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Performance Evaluation of Different Equalization Techniques for 2x2 MIMO Wireless Communication Systems

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Abstract

Inter symbol interference in wireless communication is the phenomenon which occur when the high bit data rate transmission causes the channel response to extend more than one symbol period. Inter-symbol interference in the wireless channel is very undesirable which causes the recovery of the signal difficult. Equalization in the techniques which is used to fight and overcome the ISI(inter symbol interference) problem. This paper present the performance analysis of different equalization techniques for 2x2 MIMO configuration.

Keywords

MIMO, Inter symbol interference, MMSE, BER, AWGN.

I. Introduction

Introduction of the internet and mobile technology in the world has made it possible to share and exchange the text, voice, video and other vital information among each other at very fast rate.

Emergence of wireless communication and 3G/4G mobile technology has enabled us to transfer the data at very high speed while keeping the quality of the data intact. Keeping the quality of the data high when data rate is high, is very difficult and challenging task. Using orthogonal frequency division multiplexing can minimize this problem to some extent. Unlike the wired media, wireless media suffers the phenomenon called multi path phenomenon which causes the inter symbol interference (ISI). Due to this bit error rate also increases[1]. Reaching the signal from different path to the receiver antenna is called the multipath phenomenon.

Generally, during the designing of the communication system, AWGN channel and non- dispersive channels effect are ignored i.e. it is assumed that AWGN and non dispersive channel passes all frequency which is not possible in practical case. For using the frequency spectrum wosely, generally, transmitted signal is filtered which limits the bandwidth. Apart from this most of the channels are dispersive in nature and behave like band pass filter and hence responds differently to different frequency which also degrades the performance of the communication. It is therefore very essential to make some changes in the non-dispersive channel model so that it represent the practical channel accurately. This modification is given by

$r(t)= u(t) \otimes h_c(t) +n(t)$

here $u(t)$ is the transmitted signal, $h_c(t)$ is the response of the channel, and $n(t)$ is AWGN(additive white Gaussian noise) whose PSD (Power spectral density) is given by $N_0/2$.

From the above discussion it is clear that linear filter can be used to model the dispersive characteristics of the channel.

It is found that impulse response of the dispersive or band limited channel reseble the impulse response of the ideal low pass filter. This causes the transmitted signal to be seared in time which spread the symbol length which overlapped the adjacent symbol. This is very undesirable and known as the inter symbol interference (ISI). This effect increases the bit error rate(BER) and therefore need to be corrected efficiently.

There are two solution of this problem, first approach is to design the band limited pulses also known as the nyquist pulses for transmission, second approach rely on suppressing the ISI effect by filtering method.

Mitigating the effect of the inter symbol interference (ISI) by applying appropriate filtering operation is known as the equalization technique[2].

In this paper, an attempt has been made to evaluate the performance of various equalization techniques like zero forcing, zero forcing with successive interference cancelling(ZF-SIC), MMSE, ZF-SIC with optimal ordering, Maximum likelihood(ML) equalizer, MMSE-SIC with optimal ordering 2x2 MIMO system. The performance of the above mentioned equalization techniques has been conducted under Rayleigh fading and noisy channel.

II. Channel Model

In this paper, AWGN(Additive white Gaussian noise) noise channel model is taken for producing the white Gaussian noise i.e noise which follow the Gaussian distribution and has constant spectral density.

Phenomenon like fading dispersion, frequency selectivity, and intereference is not the characteristics of this channel model.

This channel model is designed to analyze the effect of Gaussian noise produced by the various natural resources [3] on the wireless communication. This model is designed mathematically. Introduction of distortion in a carrier modulated signal transmitted wirelessly is called “fading” phenomenon. Multipath propagation in wireless media is the main reason behind the fading phenomenon. Due to multipath propagation, transmitted signal reach the receiver by two or more path. These signal from the different path creates constructive and destructive interference in the received signal which causes the phase shifting of the signal. Rayleigh fading is one such type of fading phenomenon which occurs due to the multipath propagation. This type of fading can be modeled with the help of statistical characteristics. This model can be used for analyzing the propagation environment effect on the signal[3].

A. Channel Model

In this work, channel model with multipath phenomenon is simulated for studying the effect of multipath on the signal.

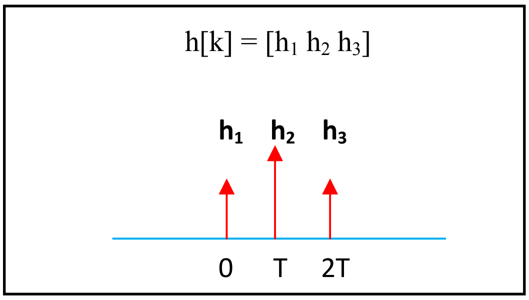

Fig. 1: Impulse Response of simulated multipath Channel

In this work, 3-tap multipath channel model is designed in which impulse response with spacing T is given in figure 1.1.
Other than suffering from multipath effect, the transmitted signal also suffered AWGN(additive white Gaussian noise) which is represented by the gaussian function as shown below

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

In this formula μ is defined as the mean of the distribution while the σ is variance.
If the known channel response is h(k) and noise is n, the signal received at the receiver side of the communication systemis given by

$$y(k)= x(k)\otimes h(k)+n$$

here the ⊗ sign is used as the convolution operation[5].

III. Equalizer [6]

Equalization is the technique which is used to mitigate the effect of the ISI(inter symbol interference) by minimizing the error probability occur in the communication system without ISI suppression method.
Since, suppression of ISI causes the noise power to enhanced therefore it is essential to create optimum balance between enhancement of noise power and suppression of ISI[4]

A. Adaptive equalization [7, 8]

An adaptive equalizer is a kind of digital filter or equalization filter which is designed to automatically adapts itself to the time varying characteristics of communication channel. This technique is most often used to mitigate the distortion caused by multipath effect.

B. Zero Forcing Equalizer [9, 10]

Proposed by Robert lucky, zero forcing method of equalization is a linear equalization method in which restoration of the transmitted signal is carried by inverting the frequency response of the channel. The name zero forcing comes from the fact that it is able to decrease the ISI level to zero value under the noise free environment. This technique of equalization is useful for the channel where the ISI is more significant than the noise.
let for a 2x2 MIMO channel, If transmitted symbol is given by x_1 and x_2, h_{11} is the channel response of the channel from first transmitter to first receiver,h_{12} is the channel response from second transmitter to first receiver, h_{21} represent the channel response from first transmitter to second receiver and h_{22} is the channel response from second transmitter to second receiver and n_1,n_2 are the noise on first and second receiver then the received symbol on the first receiver antenna is given by

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1$$

$$= [h_{11}\ h_{12}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1$$

And the received symbol on the second receiver antenna is given by

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_2$$

$$= [h_{21}\ h_{22}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

These above two equation can also be re-written as

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

from this equation it is clear that if h_{11}, h_{12}, h_{21}, h_{22} and y_1, y_2 is known then it is very simple for the receiver to compute the x_1 and x_2.
Now if we rewrite the above equation then

$$y = Hx + n$$

From here it is evident that for finding x from above equation, we need to figure out the matrix which must be inverse of matrix H. If W represents the inverse of H then it must satisfy the property

$$WH = I$$

Where I is the identity matrix.
The matrix W which fulfill the above mentioned characteristics is known as the zero forcing linear detector and is computed by equation given below

$$W = (H^H H)^{-1} H^H$$

In this equation the matrix $H^H H$ is given by

$$H^H H = \begin{bmatrix} h^*{}_{11} & h^*{}_{12} \\ h^*{}_{21} & h^*{}_{22} \end{bmatrix}\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$$

From this matrix it is clear that the off diagonal terms of this matrix are non zero which signifies that zero forcing equalizer cancel out the interference signal. It is reasonably simple and easy to implement technique of equalization but its main drawback is that it always amplifies the noise and hence gives noisy output.

C. MMSE Equalizer[11]

This type of equalizer applies the squared error for performance measurement[11]. The receiver filter is designed and develop to satisfy the minimum mean square error criterion. Main objective of this technique is to minimize the error produced between target signal and output obtained by filter. The computation procedure for this method is as follows-
If transmitted symbol is given by x_1 and x_2, h_{11} is the channel from first transmitter to first receiver,h_{12} represent the channel from second transmitter to first receiver antenna, h_{21} is the channel response from first transmitter to second receiver and h_{22} is the

channel response from second transmitter to second receiver and n_1,n_2 are noise on first and second receiver then the received symbol on first receiver antenna is given by following equation

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1$$

$$= [h_{11}\ h_{12}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1$$

And the received symbol on second receiver antenna is given by the below mentioned equation

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_2$$

$$= [h_{21}\ h_{22}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

These two above mentioned equation can also be re-written as

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

It is clear from this equation that if h_{11}, h_{12}, h_{21}, h_{22} and y_1, y_2 is known then it is easier for the receiver to compute the x_1 and x_2. Now if we rewrite the above equation then

$$y = Hx + n$$

Now, MMSE algorithm comes in to the picture and computes the coefficient of matrix W which minimize the condition

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

By Solving above equation, we get

$$W = (H^H H + N_o I)^{-1} H^H$$

From the above equation it is clear that this equation is different from the equation we obtain earlier for zero forcing equalizer by the term $N_o I$. If we set $N_o I=0$ in this equation then MMSE equalizer becomes zero forcing equalizer.

D. Zero Forcing with Successive Interference cancellation (ZF-SIC) Equalizer [12]

In this method of equalization, first of all the zero forcing equalizer computes the estimated symbol x_1 and x_2 then one of the estimated symbol is get subtracted from received symbol to compute the equalized symbol by applying maximum ration combining(MRC) algorithm[36].

If x_1 and x_2 are the two estimated transmitted symbol then

$$\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = (H^H H)^{-1} H^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$$

By subtracting one of the estimated symbol (say $\hat{x}_2$) from the received signal y_1 and y_2

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} y_1 - h_{12} & \hat{x}_2 \\ y_2 - h_{22} & \hat{x}_2 \end{bmatrix} = \begin{bmatrix} h_{12} & x_1 + n_1 \\ h_{21} & x_1 + n_2 \end{bmatrix}$$

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{11} \\ h_{21} \end{bmatrix} x_1 + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

Or

$$r = hx_1 + n$$

After applying maximum ratio combining (MRC), equalized symbol is given by the formula given below

$$\hat{x}_1 = \frac{h^h r}{h^h h}$$

E. Successive Interference Cancellation using optimal ordering Equalizer [13]

In the previously described successive interference cancellation technique, estimated symbol is chosen arbitrarily and then later on its effect is subtracted from the received symbol y1 and y2. A better result can be achieved if we choose estimated symbol who has greater influence than other symbol. For this to take effect, first of all the power of both the symbol is calculated at the receivers end and then the symbol with higher power is chosen for subtraction process.

The power of transmitted symbol x_1 is given by the following equation

$$P_{x_1} = |h_{11}|^2 + |h_{21}|^2$$

Similarly the power of transmitted symbol x_2 is given by the following equation

$$P_{x_2} = |h_{12}|^2 + |h_{22}|^2$$

If $P_{x1} > P_{x2,}$ the x1 is subtracted from y1 and y2 and then this technique re-estimate the $\hat{x}_2$

i.e.

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} y_1 - h_{11}\hat{x}_1 \\ y_2 - h_{12}\hat{x}_1 \end{bmatrix} = \begin{bmatrix} h_{12}\hat{x}_1 + n_1 \\ h_{22}\hat{x}_1 + n_2 \end{bmatrix}$$

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{12} \\ h_{22} \end{bmatrix} x_2 + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$r = hx_2 + n$$

By applying maximum ratio combining (MRC) step, the equalized symbol is given by the following formula

$$\hat{x}_2 = \frac{h^h r}{h^h h}$$

Similarly if If $P_{x2} > P_{x1,}$ the x_2 is subtracted from y1 and y2 and re-estimation of $\hat{x}_1$ is carried out.

F. MMSE SIC with optimal ordering [14]

The similar concept/algorithm of successive interference with optimal ordering can also be applied to the MMSE equalizer technique and the resultant equalizer obtained is known as MMSE SIC with optimal equalizer.

G. ML (Maximum Likelihood) Equalizer

Let x is the signal matrix, H is the channel response and n is the noise then the signal obtained at the receiver is expressed as

$$y = Hx + n$$

Maximum likelihood equalizer[15] compute the transmitted signal by finding out estimate which can minimize the below equation

$$J = \left\| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{11} h_{12} \\ h_{21} h_{22} \end{bmatrix} \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} \right\|^2$$

Since in BPSK modulation method, each signal can have either +1 or -1 value. So the ML equalizer always tries to find the minimum value of J from all four possible values of x_1 and x_2.

IV. Experimental Results

For performance comparision, of all the above mentioned equalizer, a simulation is designed and developed. The simulation program is carried out under the MATLAB Ver 2009B environment. This simulation program perform BPSK/QAM/DPSK modulation on the input binary values which is taken as +1 and -1 as input in 2x2 MIMO system. For producing the multipath effect and noise effect in the channel,

Rayleigh channel model and AWGN noise model are also designed. At the receiver side, demodulation and BER performance is also performed for analysis.

A. Results of Equalizers For BPSK Modulation

The BER performance of ZF equalizer for BPSK Modulation is shown in figure 4.1 which shows that the performance of ZF equalizer for 2x2 MIMO systems is just like its performance in 1x1 BPSK systems.

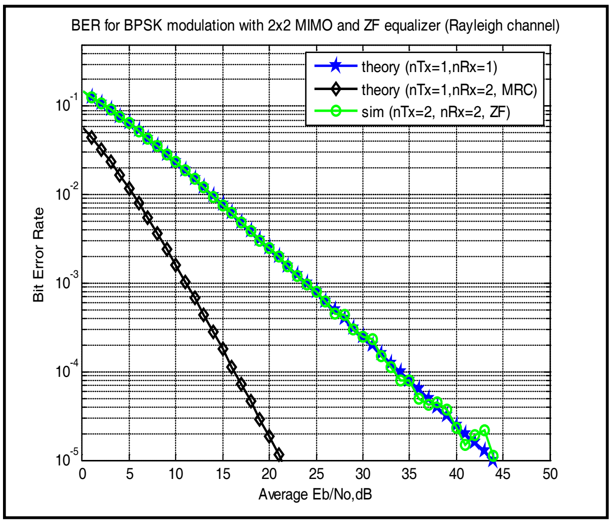

Fig. 4.1 : BER for ZF Equalizer for BPSK Modulation

The result of ZF-SIC is shown in figure 4.2 which depicts that the improvement of approx. 2dB for $^{10-}$3 is achieved by ZF-SIC as compared to ZF equalizer.

From the figure 4.1 it is clear that the BER curve for the zero forcing equalizer is nearly same as that of the theoretical BER Vs.Eb/No curve. Figure 4.2 represent the BER Vs Eb/No curve for the ZF SIC equalization method. It is clear from this figure that its performance is better than the zero forcing equalizer if we take the BPSK modulation and 2x2 MIMO channel.

While the performance of MMSE equalizer shows (figure 4.3) more improvement in BER performance as compared to ZF equalizer.

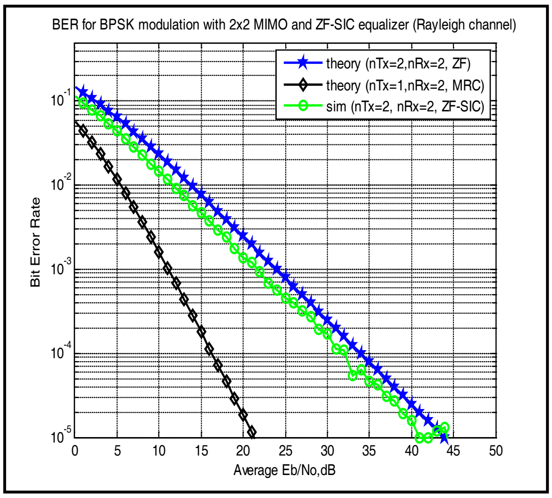

Fig. 4.2 : BER for ZFSIC equalizer for BPSK modulation

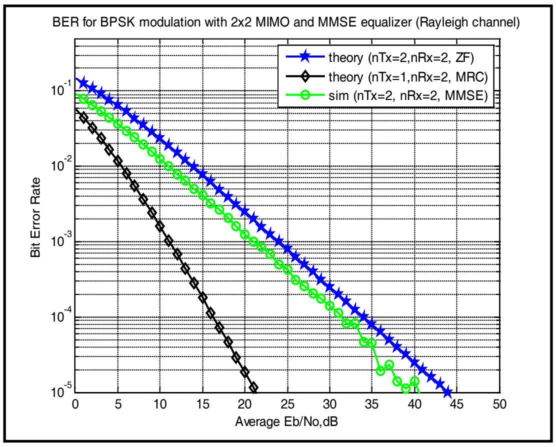

Fig. 4.3 : BER for MMSE equalizer For BPSK Modulation

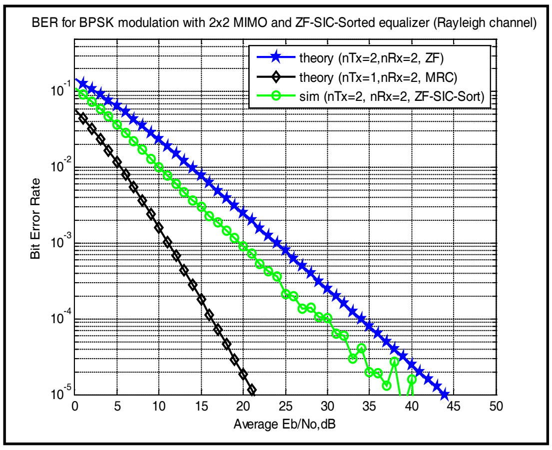

Fig. 4.4 : BER for ZFSIC with optimal ordering for BPSK Modulation

An improvement of about 4 dB for 10^{-3} BER is obtained if ZF-SIC with optimal ordering equalizer is used as shown in figure 4.4. MMSE-SIC with optimal ordering gives even better result by showing the improvement of about 5dB for 10^{-3} with respect to MMSE-SIC as shown in figure 4.5.

The performance of ML equalizer is very close to the theoretical BER performance for 1x1 systems.

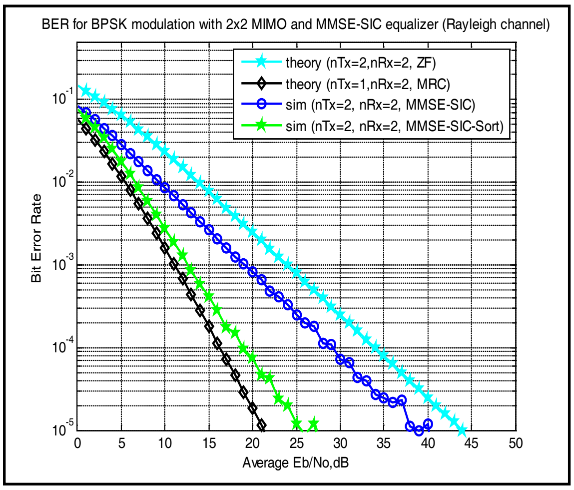

Fig. 4.5 : BER for MMSE-SIC with optimal ordering for BPSK Modulation

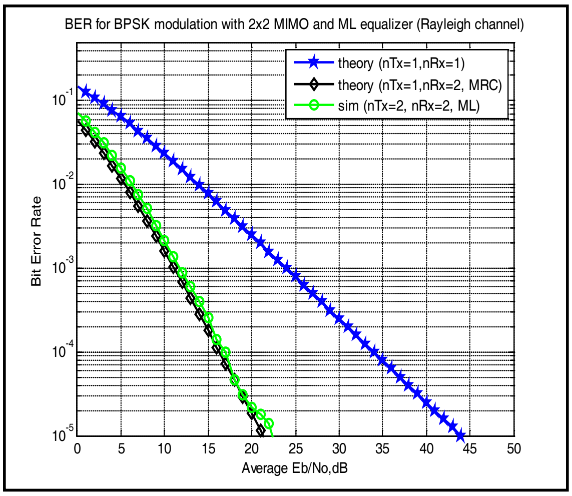

Fig 4.6 : BER for ML Equalizer for BPSK Modulation\

From figure 4.5 and 4.6 it is clear that for BPSK modulation and under the Rayleigh fading channel, the performance of ML equalizer is better than the other equalizer present in this thesis. Equalization technique of MMSE-SIC-SORT is very close to the BER performance of ML equalizer.

B. Results of Equalizers For QAM Modulation

Results obtained for all the equalizers for QAM modulation are exhibited in this section and discussed. SER (Symbol error Rate) Vs Eb/No curve is shown in the figure 4.7 for the ZF equalizer. The results clearly depicts that the performance of the ZF (Zero Forcing) equalizer for 2x2 MIMO channel is close to the theoretical values for 1x1 channel.

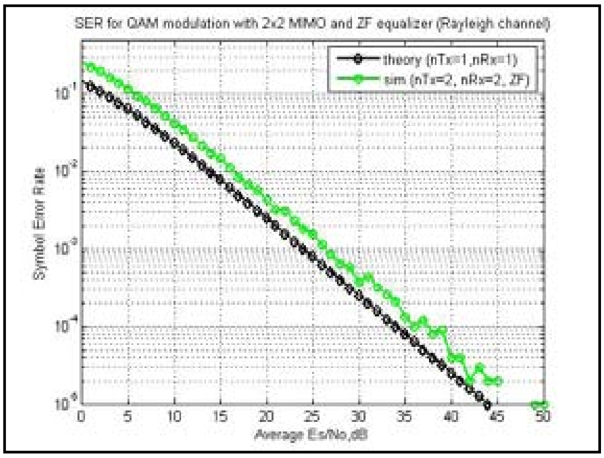

Fig. 4.7 : SER for ZF Equalizer For QAM Modulation

Figure shows the similar curve obtained for the ZF-SIC equalizer for 2x2 MIMO channel. It is clear from this figure that the performance of this equalizer is worst.

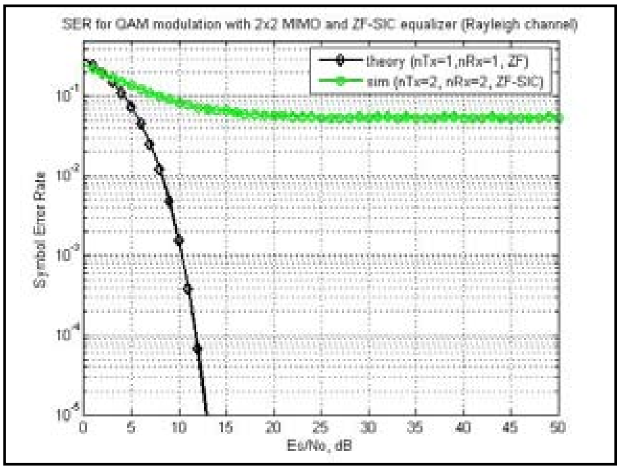

Fig. 4.8 : SER for ZF-SIC Equalizer For QAM Modulation

Figure 4.9 shows the ZF-SIC-SORTED equalizer for 2x2 MIMO channel and is evident that the performance of this method of equalization is also very poor.

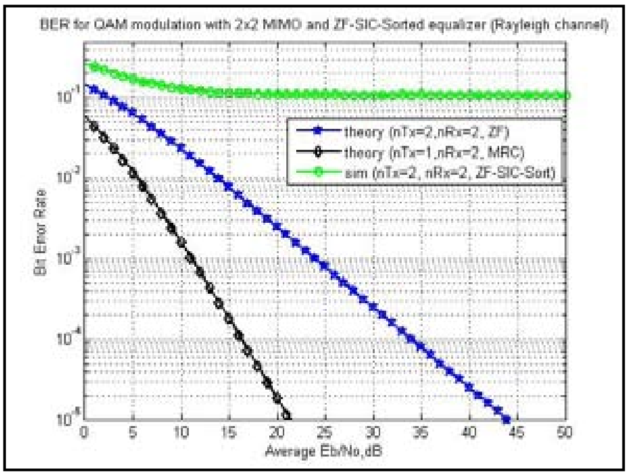

Fig. 4.9 : SER for ZF-SIC Sort Equalizer For QAM Modulation

Figure 4.10 shows the performance of the MMSE equalizer for QAM modulation under the 2x2 MIMO channel. It is clear from this curve that 2x2 MMSE equalizer is close to the theoretical 2x2 ZF performance. But worst than the theoretical 1x2 MRC.

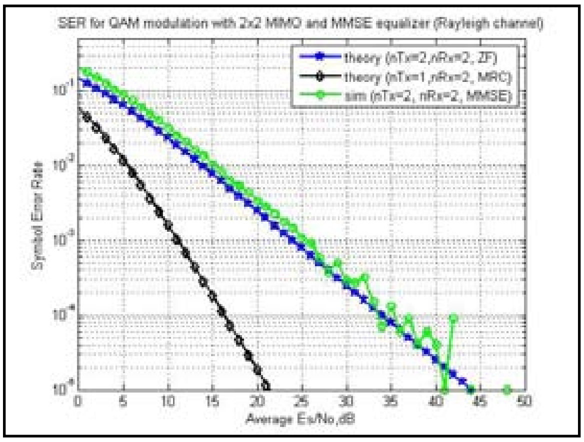

Figure 4.10 : SER for MMSE Equalizer For QAM Modulation

Figure 4.11 shows the performance of the MMSE-SIC-SORT. It os clear from this graph that the performance of this equalization algorithm is very poor as it becomes flatten for higher Eb/No.

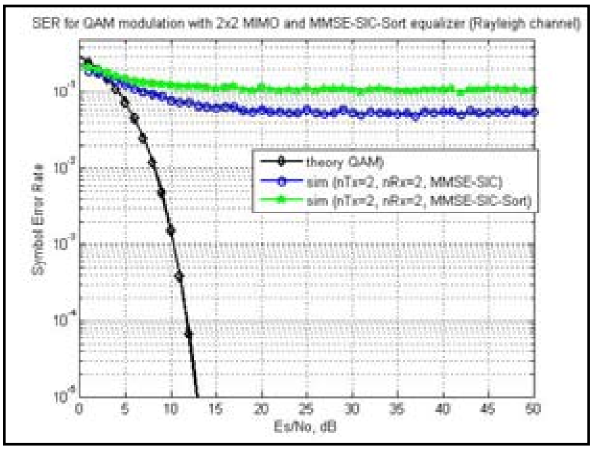

Fig. 4.11 : SER for MMSE-SIC SORT Equalizer For QAM Modulation

Figure 4.12 shows the performance of the ML equalizer and it is clear that its performance is far better than the theoretical 1x1 configuration and very close to the theoretical 1x2 MRC.
From all the graph obtained in this section it is clear that for QAM modulation, again ML equalizer is able to deliver least BER and recommended to be used incase of QAM modulation.

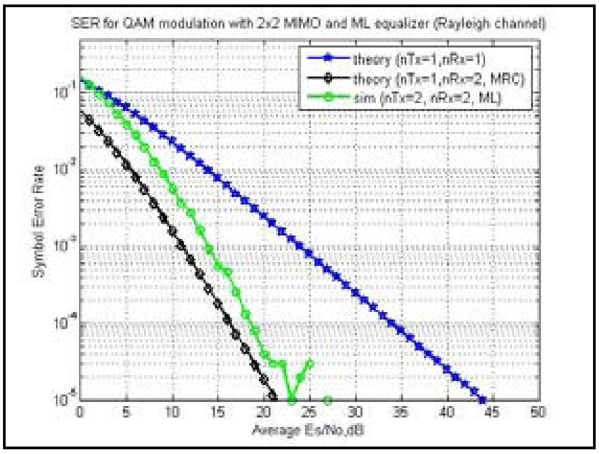

Fig. 4.12 : SER for ML Equalizer For QAM Modulation

C. Results of Equalizers For DPSK Modulation

This section discuss the BER Vs Eb/No performance of different equalization techniques for higher modulation such as DPSK(Differential Phase Shift Keying).
Figure 4.13 shows the BER performance of the ZF equalizer for 2x2 MIMO channel. This graph, as expected is very close to the theoretical 1x1 configuration.

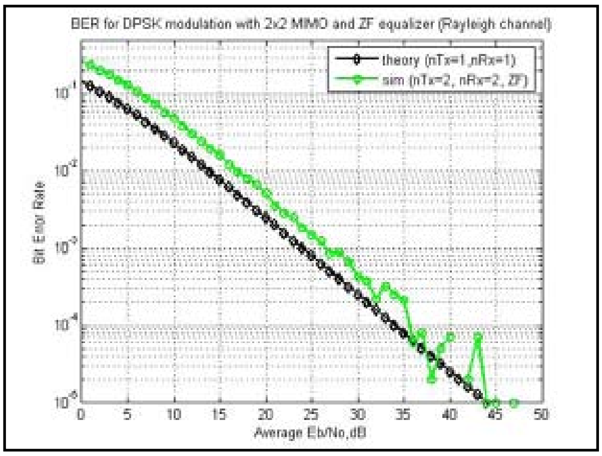

Fig. 4.13 : SER for ZF Equalizer For DPSK Modulation

The BER performance of the ZF-SIC for DPSK modulation for 2x2 MIMO channel is shown in the figure 4.14. From this graph it is clear that initially the BER curve is very near to the theoretical graph but start deviating largely as we increase the Eb/No.

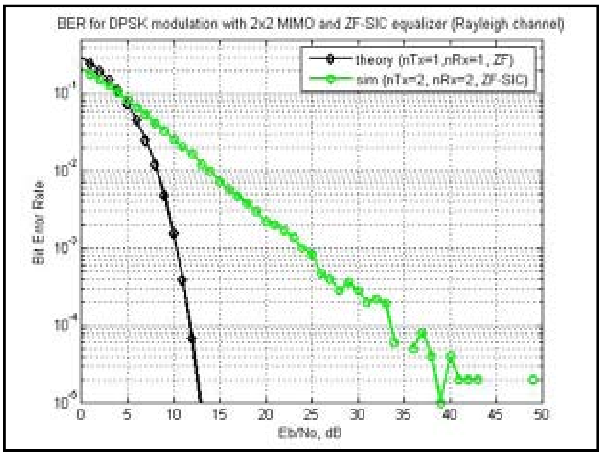

Fig. 4.14 : SER for ZF-SIC Equalizer For DPSK Modulation

Figure 4.15 represent the BER performance of ZF-SIC-SORT method under the channel 2x2 and having the DPSK as the modulation. The curve for the simulation is very close to the theoretical graph of the ZF equalizer but not able to follow the graph of theoretical 1x2 MRC.

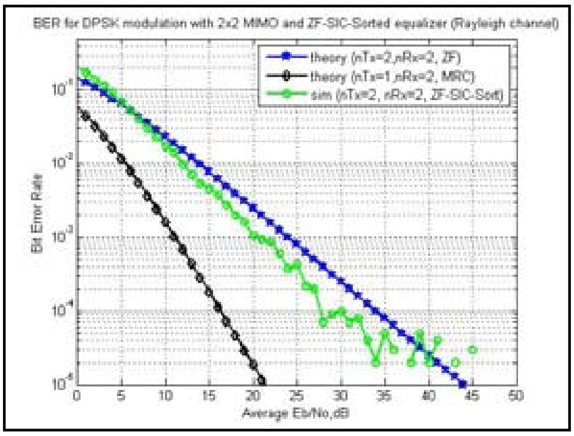

Fig. 4.15 : SER for ZF-SIC-SORT Equalizer For DPSK Modulation

Figure 4.16 depicts the curve of the MMSE equalizer for DPSK modulation under the 2x2 MIMO channel. This graph is again very close to the curve drawn for the theoretical graph for the 2x2 ZF. But it is still far away from the theoretical curve of configuration 1x2 MRC.

Figure 4.17 and 4.18 represent the BER performance of MMSC-SIC-SORT and ML equalizer respectively. From these graph it is clear that with increase in the Eb/No, these curve start becoming flat.

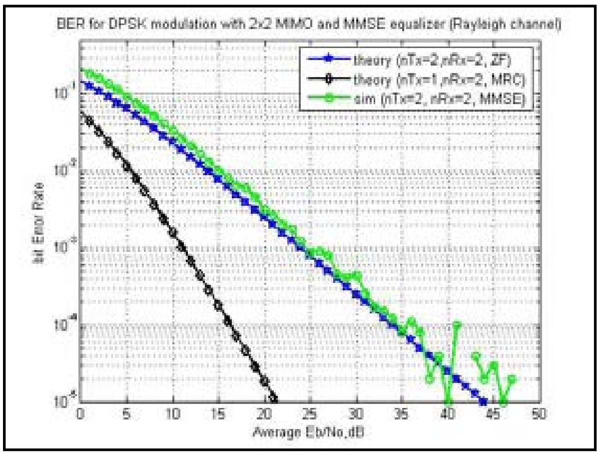

Fig. 4.16 : SER for MMSE Equalizer For DPSK Modulation

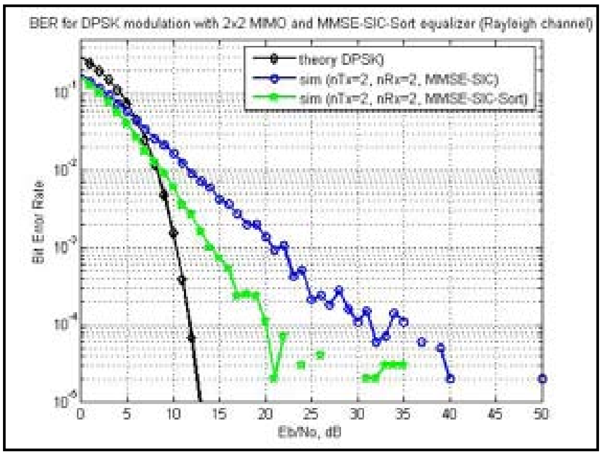

Fig. 4.17 : SER for MMSE-SIC-SORT Equalizer For DPSK Modulation

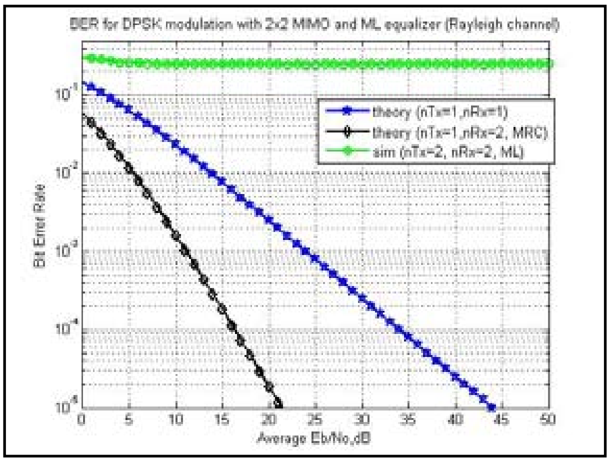

Fig. 4.18 : SER for ML Equalizer For DPSK Modulation

From the above discussion it is clear in case of DPSK modulation, BER performance of the MMSE-SIC-SORT is the best method for equalization. After seeing the BER VS Eb/No, performance, it is clear that incase of BPSK and QAM (lower and Mid Modulation) ML equalizer is the best method for equalizing the symbol. In case of High modulation like DPSK, MMSC-SIC-SORT is the best method for equalization.

V. Conclusion

To achieve higher data rate and least BER is the demand of wireless system design. Equalization techniques play very important role for designing such system. In this paper performance comparison of different key equalization techniques has been carried out under the fading and noisy environment to find out the appropriate equalizer for 2x2 MIMO system. From the result obtained it is evident that zero forcing equalizer shows better performance if noise is zero and shows degradation under fading environment. The performance of ZF-SIC,MMSE, ZF-SIC with optimal ordering, MMSE-SIC with optimal ordering and ML equalizer are in increasing order. From the results it can be concluded that the ML equalizer and MMSE-SIC with optimal ordering are best among these above mentioned equalizer in term of cancelling the interference to optimum level.

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