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# BER Analysis & Comparison of Different Equalization Techniques for MIMO-OFDM System

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***Abstract—Multiple-input–multiple-output (MIMO) technology is a recent breakthrough in wireless communications and has been shown to enhance channel capacity in single user systems. Multiple input multiple output (MIMO) orthogonal frequency division multiplexing (OFDM) systems ease high data rate communications. The use of multiple antennas at both the transmitter and receiver can considerably increase the channel capacity. These systems are called the multiple-input multiple-output (MIMO) systems. By using orthogonal frequency division multiplexing (OFDM) transmission techniques, the MIMO-OFDM system can achieve high spectral efficiency, throughput which makes it irresistible for high-data-rate wireless applications. In this paper we study the equalization problem for multiple-input multiple-output (MIMO) systems & by using numerical results simulated performance of the equalization techniques for MIMO systems is carried out & it is shown that BER(Bit Error Rate) decreases as number of receiving antenna increases.***

***General Terms-- Equalizer, Bit error rate, Signal to noise ratio (Eb/N0), transmitting antenna, receiving antenna.***

***Keywords-- MIMO (Multiple Input Multiple output), MMSE (Minimum Mean Square Error), MRC (Maximal Ratio Combining), ZF (Zero Forcing) ISI (Inter Symbol Interference), SNR (Signal to Noise Ratio).***

## I. INTRODUCTION

MIMO Systems use multiple inputs and multiple outputs from a single channel. They are defined by Spatial Diversity and Spatial Multiplexing. In the never-ending search for increased capacity in a wireless communication channel it has been shown that by using MIMO (Multiple Input Multiple Output) system it is possible to increase that capacity considerably. Usually fading is seen as a problem in wireless communication but MIMO channels uses the fading to increase the capacity. The system with multiple antennas at the transmitter and receiver is known as multiple input multiple output (MIMO) systems. MIMO systems transmit different signals from each transmit element so that the receiving antenna array receives a superposition of all the transmitted signals. All signals are transmitted from all elements once and the receiver solves a linear equation system to demodulate the message. The multiple antennas are thus used to increase data rates through multiplexing or to improve performance through diversity. MIMO channel model is shown in Fig. 1 with M transmitter and N receiver antennas. It is achieved by higher spectral efficiency, link reliability and diversity (reduced fading).

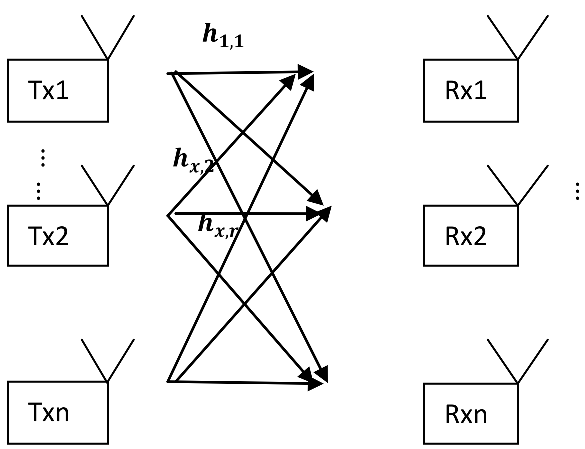


**Fig.1 MIMO SYSTEM OFDM (Orthogonal Frequency Division Multiplexing)**

A MIMO-OFDM system with four transmit and r (r≥4) receive antennas is shown in Fig.2. The figure shows MIMO-OFDM system with four transmit antennas, the techniques developed for this can be directly applied to OFDM systems with any number of transmit antennas.
At a time , each of two data blocks, bi[n,k] : k= 0,1….for i=1 and 2, is transformed into two different signals, {t2(i-1)+ j[n,k] : k =0,1….., j=1,2}for i= 1 and 2,respectively, through two space–time encoders. The OFDM signal for the th transmit antenna is modulated by ti[n,k] at the kth tone of the nth OFDM block.

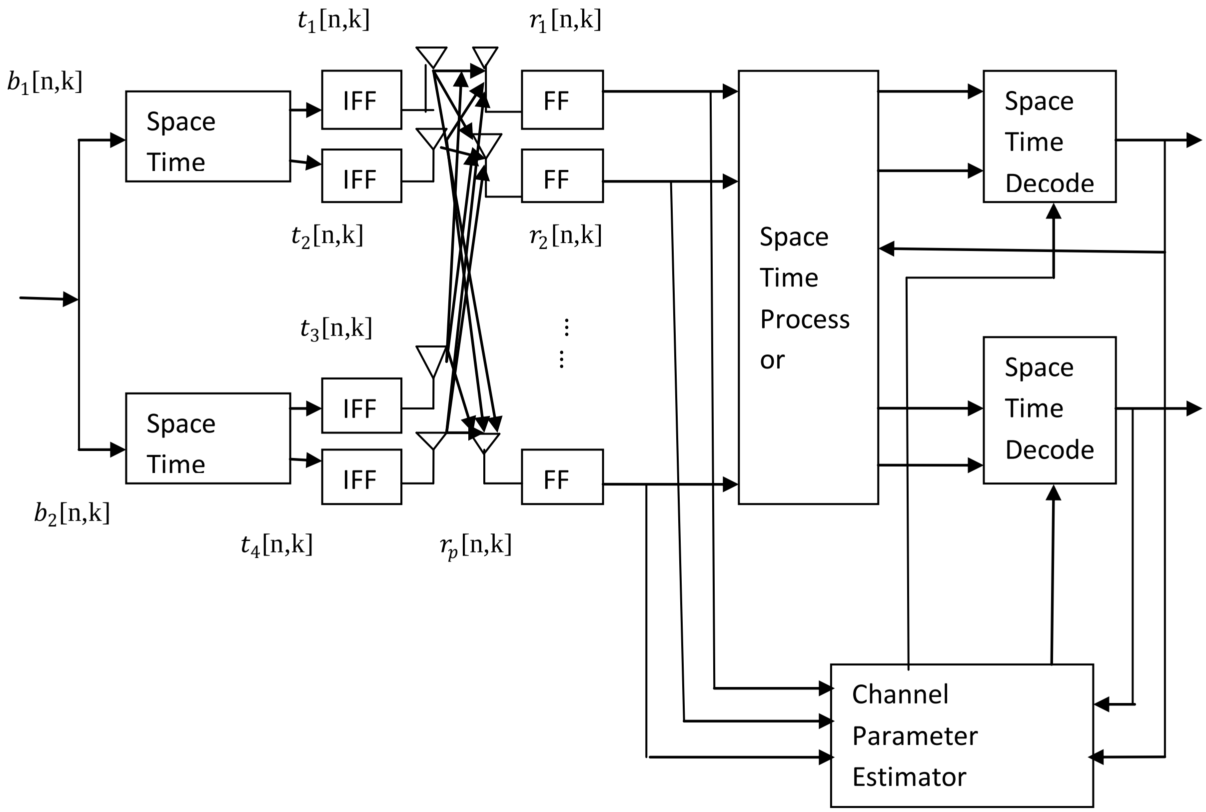


**Fig.2 MIMO-OFDM SYSTEM**

## II. MMSE EQUALIZER

In MIMO wireless communication, an equalizer is used to recover a signal that suffers from Inter symbol Interference (ISI) and the BER characteristics is improved and a good SNR can be obtained. A Minimum Mean Square Error (MMSE) estimator is a method which reduces the mean square error (MSE). MMSE equalizer does not completely exclude ISI but minimizes the total power of the noise and ISI components in the output.

### A. Definition:-

**Mean Square Error:-**

Suppose X is an unknown random variable, and Y is a known random variable. An estimator $\hat{X}$ (y) is any function of the measurement Y and Mean square error is mathematically given as:

$$\text{MSE} = E\{(\hat{X} - X^2)\}$$

where the expectation is taken over both X and Y. The MMSE estimator is defined as the estimator which achieves minimal MSE. Generally, it is very difficult to determine a closed form for the MMSE estimator. In these cases, one possibility is to search the technique that minimizes the MSE within a particular class such as linear estimators. The linear MMSE estimator is the estimator that achieves minimum MSE from all estimators of the form AY + b. If the measurement Y is a random vector then A is a matrix and b is a vector.

### B. Minimum Mean Square Error (MMSE) equalizer for 2×2 MIMO channel:-

Now there is a method to understand for extracting the two symbols which interferes with each other. In the first time slot, the received signal on the first receive antenna is,

$$y_1 = h_{1,1} x_1 + h_{1,2} x_2 + n_1 = [h_{1,1}\ h_{1,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1.$$

The received signal on second receive antenna is

$$y_2 = h_{2,1} x_1 + h_{2,2} x_2 + n_2 = [h_{2,1}\ h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

where

$y_1$ ,$y_2$ - received symbols on the first and second antenna respectively,

$h_{1,1}$ - channel from 1st transmit antenna to 1st receive antenna,

$h_{1,2}$ - channel from 2nd transmit antenna to 1st receive antenna,

$h_{2,1}$ - channel from 1st transmit antenna to 2nd receive antenna,

$h_{2,2}$ - channel from 2nd transmit antenna to 2nd receive antenna,

$x_1$ , $x_2$ - transmitted symbols and

$n_1$ ,$n_2$ - noise on 1st, 2nd receive antenna.

Now assuming that the receiver knows $h_{1,1}$ ,$h_{1,2}$ , $h_{2,1}$ , $h_{2,2}$ , $y_1$ and $y_2$ . Equivalently the above equation is represented as:-

$Y = hx + n$

where,

Y= received symbol in channel matrix

x= input symbol &

n= noise

& in matrix notation it is given as:-

$$\begin{matrix} y_1 \\ y_2 \end{matrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} * \begin{matrix} x_1 \\ x_2 \end{matrix} + \begin{matrix} n_1 \\ n_2 \end{matrix}$$

The **Minimum Mean Square Error** (**MMSE**) also tries to find a coefficient W which minimizes

$$E\left\{\left[W_y - x\right]\left[W_y - x\right]^H\right\}$$

To solve this, a matrix is needed which satisfies MMSE detector for meeting this constraint is given as:-

$$W = \left[H^H H + N_0 I\right]^{-1} H^H$$

Where W - Equalization Matrix,

H - Channel Matrix. This matrix is known as the pseudo inverse for a general m x n matrix.

&

$$H^H H = \begin{bmatrix} h_{1,1}^* & h_{2,1}^* \\ h_{1,2}^* & h_{2,2}^* \end{bmatrix} \begin{bmatrix} h_{1,1}^* & h_{1,2}^* \\ h_{2,1}^* & h_{2,2}^* \end{bmatrix} = \begin{bmatrix} |h_{1,1}|^2 + |h_{2,1}|^2 & h_{1,1}^* h_{1,2} + h_{2,1}^* h_{2,2} \\ h_{1,2}^* h_{1,1} + h_{2,2}^* h_{2,1} & |h_{1,2}|^2 + |h_{2,2}|^2 \end{bmatrix}$$

When comparing the equation in Zero Forcing equalizer, apart from the $N_0 I$ term both the equations are comparable. Infact, if the noise term is zero, the **MMSE** equalizer reduces to Zero Forcing equalizer.

The BER for BPSK Modulation in Rayleigh fading channel is defined as:-

$$P_b = \frac{1}{2}\left(\sqrt{\frac{E_b/N_0}{\left(E_b/N_0\right) + 1}}\right)$$

Where

$P_b$ = Bit Error Rate

$E_b/N_0$ = Signal to Noise Ratio

**C. Zero Forcing Equalizer:-**

Zero forcing equalizer refers to a form of linear equalization algorithm used in communication systems which inverts the frequency response of the channel. The Zero-Forcing Equalizer applies the inverse of the channel to the received signal, to restore the signal before the channel. It has many useful applications. For example, it is studied heavily in MIMO channel which allows recovery of the two or more streams which will be received on top of each other on each antenna. The name Zero Forcing corresponds to bringing down the Inter symbol Interference (ISI) to zero in a noise free case. This will be useful when ISI is significant compared to noise.

**D. Maximal-Ratio Combining Equalizer:** In telecommunications, maximal-ratio combining is a method of diversity combining in which:-

(a) The signals from each channel are added together.

(b) The gain of each channel is made proportional to the RMS signal level and inversely proportional to the mean square noise level in that channel.

(c) Different proportionality constants are used for each channel. It is also known as ratio-squared combining and pre-detection combining. Maximal-ratio-combining is the optimum combiner for independent AWGN channels.

## III. Results & Discussions

Equalization Techniques are of vast importance in the design of high data rates wireless systems. They can combat for Intersymbol Interference even in mobile fading channels with high efficiency. Zero forcing Equalizer performs well only in theoretical assumptions that are when noise is zero. This also helps to achieve data rate gain, as shown in fig.3. Minimum Mean Square Equalizer uses LMS (least mean square) as a criterion to compensate ISI, as shown in fig.3.

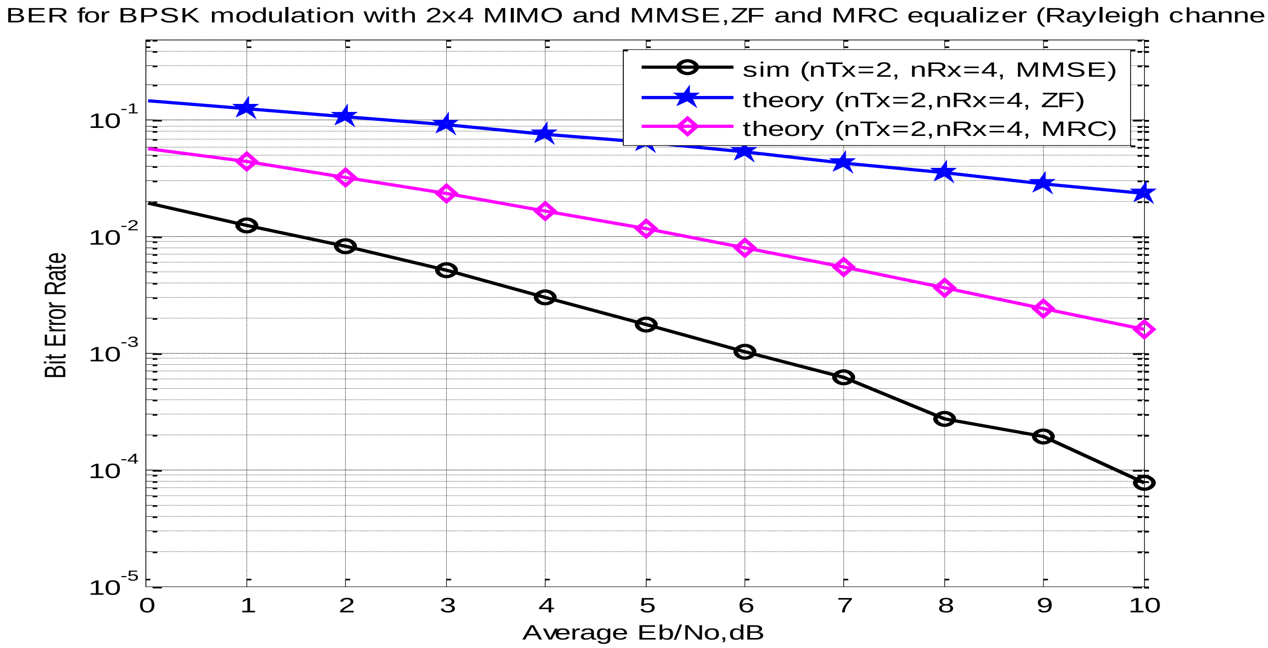


**Fig.3 Plot for BER for BPSK modulation for MMSE, MRC and ZF Equalizer in Rayleigh Channel for (2×2) MIMO system**.

Minimum Mean Square Equalizer not only excludes ISI components but also minimizes the total power of noise as shown in fig no.4 as compared to Zero Forcing Equalizer the results in lowering the chances of incorrect decisions resulting in enormous interference cancellation as shown in fig.4 and there is a less improvement in the Bit Error Rate.

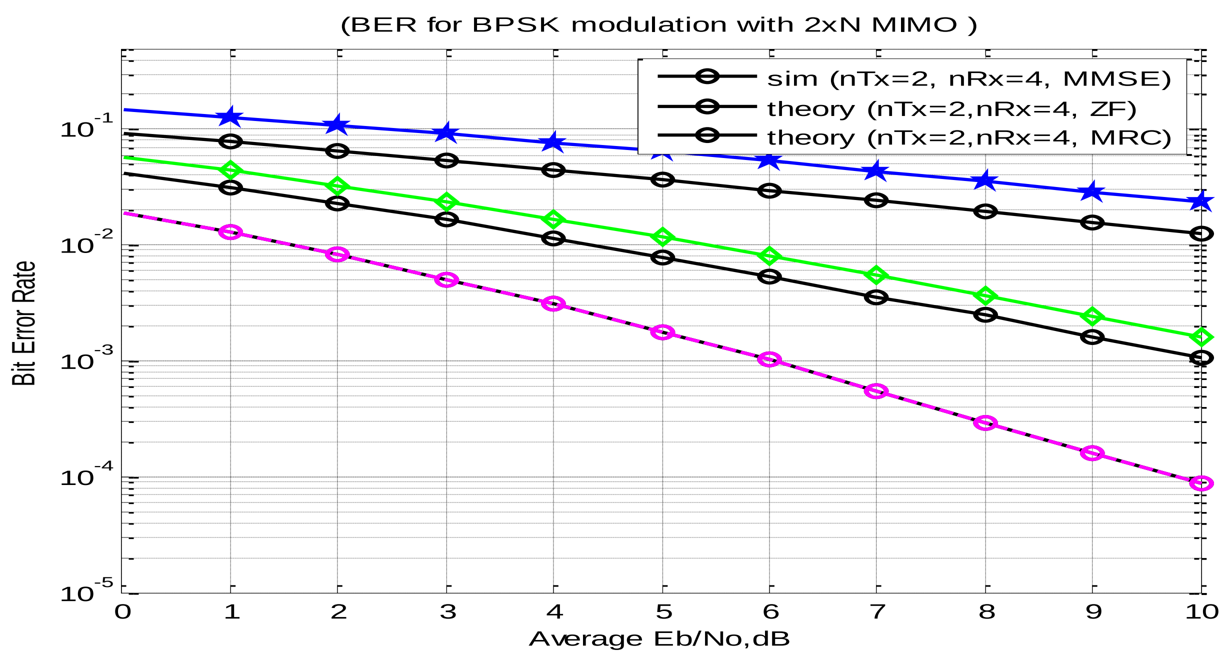


**Fig.4 Plot for BER and Eb/No for MMSE for different number of receivers.**

From the simulation, results in the form of bar chart are shown in the fig.5 shows that the Bit Error Rate of MMSE equalizer based receiver is less as compared to Zero Forcing Equalizer.
As shown in Table1.1 the BER for Theoretical MRC is 0.0581, Simulated MMSE is 0.0925 and for Theoretical ZF is 0.1464. This shows that MRC has lower BER as compared to MMSE in every case.

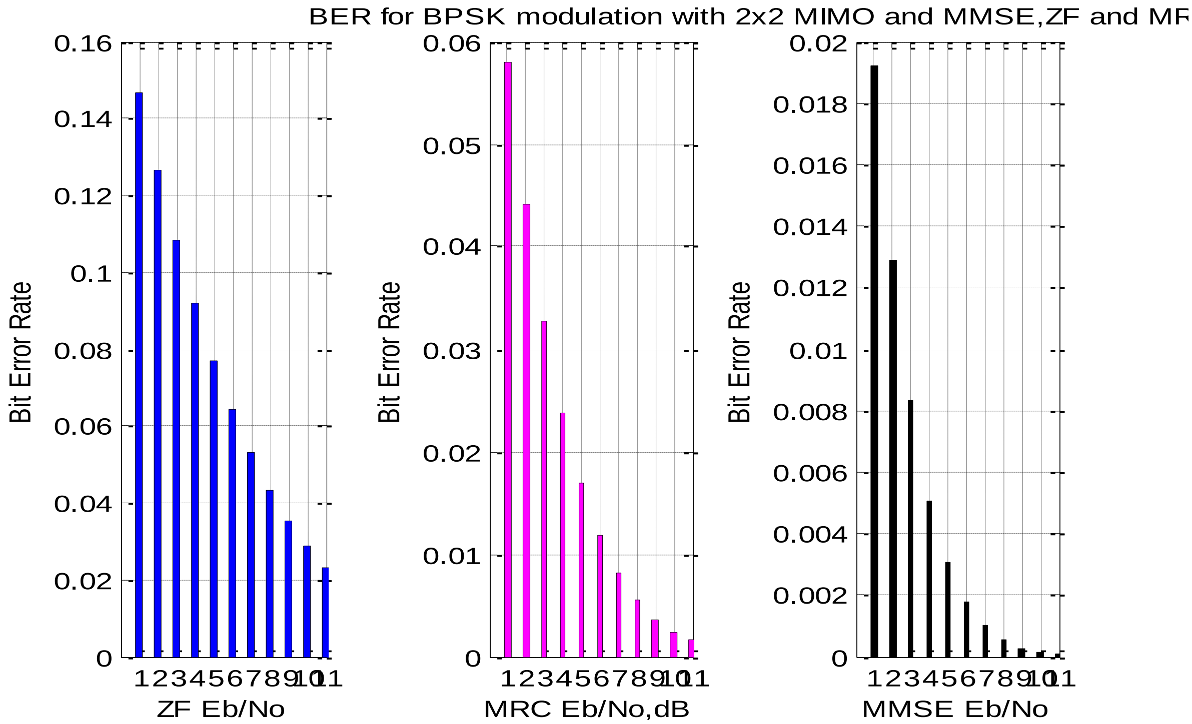


**Fig.5 Plot for BER and Eb/No for MMSE, MRC and ZF Equalizer in Rayleigh Channel for (2×2) MIMO system.**

The simulations were carried out at MATLAB which means keeping the transmitter antenna as two and vary the number of antennas in the receiver side as shown in figure below.

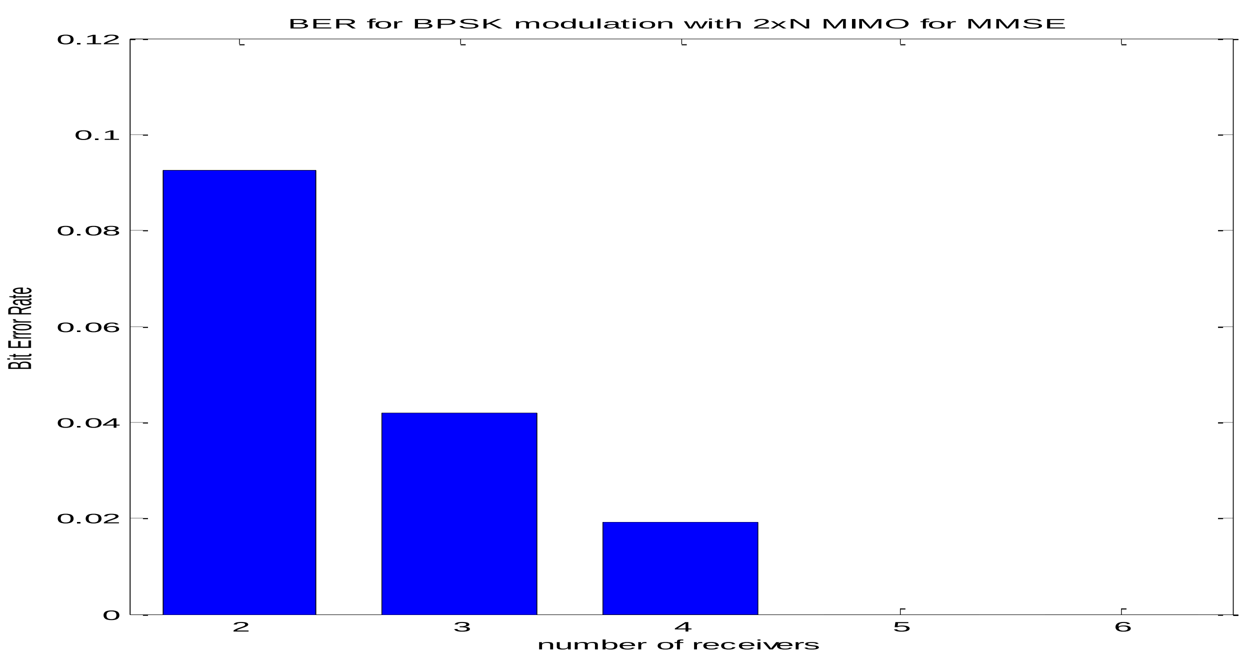


**Fig.6 Bar graph plot for BER with varying number of receivers**

From the MATLAB figure window shown in fig.5 shows the consolidated result in the form of bar chart comparison. From fig.6, it is evident that BER decreases as the receiver antenna increases for Minimum Mean Square Equalizer. For a better clarity the data from the fig.3 is taken and plotted in the form of bar chart as shown in fig.5. Similarly now the antenna configuration is varied namely 2×n as shown in fig.6, as the number of receivers (n) is increased keeping the number of transmitters (m=2) as constant, the Bit Error rate decreases in MMSE equalizer with increase in receivers.

 

**Table-1 BER and Eb/No dB values for MMSE, MRC and ZF Equalizer in (2×2) MIMO system**

| Eb/No | BER Values for MMSE,MRC and ZF Equalizer in (2×2)MIMO system | | |
|---|---|---|---|
| No of Receivers | MRC | ZF | MMSE |
| Column 1 | 0.0581 | 0.1464 | 0.0925 |
| Column 2 | 0.0441 | 0.1267 | 0.0783 |
| Column 3 | 0.0328 | 0.1085 | 0.0654 |
| Column 4 | 0.0238 | 0.0919 | 0.0541 |
| Column 5 | 0.0169 | 0.0771 | 0.0449 |
| Column 6 | 0.0118 | 0.0642 | 0.0367 |
| Column 7 | 0.0081 | 0.0530 | 0.0297 |
| Column 8 | 0.0055 | 0.0435 | 0.0242 |
| Column 9 | 0.0037 | 0.0355 | 0.0194 |
| Column 10 | 0.0024 | 0.0288 | 0.0155 |
| Column 11 | 0.0016 | 0.0233 | 0.0126 |
| Column 12 | 0.0013 | 0.0187 | 0.0100 |
| Column 13 | 0.0011 | 0.0151 | 0.0080 |
| Column 14 | 0.0009 | 0.0121 | 0.0064 |

The following observations are made. ZF is low computational complexity. It minimizes the probability of a sequence error. Hence from the above graphs it is clear that the BER decreases as the number of receiving antenna increases with respect to number of transmitting antenna in ZF equalizer based MIMO receiver. This equalizer is used for mobile communication link. Fig.3 and 5 and table 1.1 shows that as the no of receivers (n) is increased keeping the no of transmitters (m=2) as constant it is proved that the Bit Error Rate (BER) decreases in MMSE equalizer and also when the number of transmitters is less than the number of receivers. In this analysis we consider a fixed antenna MIMO antenna configuration and compared the performance with the three types of equalizer based receiver namely MRC, MMSE and ZF. Comparative values of BER for fixed MIMO configuration and how the two different equalizers exhibit the BER characteristics for a particular Eb/No value using BPSK modulation method. As the no of receivers (n) is increased keeping the no of transmitters (m) constant it is proved that the Bit Error Rate (BER) decreases.

## IV. Conclusion

To conclude this paper provides the complete knowledge of the key issues in the field of mobile communication. The data transmission at high bit rate is essential for many services such as video, high quality audio and mobile integrated service digital network. When data is transmitted at high bit rates over mobile radio channels, the channel impulse response can extend over many symbol periods which leads to Intersymbol Interference. The ultimate goal is to provide universal personal and multimedia communication without regard to mobility or location with a high data rates. To achieve such an objective a strong equalization technique i.e. MMSE is taken. The receiver scheme is based on MMSE. Bit Error Rate performance for MIMO-MMSE in correlated Rayleigh flat fading channel is better than Zero Forcing Equalizer. Two types of simulation analysis are carried out at MATLAB. The Simulation analysis is that by varying the receiver antenna keeping transmitter antenna constant for a particular type of equalizer based receiver at a particular Eb/No value using BPSK modulation method. Simulation analysis 2 presents about the fixed antenna MIMO antenna configuration and compare the performance with the three types of equalizer based receiver namely MRC, MMSE and ZF. The Zero Forcing Equalizer removes all ISI and is ideal only when the channel is noiseless. When the channel is noisy, the Zero Forcing Equalizer has a tendency to amplify the noise and is much suited for static channels with high SNR. Though MMSE is a balanced linear equalizer it does not eliminate ISI completely but instead minimizes the total power of the noise and ISI components in the output. The MMSE equalizer gives minimum BER values for corresponding Eb /No values. As the number of transmitters is less and more increasing in number, and BER decreases for a particular value of Eb/No value. BER performance of MRC Equalizer is superior then MMSE Equalizer. The BER values from fig.3 are 0.0581 for MRC and 0.0925 for MMSE. Based on the mathematical modeling and the simulation result it is inferred that the MRC equalizer is the best of the three equalizers.

 

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