = 1, 2$; $i = 1, 2, \dots, N_R$) is the fading coefficient for the path from sending antenna j to receiving antenna i, and n_1^i and n_2^i are the noise signals for receiving antenna i at 1st and 2nd symbol periods, respectively.

The receiver emerger produces dual decision statistics according to linear set of the received signals. The decision statistics, represented by $\tilde{x}_1$ and $\tilde{x}_2$, are written as :

$$\tilde{x}_1 = \sum_{j=1}^{N_R} h_{j,1}^* r_1^j + h_{j,2}\left(r_2^j\right)^* \qquad (19)$$

$$\tilde{x}_2 = \sum_{j=1}^{N_R} h_{j,2}^* r_1^j - h_{j,1}\left(r_2^j\right)^* \qquad (20)$$

3 MIMO-OFDM SYSTEM MODEL

In MIMO systems, Alamouti scheme has been implemented widely. The transmit diversity technique proposed by Alamouti was the space time block coding (STBC) [6] .A new block diagram of MIMO-OFDM that combines OFDM with MIMO systems with the help of STBC encoder and decoder at the transmitter and receiver side has been implemented .

The data is encoded by a channel code and the encoded data is split into multiple streams that are simultaneously transmitted using multiple transmit antennas. The received signal at each receive antenna is a linear superposition of the different transmitted signals .

The adopted block diagram of MIMO-OFDM is presented in **Figure.4** . The system consists of number of transmit and receive antennas. In this paper the cyclic prefix (CP) is assumed to be longer than the channel delay spread. The OFDM signal for each antenna is obtained by using inverse fast Fourier transform (IFFT) . The OFDM symbol can be expressed as:

$$x(n) = \frac{1}{N} \sum_{m=0}^{N-1} X(m) e^{j\frac{2mn\pi}{N}} \qquad (21)$$

The discrete OFDM signal can be detected by fast Fourier transform (FFT) after removing CP . The demodulated symbol stream can be calculated by:

$$y(m) = \sum_{n=0}^{N-1} y(n) e^{-j\frac{2mn\pi}{N}} + G(m) \qquad (22)$$

where, G(m) is related to the FFT of the samples of g(n), which is the Additive White Gaussian Noise (AWGN) introduced in the channel.

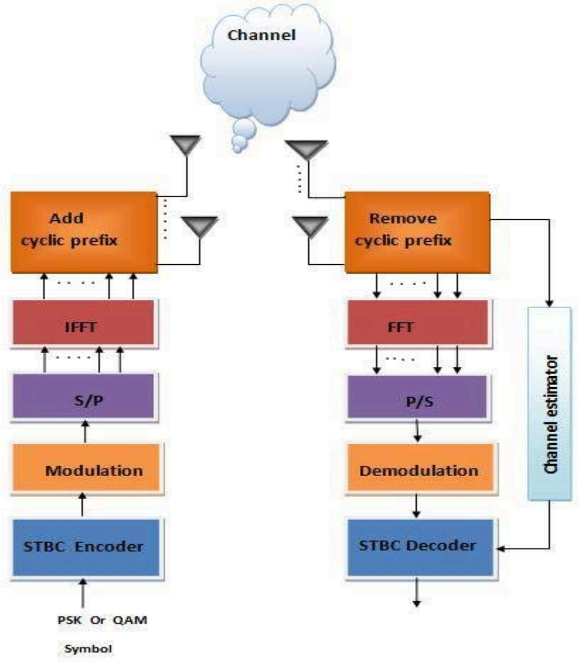

Figure.4. The Proposed MIMO-OFDM transceiver

In general for STBC transceivers , Let us consider the system where the transmitter has n_t antennas and the receiver has n_r antennas. For practical purposes, it is common to model the channel as frequency flat whenever the bandwidth of the system is smaller than the inverse of the delay spread of the channel; hence wideband system operating where the delay spread is fairly small may sometimes also be considered as flat frequency .

Let $h_{m,n}$ be a complex number corresponding to the channel gain between transmit antenna *n* and the receive antenna *m*. If at a certain time instant the complex signals $\{x_1, x_2, \ldots, x_{nt}\}$ are transmitted via the n_t antennas, the received signals at antenna *m* can be expressed as [4,11] :

$$y_m = \sum_{n=1}^{n_t} h_{m,n} x_n + e_m \qquad (23)$$

where e_m is a noise term. The relation in equation (23) can be expressed in a matrix framework. Let *x* and *y* be n_t and n_r vectors containing the transmitted and receiver data, respectively. Define the following n_r x n_t channel gain matrix:

$$H = \begin{bmatrix} h_{1,1} \ldots\ldots\ldots h_{1,nt} \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ . \\ h_{nr,1} \ldots\ldots. h_{nr,nt} \end{bmatrix} \qquad (24)$$

Then we have,

$$y = Hx + e \qquad (25)$$

where e = $[e_1 \ldots\ldots. e_{nr}]^T$ is a vector of noise samples. If several consecutive vectors {x1,..,xN} are transmitted, the corresponding received data can be arranged in a matrix

$$Y = [y_1 \ldots\ldots y_N] \qquad (26)$$

and written as follows:

$$Y = HX + E \qquad (27)$$

where $X = [x_1 \ldots \ldots x_N] \qquad (28)$

and $E = [e_1 \ldots \ldots e_N] \qquad (29)$

However , detailed STBC encoding and decoding with different number of transceiver antennas are given in [12,13,15] .

Channel estimation for adopted MIMO-OFDM model can be achieved by transmitting a training sequence from receive antennas during CP removal to STBC decoder to get some correlation effects for STBC decoder.

4 SIMULATION RESULTS AND DISCUSSION

The paper plan aims to analyze the effect of antenna array length on transmitting and receiving sides on the performance of suggested MIMO-OFDM system as shown in **Figure.4** using Matlab simulator. The performance analysis will give insight into the impact of important and optimal number of transmitter and receiver antennas with lowest bit error rate using PSK and QAM constellations .In this section, a comparative study of BER performance of the system with different number of transceiver antennas with OFDM are simulated and analyzed. The simulation parameters are chosen for MIMO-OFDM of **Figure.4** as shown in **Table I** .

The MIMO-OFDM algorithm for computing BER for different M-ary PSK or QAM using STBC techniques are as following:

1. Random generation of M-ary PSK and QAM symbols using rand command and choose Eb/N0 range.
2. Choosing (n_t x n_r) antenna configurations.
3. Assuming a transmission sequence has been used, For example $\{X_1, X_2, X_3, \ldots.\}$.Normally, X_1 will be sent in the first time slot, X_2 in the second time slot, X_3 and so on .
4. Encode these sequences by using STBC encoder.
5. M-ary PSK or QAM Modulation and then serial in parallel out the data bits groups.

6. Use IFFT for bit groups to get OFDM signals .The idea in OFDM generation, the transmitter accepts a stream of data and converts them to symbols using modulation technique, for example QPSK. Then add cyclic prefix (CP) to retain sinusoids properties in multipath channels.
7. Calculate channel matrix, transmission matrix and received signal per receiver antenna.
8. Remove CP and FFT the incoming signals from multiple receive antennas separately.
9. Parallel to serial conversion and demodulate received signals.
10. Decode demodulated signals using STBC decoder .
11. Counting the number of bit errors corresponding to chosen values of Eb/N_0.
12. Plot the bit error rate versus Eb/N_0.

Table I:MIMO-OFDM Simulation Parameters

Number of bits per OFDM symbol	52
Number of symbols	10000
No. Of Subcarrier	64
FFT sampling frequency	20 MHz
Subcarrier spacing	312.5kHz
Constellation	16 PSK ,64PSK ,16QAM and 64QAM
Cyclic Prefix	0.8 µs
symbol interval	3.2 µs

BER responses with respect to Eb/N0 (bit energy to noise power spectral density) for different antenna configurations (1x2, 1x4,2x4,2x1,2x2, 3x1,3x4, 4x1, 4x4) over Rayleigh channel have been depicted in **Figures.5-6**. They show as the number of transmit and receive antennas increase, the BER keeps on decreasing and provide better BER performance due to spatial diversity.

It is worth pointing that (1x2 and 1x4) antenna configurations have better BER responses as compared with (2 x1 and 4x1) configurations . This is because the effective channel concatenating the information from receive antennas results in a diversity order of 4 and 8 ,where diversity order is twice the number of receive antennas .The optimal BER can be observed in (4 x 4) transceiver configuration for all M-ary PSK modulation levels. **Figures.7-8** present bit error rate comparisons with QAM modulation using constellation orders of 16 and 64 for selected antenna transceiver configurations (2x1,1x2,2x2,2x4 and 4x4). Those figures show as we increasing the number of transmitting and receiver antennas, the BER keeps as before on decreasing because of spatial diversity. In general from **Figure.5-8** ,with number of symbols = 10000 (transmitted), BER can be only measured down to $\mathbf{10^{-3}}$ reliably .

On the other hand ,MATLAB simulations have been conducted to investigate the effect of channel order (No. of channel paths,L) as in **Figure.9** in the case of 2PSK digital modulation . From this graph, it can be noted that as L increases, the error probability will also increase over Rayleigh channel. Increasing L will increase the SNR clearly as from this figure .

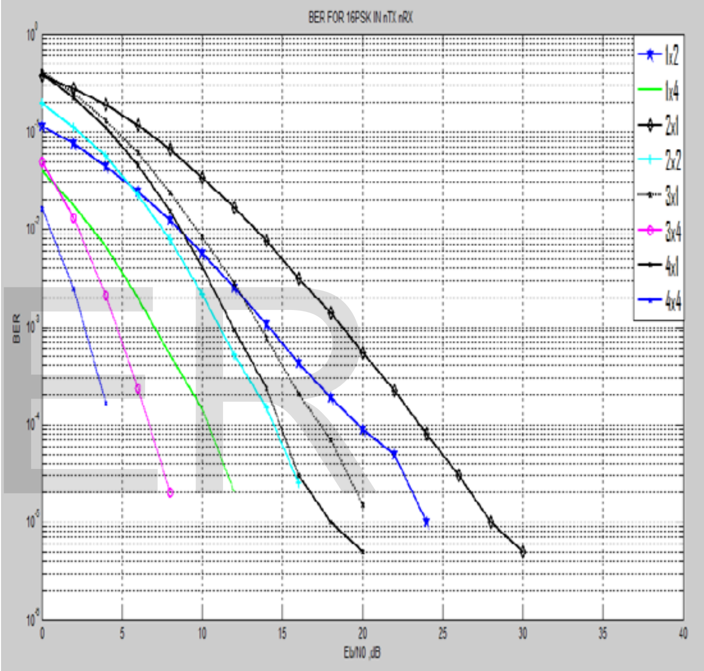

Figure.5. BER performance of 16 PSK MIMO OFDM system

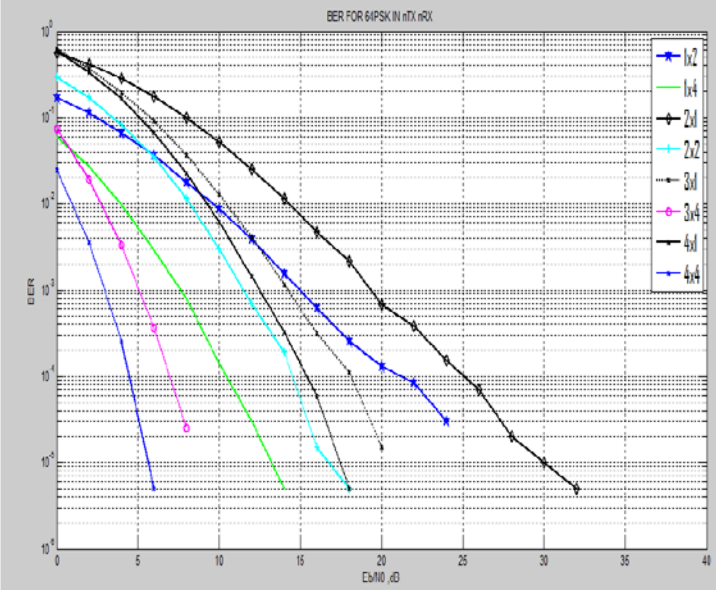

Figure.6. BER performance of 64PSK MIMO OFDM system

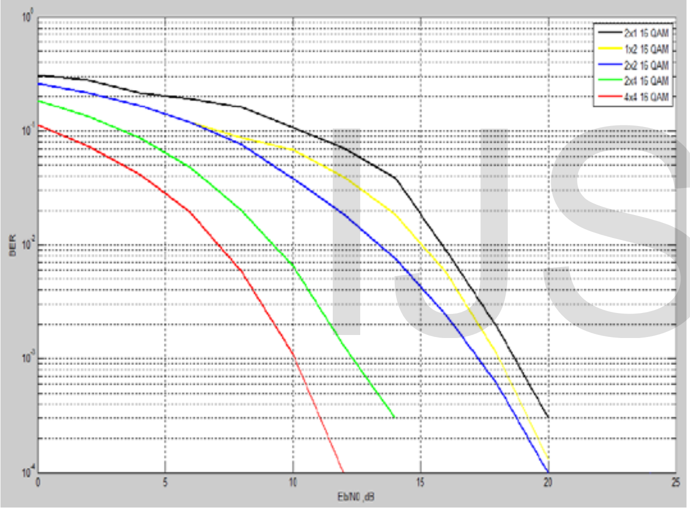

Figure.7. BER performance of MIMO OFDM system with different antenna configuration using 16QAM digital modulation

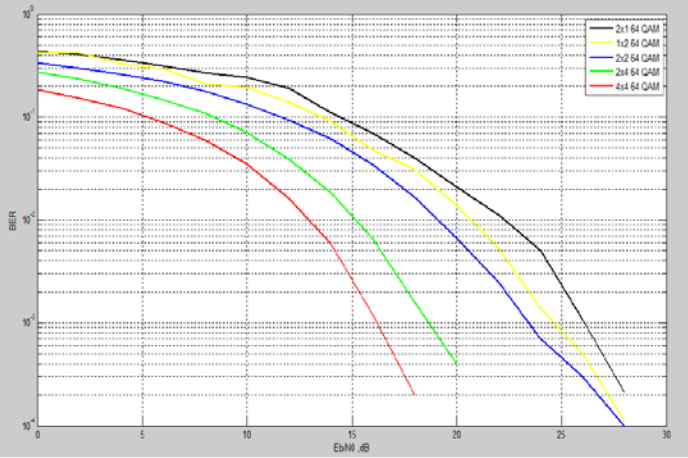

Figure.8. BER performance of MIMO OFDM system with different antenna configuration using 64QAM digital modulation

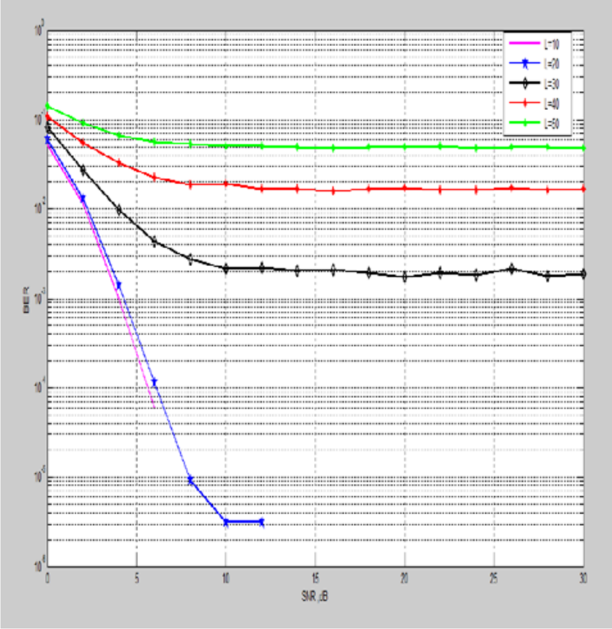

Figure.9. BER performance of MIMO OFDM system with using 2PSK digital modulation

5 CONCLUSION

In this paper, the performance of new proposed MIMO-OFDM systems using PSK and QAM digital modulations for different antenna configurations is reported. Performance of MIMO OFDM system is analyzed under Rayleigh fading channel. The proposed MIMO-OFDM system can be implemented using higher order modulations to achieve large data capacity. It should be mentioned that the new proposed MIMO-OFDM model has higher data rate and lower bit error rate as compared to [9] and [10] .

The motive of using high order antenna configuration is to decrease the BER at given Eb/N0 as compared to lower order antenna configurations,where the lowest BER can be obtained at highest number of transmitting and receiving antenna configurations.Also, the effect of the channel order on a MIMO - OFDM system has been introduced and analyzed.

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