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Comparison & Performance Evaluation of Various Equalization Techniques for MIMO–OFDM System

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ABSTRACT- MIMO Systems use multiple inputs and multiple outputs from a single channel. They are defined by Spatial Diversity and Spatial Multiplexing. The effect of fading and interference effects can be minimized with equalizer. The performance of different equalization techniques for MIMO-OFDM system is analyzed. The BER characteristics for varying number of receiving antenna are determined in mat lab tool box. The simulation is carried out & it is observed that the MMSE equalizer based receiver is a good choice for removing some ISI and reduces the total noise power. The results show that the BER decreases as the m x n antenna configuration increases.

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

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

1. INTRODUCTION

In the never-ending search for increased capacity in wireless communication channel it has been shown that by using MIMO (Multiple Input Multiple Output) systems it is possible to increase that capacity substantially.

Usually fading is considered 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).

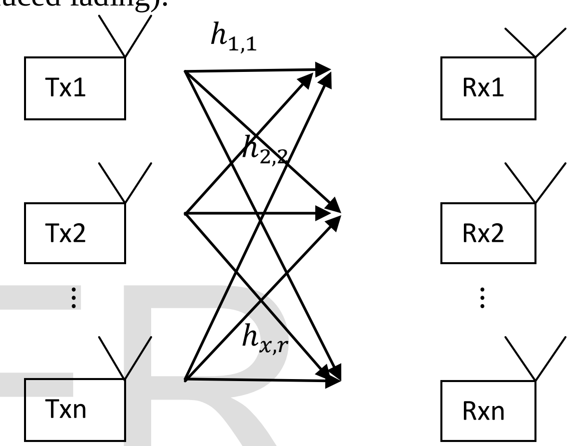

Fig. 1 MIMO SYSTEM

OFDM (Orthogonal Frequency Division Multiplexing)

OFDM is becoming widely applied in wireless communications systems due to its high rate transmission capability with high bandwidth efficiency and its robustness with regard to multi-path fading and delay. OFDM involves sending several signals at one given time over several different frequency channels, or subcarriers. The principle of orthogonality helps to ensure that cross talk does not occur between the carrier frequencies. Despite the fact that the signals overlap in the frequency domain, it is possible from a receiver's point of view to extract data from one specific carrier simply by knowing its frequency.

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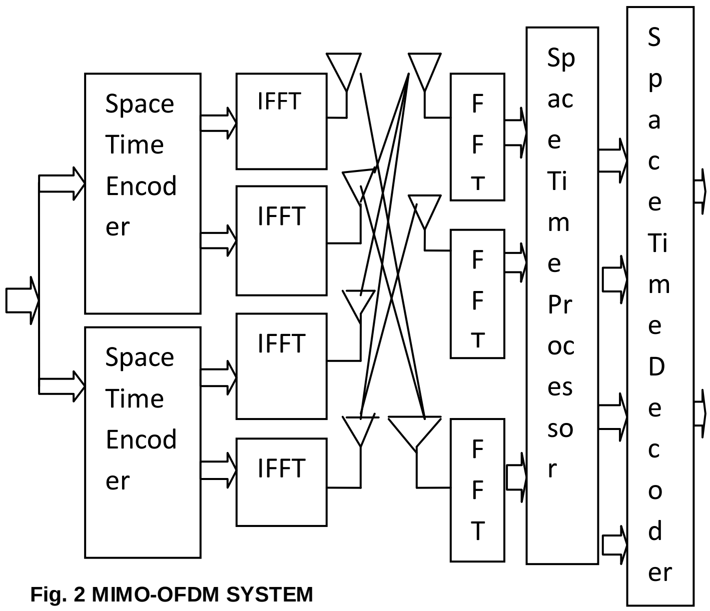

Fig. 2 MIMO-OFDM SYSTEM

The figure shows that the received signal at each receive antenna is the superposition of four distorted transmitted signals.

2. MMSE EQUALIZER

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

2.1. Definition

Mean Square Error

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

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

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.

2.2. 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

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

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

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

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. In fact, 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:-

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

Where

P_b = Bit Error Rate

E_b/N_O = Signal to Noise Ratio

2.3. 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. In this, the equalizer coefficients (C_n) are chosen to force the samples of the combined channel & equalizer impulse response to zero at all but one of the NT spaced sample points in tapped delay line filter. By letting the number of coefficients increases without bound, infinite length equalizer with zero ISI at output can be obtained.

2.4. Maximal-ratio combining Equalizer

In telecommunication, maximal-ratio combining is a method of diversity combining in which:-
(a) The signals from M branches are weighted according to their individual signal voltage to noise power ratios & then summed.
(b) Before being summed, individual signals must be co phased which generally requires individual receiver & phasing circuit for each antenna element.
(c) MRC produces an output with an acceptable SNR equal to sum of individual SNR's.
(d) In Maximum Ratio Combining (MRC) amplitudes and phases of the data signals received are adjusted with the help of digital signal processing in such a way that signal addition leads to gains in the S/N ratio and hence to a better bit error ratio (BER).

3. RESULTS & DISCUSSIONS

Equalization Techniques are of enormous 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 assumption that is when noise is zero. This also helps to achieve data rate gain, as shown in fig no. 3. Minimum Mean Square Equalizer uses LMS (least mean square) as a criterion to compensate ISI, as shown in fig.3.

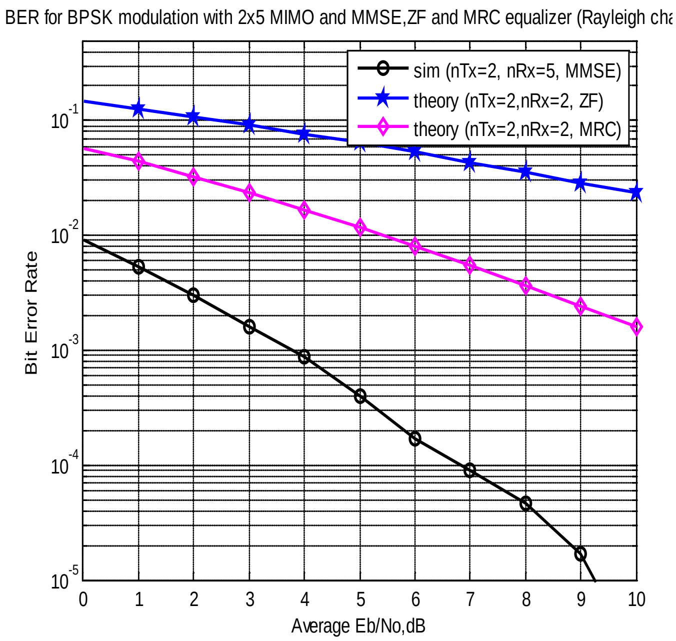

Fig.3 Plot for BER for BPSK modulation for MMSE, MRC and ZF Equalizer in Rayleigh Channel for (2×5) MIMO system.

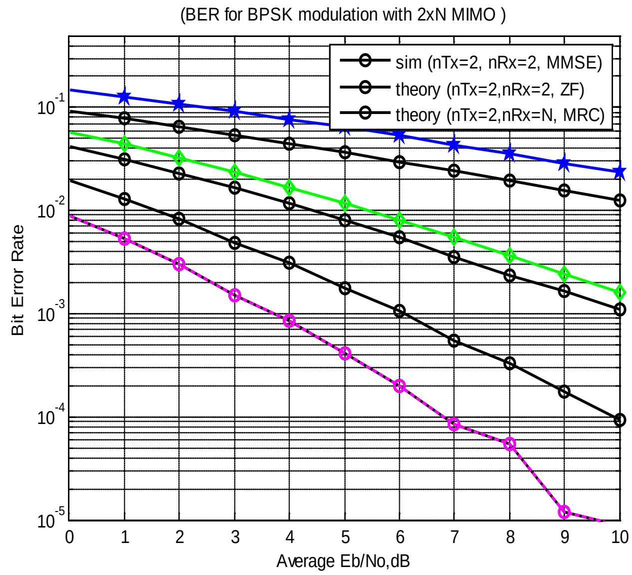

Fig.4 Plot for BER and SNR for MMSE for different number of receivers.

BER and SNR values for MMSE, MRC and ZF Equalizer in 2×2 MIMO system.

Minimum Mean Square Equalizer not only eliminates 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 no 4 and there is a less improvement in the Bit Error Rate.

From the simulation, results in the form of bar chart are shown in the fig.6 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.

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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

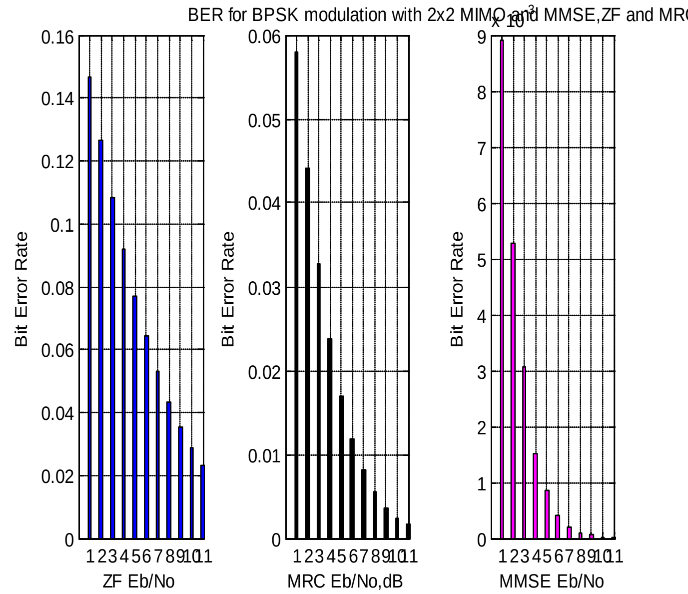

Fig.5 Plot for BER and SNR for MMSE, MRC and ZF Equalizer in Rayleigh Channel for (2×2) MIMO system.

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.

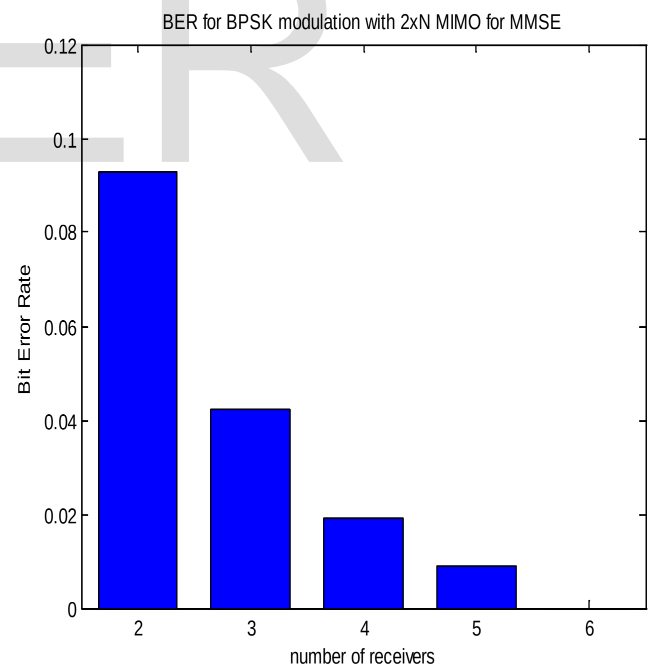

Fig.6 Bar graph plot for BER with varying number of receivers.

From the MATLAB figure window shown in fig.5 shows the consolidated result in the form of 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.6. 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.

The following observations are made. ZF has low computational complexity. It minimizes the probability of a sequence error. Hence from the above graphs it is evident 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 transmitter (m=2) as constant it is evident 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 evident that the Bit Error Rate (BER) decreases.

4. CONCLUSION

To conclude this paper provides the detailed 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 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 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 in number, BER decreases for a particular value of Eb/No value. BER performance of MRC Equalizer is superior to 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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