Analysis and Optimization of Equalisation Techniques in MIMO Systems

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***Abstract*— Multiple Inputs and Multiple Output System (MIMO), is being used for improving the performance of the channel fading of system consisting of more than one transmitting antenna and more than one receiving antenna. In this paper, the comparison of different equalization techniques has been discussed for better analysis of a MIMO system. The 2×2 MIMO Systems consisting of two transmitting and two receive antennas have simulated through MATLAB software.The radio channelsin mobile radio systems are a usually multipath fading channel which causes Inter-symbol interference (ISI) in the received signal. To remove ISI from the signal, there is a need of strong Equalizer .The different Equalization techniques such as Zeroforcing equalization, Minimum mean square error and Maximum Likelihood Decoding are implemented and the best suited techniques have been predicted.**

Keywords—MIMO,SISO,SIMO,MISO,MMSE,ZFE.

1. INTRODUCTION

In the past few years there had been tremendous growth in wireless communication system.The growth has opened effective ways to future wireless communication without regard to mobility or location with high data rates,the communication network needs to support a wide range of services which includes peak quality voice, facsimile, data streaming videos and still pictures.All these Services are likely to include application which requires high transmission rates of several Megabits per second (Mbps).The data rate and spectrum efficiency of wireless mobile communication system has improved manifold over last decade in mobile communication systems. The radio channels in mobile radio systems are a usually multipath fading channel that causes Inter-symbol interference (ISI) in the received signal. There is a need of strong Equalizerinorder to remove this ISI from the received signal.

The traditional digital communication systems used BPSK modulation or other modulation schemes and single transmitting and single receive antenna system (ie SISO System).Then came into existence was the SIMO System which used single transmitting antenna and multiple receive antenna .MISO systems are the system which has multiple transmitting and single transmitting antenna. Then came MIMO system, they combined the concepts from both SIMO and MISO[2][3] systems. MIMO[4] systems use multiple transmitting antenna and multiple receiving antenna.

2.MIMO SYSTEMS

A MIMO usually consists of m transmit and n receive antenna ,by using the same channel.Each antenna receives not only the direct component intended for it but also the indirect components intended for other antennas. Usually direct connection from antenna 1 to 2 is symbolized as cross factor h_{21}, etc.From this we obtain a transmission matrix 'H' with the dimension n×m.

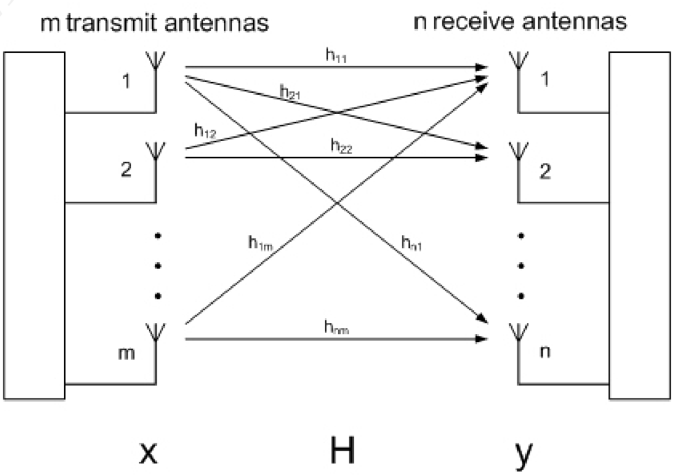

Figure 1, Showing a Geneal MIMO System.

The transmission formula resulting from receive vector y,transmit vector x, and noise n is given below

$$y = Hx + n$$

Formula 1: MIMO Transmission

The data to be transmitted is divided into independent data streams. The no of these independent data stream M is always less than or equal to number of antenna. In case of asymmetrical (m≠n) antenna constellation it is always smaller or equal to the minimum number of antennas.Let us suppose 4×4 system could be used to transmit four or fewer stream, while a 3×2 system could be used to transmit two or fewer streams M.

$$C = M\, B\log_2\left(1+\frac{S}{N}\right)$$

Formula 2: Shannon-Hartley theorem for MIMO.

In MIMO system, equalization is done at the receiving end or at the destination end.There are three different equalization technique [5]which are at the receiver. The three equalization techniques that are dealt in this paper are Zero forcing Equalization, Minimum Mean Square Equalization and Maximum likelihood Equalization. These techniques are briefly explained below.

Zero forcing Equaliser

Zero forcing equalizer[7][8]is linear equalization process in communication system which inverts frequency response of the channel.Zero forcing equalizer again restores the transmitted signal by applying the inverse of the channel to the received signal and decrease the Inter-symbol interference. It is quite good technique to reduce ISI when ISI is high as compared to the channel noise.

Let us apply mathematical model for the system, the initial equation will be same for all the three equalization technique of MIMO system we are discussing here.

Let us suppose that there are two signals received on antenna 1 and antenna 2 be y_1 and y_2 respectively, h(1,1), h(1,2), h(2,1), h(2,2) are the channel parameters showing the relation between transmitted and received antenna and x_1, $x_2$are the transmitted signals from antenna 1 and antenna 2 respectively and n_1 , n_2 are the noise on receiving antenna 1 and antenna 2 respectively,so that,

$$y_1 = h_{1,1}x_1 + h_{1,2}\, x_2 + n_1 = [h_{1,1}\; h_{1,2}]\begin{bmatrix} x1 \\ x2 \end{bmatrix} + n_1$$

$$y_2 = h_{2,1}x_1 + h_{2,2}\, x_2 + n_2 = [h_{2,1}\; h_{2,2}]\begin{bmatrix} x1 \\ x2 \end{bmatrix} + n_1$$

The above written equation can be expressed mathematically as

$$\begin{bmatrix} y1 \\ y2 \end{bmatrix} = \begin{bmatrix} h1,1 & h1,2 \\ h2,1 & h2,2 \end{bmatrix} \begin{bmatrix} x1 \\ x2 \end{bmatrix} + \begin{bmatrix} n1 \\ n2 \end{bmatrix}$$

i.e. Y=Hx + n

Now we can solve x by the help of matrix Z such that ZH=1, i.e. Z should be inverse of channel matrix H.Matrix Z can be expressed mathematically as

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

The term

$$H^H H = \begin{bmatrix} h1,1^* & h1,2^* \\ h2,1^* & h2,2^* \end{bmatrix}$$

$$= \begin{bmatrix} \lfloor h1,1 \rfloor^2 + \lfloor h2,1 \rfloor^2 & h1,1^* h1,2 + h2,1^* h2,2 \\ h1,2^* h1,1 + h2,2^* h2,1 & \lfloor h1,2 \rfloor^2 + \lfloor h2,2 \rfloor^2 \end{bmatrix}$$

Above is the final matrix for ZFE

The bit error rate (BER)for BPSK modulation in Rayleigh fading channel is given by

$$P_b = \frac{1}{2}\left(1 - \sqrt[2]{\frac{\frac{Eb}{No}}{\frac{Eb}{No}+1}}\right)$$

Minimum Mean Square Error

Minimum mean square error (MMSE) is an estimation technique which minimizes the mean square error and is very common method used for quality estimation. Though it does not minimizes the mean square error but it minimizes the component of noise and ISI in the output. MMSE uses the coefficient M which minimizes criteria:

$E\{[My-x][My-x]^H\}$

On solving the above criteria, the mathematical value of M is found as

$$M = [H^H H + N_o I]^{-1} H^H$$

On comparing the equation of ZFE with MMSE it is found that both the equation seems similar except the term N_oI which means in the absence of noise MMSE and ZFE works similar to each other.

Maximum Likelihood Equaliser

The ML or Maximum Likelihood equalizer technique find the term m such that

$$J = |y - Hm|^2$$

Can be minimized. The relation can be again expressed in the terms of received signal, channel parameter and m.

$$J_{+1,+1} = \left| \begin{bmatrix} y1 \\ y2 \end{bmatrix} - \begin{bmatrix} h1,1 & h1,2 \\ h2,1 & h2,2 \end{bmatrix} \begin{bmatrix} m1 \\ m2 \end{bmatrix} \right|^2$$

For BPSK modulation ,the value of x_1 andx_2 can either be+1 or -1 hence inorder to find solution for m_2 all the four combination below for x_1 and x_2 needed to be minimized

$$\mathbf{J_{+1,+1}} = \left| \begin{bmatrix} y1 \\ y2 \end{bmatrix} - \begin{bmatrix} h1,1 & h1,2 \\ h2,1 & h2,2 \end{bmatrix} \begin{bmatrix} +1 \\ +1 \end{bmatrix} \right|^2$$

$$\mathbf{J_{+1,-1}} = \left| \begin{bmatrix} y1 \\ y2 \end{bmatrix} - \begin{bmatrix} h1,1 & h1,2 \\ h2,1 & h2,2 \end{bmatrix} \begin{bmatrix} +1 \\ -1 \end{bmatrix} \right|^2$$

$$\mathbf{J_{-1,+1}} = \left| \begin{bmatrix} y1 \\ y2 \end{bmatrix} - \begin{bmatrix} h1,1 & h1,2 \\ h2,1 & h2,2 \end{bmatrix} \begin{bmatrix} -1 \\ +1 \end{bmatrix} \right|^2$$

$$\mathbf{J}_{-1,-1} = \left\| \begin{bmatrix} y1 \\ y2 \end{bmatrix} - \begin{bmatrix} h1,1 & h1,2 \\ h2,1 & h2,2 \end{bmatrix} \begin{bmatrix} -1 \\ -1 \end{bmatrix} \right\|^2$$

The estimate of the transmit symbol is choosed based upon the minimum value from the above four values

If the minimum is $J_{+1,+1}$ => [1 1]

If the minimum is $J_{+1,-1}$ => [1 0]

If the minimum is $J_{-1,+1}$ => [0 1]

If the minimum is $J_{-1,-1}$ =>[0 0]

3. RESULTS

3.1 Zero forcing equalizer

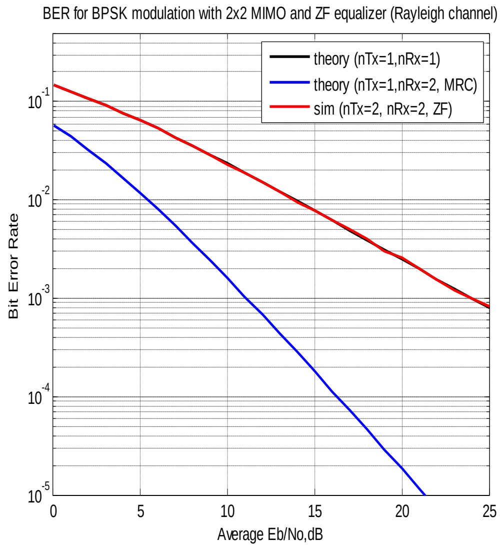

Figure 3.1 BER plot for 2×2 MIMO system channel with ZF equalizer.

The simulated result is showing matching result as obtained for 1×1 system for BPSK modulation[10][11] in Rayleigh channel.

ZFE helps in achieving data rate gain but not take advantage of diversity gain[9].

3.2 Minimum Mean Square Error(MMSE) Equalization

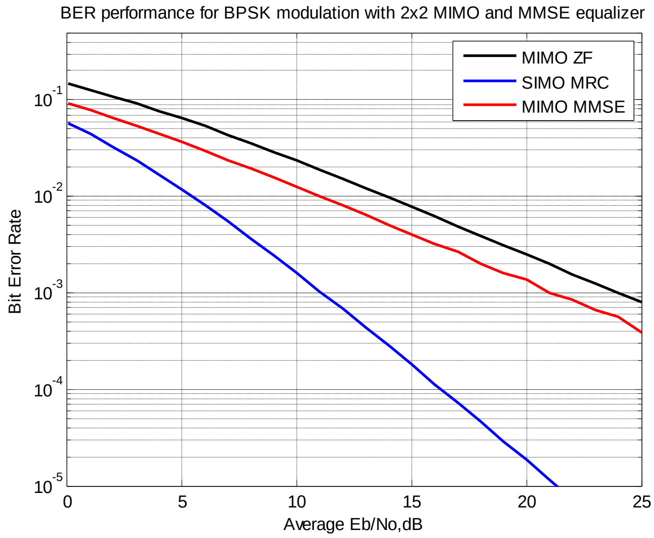

Figure3.2 BER plot for 2×2MIMO with MMSE equalization for BPSK in Rayleigh channel

In comparison to the Zero forcing equalizer, at 10^{-3} BER point' it can be seen that the MMSE equalizer results in around 3db of improvement.

3.3 Maximum Likelihood Equalizer

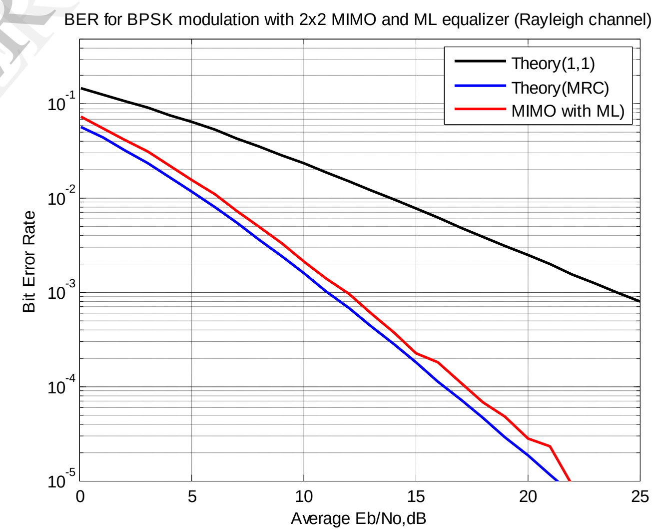

Figure 3.3 BER plot for 2×2 MIMO system channel with ML equalizer.

The result for 2×2 MIMO with ML Equalizer help us to achieve a performance closely matching the one transmit and two receive antenna Maximal Ratio combination (MRC) case.

ISSN: 2278-0181
Vol. 3 Issue 5, May - 2014

4. CONCLUSION

Equalization techniques are very useful in the design of high data rate wireless systems. They can combat the inter-symbol interference even in the mobile fading channel with high efficiency.In this paper different type of equalization techniques are analyzed to find the best suitable equalizer for 2×2 MIMO system in Rayleigh multipath fading channel.

Zero forcing equalizer performs well in theoretical assumptions when the noise is zero. The performance of the ZF equalizer degrades in mobile fading environment.

Minimum mean Square error (MMSE) equalizer uses LMS (Least mean squares) as criteria to compensate Inter-symbol interference. The MMSE equalizer results in around 3 dB of improvement when compared to zero forcing equalizer.

Maximum likelihood equalizer help us to achieve a performance closely matching the one transmit and two receive antenna Maximal Ratio combination (MRC) case.

So by observing the simulation results we conclude that by using Maximum likelihood Equalizer interference can be cancelled effectively even in mobile fading channel.

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