Performance Evaluation of Equalization Techniques under Fading and Noisy Environment for MIMO Systems in Wireless Communication

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***Abstract*:** Mobile radio systems where data bits are transmitted in radio space, channels are typically multipath fading channels, which cause inter-symbol interference (ISI) in the received signal. High bit data rate transmission over wireless channel makes the channel response extend over more than one symbol period causing phenomenon inter-symbol interference. This is undesirable and makes the recovery of signal difficult. Equalization is method which is commonly employed to fight with ISI. In this paper different equalizer has been analyzed and compared for 2x2 MIMO channel.

Keywords: *MIMO, Interference, MMSE, Zero Forcing AWGN, Rayeligh*

1. INTRODUCTION

The emergence of internet and mobile technology has enabled us to share video, text, voice and all other information in all over the world. Introduction of wireless and 3G mobile technology has made it possible to transfer the data at very high speed while keeping the high quality of the data intact. To achieve high quality data at very high data rate is a big challenge. This problems can be minimized by applying Orthogonal Frequency division Multiplexing technology. Unlike wired media, in wireless media, signal reach the receiver from different path and hence lead to the inter symbol interference. This inter symbol interference phenomenon causes the increased bit error rate[1].

Generally in designing the communication system, it is assumed that the AWGN Channel or non dispersive channel passes all the frequency which is practically not possible. In order to utilize the frequency spectrum wisely, the transmitted signal is generally filtered to limit its bandwidth. Moreover, most of the channel are dispersive in nature i.e. channels are of band-pass type and therefore responds differently to different frequencies.

It is very important to make some refinement in simple non-dispersive channel model to represent the practical channel which is given by

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

where u(t) represents the signal to be transmitted, $h_c(t)$ represents the channel response and n(t) represents AWGN whose PSD (Power spectral density) is given by $N_0/2$. From this it is clear that the dispersive nature or characteristics of channel is modeled with the help of linear filter $h_c(t)$.

For any band-limited or dispersive channel, the impulse response of the channel resemble the impulse response of ideal low pass filter. Due to this the transmitted signal is smeared in time and hence spread the symbols length causing the overlapping of adjacent symbols. The interference caused by this phenomenon is known as inter-symbol interference (ISI). This phenomenon is undesirable in communication system and increased the bit error rate (BER) and hence need to be resolved correctly. This problem of ISI can be overcome by either designing the band-limited pulses otherwise known as nyquist pulses for transmission or by filtering the received signal to suppress the effect of ISI introduced by the impulse response of the channel. The process of mitigating the effect of ISI by using appropriate filtering operation is known as equalization process[2].This paper presents a performance evaluation of some of the 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 under Rayleigh fading and noisy channel for QAM.

II. CHANNEL MODEL

AWGN(additive white Gaussian Noise) is model of channel which produces only white Gaussian noise (having Gaussian distribution) whose spectral density is constant . This channel model does not introduce frequency selectivity, fading dispersion and interference phenomenon. This channel model is sufficient enough to analyze the effect of Gaussian noise coming from various natural sources[3] with the simple mathematical model. Fading is the phenomenon of introducing distortion in carrier modulated signal in some propagation medium[4]. The main reason of fading phenomenon in wireless media is multipath propagation which results in transmitting signal's reaching the receiver by two or more path. These different path introduce constructive and destructive interference in the signal causing phase shifting of the signal. Rayleigh fading is one of the types of fading which occurs due to the multipath reception. It can be simulated with the help of statistical model for analyzing the effect of propagation environment on a signal [3].

A. Channel Model

Channel model having the characteristics of multipath environment can be simulated. The impulse response of 3-tap multipath channel model with spacing T is shown below-

$$h[k] = [h_1\ h_2\ h_3]$$

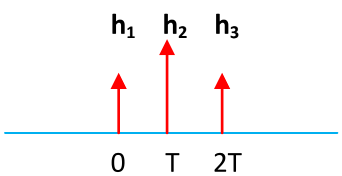

Figure 1 Impulse Response of Multipath Channel

Apart from experiencing multipath effect, the transmitted signal is also affected by AWGN (Absolute Gaussian noise) noise n. This noise is represented by Gaussian function given by

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

Here the μ represents the mean of distribution and σ is variance.
With the known channel response h(k) and noise n, the signal received at the receiver is given by

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

here the $\otimes$ represents the convolution operation[5].

III. EQUALIZER

Equalization is the process of mitigating the ISI effect by decreasing the error probability which occurs in the communication system when no ISI suppression method is applied. But since the suppression of ISI tends to enhance the noise power therefore the optimum balance between noise power enhancement and suppression of ISI need to catered[4].

A. Adaptive Equalization[7][8]

An adaptive equalizer is a type of digital filter or equalization filter which is designed in such a way that it automatically adapts itself to the time varying properties of communication channel. This technique is frequently used to mitigate the distortion produced by multipath effect.

B. Zero Forcing Equalizer[9][10]

Proposed by Robert lucky, zero forcing method of equalization is a linear equalization method which restore the transmitted signal by inverting the frequency response of the channel. The name zero forcing comes from the fact that it is able to reduce the ISI to zero value in case of noise free environment. This method is useful for the channel where the ISI is more pronounced than the noise.

Suppose for a 2x2 MIMO channel If transmitted symbol is represented by x_1 and x_2, h_{11} represent the channel from first transmitter to first receiver,h_{12} represent the channel from second transmitter to first receiver, h_{21} represent the channel from first transmitter to second receiver and h_{22} represent the channel from second transmitter to second receiver and n_1,n_2 represent noise on first and second receiver then the received symbol on first receiver 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 second receiver 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 two above equation can also be 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

$$y = Hx + n$$

From here it is clear that in order to find x from above equation, we need to find out the matrix which is inverse of matrix H. If W represent the inverse of H then it must satisfy the property

$$WH = I$$

Where I is the identity matrix.
The matrix W which satisfy the above mentioned property is known as the zero forcing linear detector and is computed by following equation

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

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 term are non zero and hence zero forcing equalizer cancel out the interference signal. It is reasonably simple and easy to implement but its main drawback is that it tends to amplify the noise and hence gives noisy output.

C. MMSE Equalizer[11]

This type of equalizer uses the squared error as performance measurement[11]. The receiver filter is designed to fulfill the minimum mean square error criterion. Main objective of this method is to minimize the error between target signal and output obtained by filter. The computation for this method is as follows-

If transmitted symbol is represented by x_1 and x_2, h_{11} represent the channel from first transmitter to first receiver, h_{12} represent the channel from second transmitter to first receiver, h_{21} represent the channel from first transmitter to second receiver and h_{22} represent the channel from second transmitter to second receiver and n_1, n_2 represent noise on first and second receiver then the received symbol on first receiver 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 second receiver 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 two above equation can also be 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 computes the coefficient of matrix W which minimize the condition

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

Solving above equation gives

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

From the above equation it is clear that this equation is different from the equation of zero forcing equalizer by the term N_oI. If we put $N_oI=0$ in this equation then MMSE equalizer becomes zero forcing equalizer.

D. Zero Forcing With Successive Interference Cancellation (Zf-Sic) Equalizer[12]

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

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

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

Or

$$r = \hbar x_1 + n$$

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

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

E. Successive Interference Cancellation Using Optimal Ordering Equalizer[13]

In the previous successive interference cancellation method, estimation symbol is chosen arbitrarily and then its effect is subtracted from received symbol y1 and y2. A better result can be obtained if we choose estimated symbol whose influence is more than other symbol. For this first of all the power of both the symbol is computed at the receivers and then the symbol having higher power is chosen for subtraction process.
The power of transmitted symbol x_1 is given by

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

Similarly the power of transmitted symbol x_2 is given by

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

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

i.e.

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

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

$$r = h x_2 + n$$

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

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

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

F. Mmse Sic With Optimal Ordering[14]

The same concept of successive interference with optimal ordering can also be applied to the MMSE equalizer and the resultant equalizer is known as MMSE SIC with optimal equalizer.

G. ML (Maximum Likelihood) Equalizer

Let x represent the signal matrix, H represent the channel response and n represent the noise then the signal obtained at the receiver is given by

$$y = Hx + n$$

Maximum likelihood equalizer[15] compute the signal by finding out estimate $\hat{x}$ which 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, each signal can take either +1 or -1 value. So the ML equalizer tries to find the minimum value of J from all four values of x_1 and x_2.

IV. EXPERIMENTAL RESULTS

In order to compare the performance of all the six equalizer, a simulation is designed in MATLAB ver.2009B. This simulation takes the binary value +1 and -1 as input and perform BPSK modulation in 2x2 MIMO system. Rayleigh channel model and AWGN noise model are also designed for producing multipath effect and noise. The modulated signal is then passed through these model. At the receiver side, demodulation and BER performance is carried out. The BER performance of ZF equalizer is shown in figure 1.2 which shows that the performance of ZF equalizer for 2x2 MIMO system is just like its performance in 1x1 BPSK system.The result of ZF-SIC is shown in figure 1.3 which depicts that no improvemen is achieved by ZF-SIC as compared to ZF equalizer.

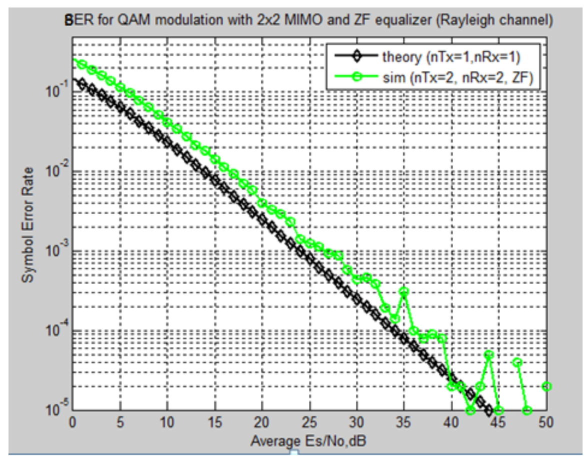

Figure 2: BER for ZF Equalizer

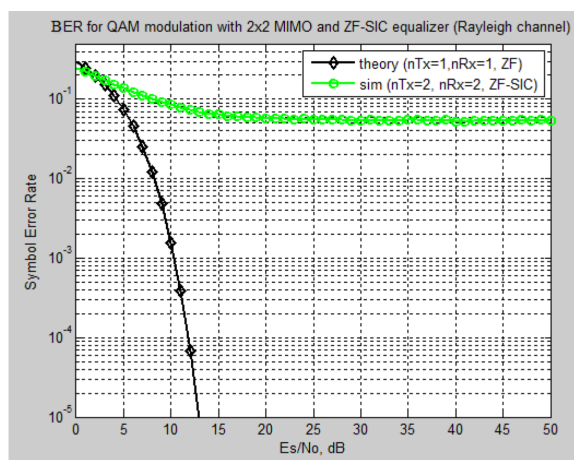

Figure 3: BER for ZFSIC equalizer

While the performance of MMSE equalizer shows(figure 1.4) more improvement about 8dB for 10^{-3} BER performance as compared to ZF equalizer. ZF-SIC with optimal ordering equalizer and MMSE- SIC with optimal ordering is not gives better result as compared to ZF equalizer. for 10^{-3} BER as shown in figure 1.5 and figure 1.6 respectively. The performance of ML equalizer results in around 10 dB of improvement for BER.

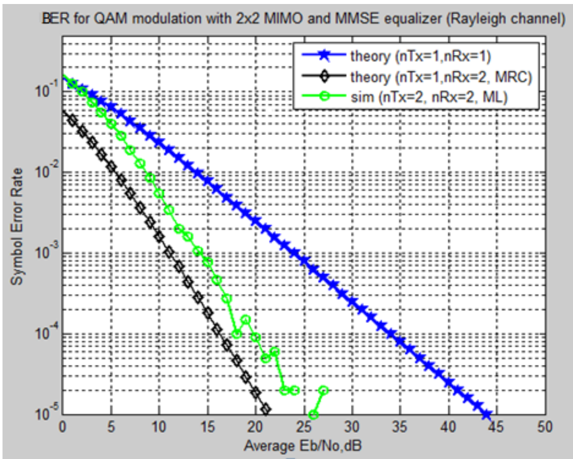

Figure 4: BER for MMSE Equalizer

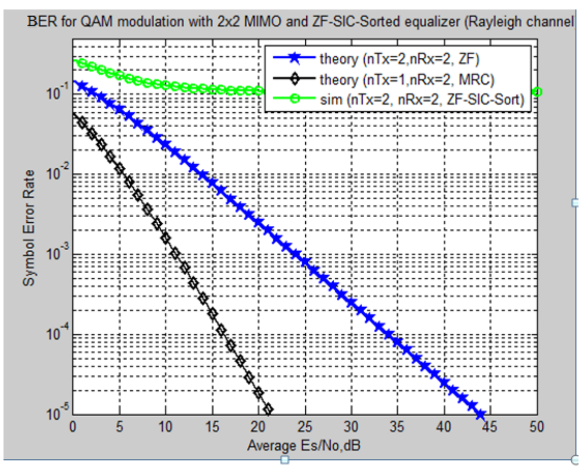

Figure 5: BER for ZFSIC with Optimal Ordering

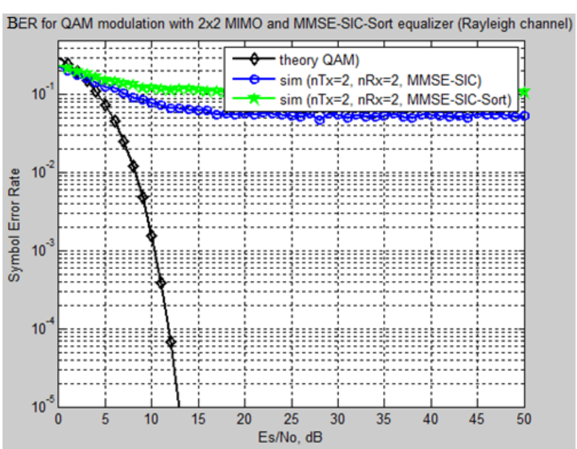

Figure 6 BER for MMSC-SIC with Optimal Ordering.

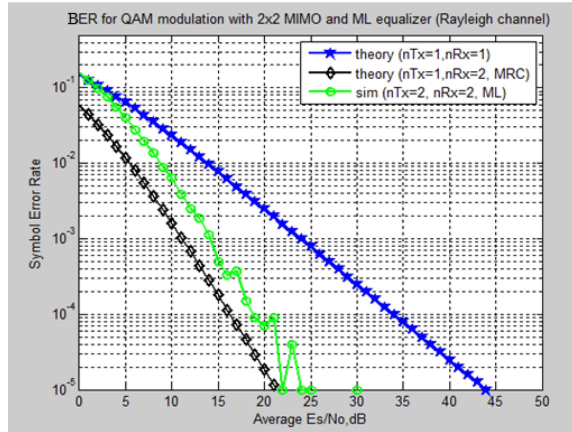

Figure 7 BER for ML Equalizer

CONCLUSION

To achieve higher data rate and least BER is the demand of wireless system design. Equalization techniques play very important role for designing sucg 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, ZF-SIC with optimal ordering, MMSE-SIC with optimal ordering not shows the better result as compared to ZF. The MMSE equalizer results in around 8dB of improvement when compared to zero forcing equalizer. and ML equalizer results in around 10dB of improvement for BER.

So, by observing the simulation results we conclude that by using ML, interference can be cancelled at optimum level even in a mobile fading channel.

References

[1]. G.L. Stuber, J.R. Barry, S.W. McLaughlin, Ye Li, M.A. Ingram and T.G. Pratt, "Broadband MIMO-OFDM wireless communications," Proceed-ings of the IEEE, vol. 92, No. 2, pp. 271-294, February. 2004.

[2]. [Dig-Comm-Barry Leemesserschmitt], Digital Communication:Third Edition, by John R. Barry, Edward A. Lee, David G. Messerschmitt.

[3] 'Fading' – Online Article in Wikipedia en.wikipedia.org/wiki/Fading

[4] 'A Comparative Study of Rayleigh Fading Wireless Channel Simulators' by VRS Ramaswamy

[5] Bit Error Rate Performance in OFDM System Using MMSE & MLSE Equalizer Over Rayleigh Fading

Channel Through The BPSK, QPSK,4 QAM & 16 QAM Modulation Technique. Vol. 1, Issue 3, pp.1005-1011,

[6]D. W. Tufts, "Nyquist's problem-The joint optimization of transmitter and receiver in pulse amplitude modulation," *Proc. IEEE,* vol. 53, pp. 248-260, Mar. 1965.

[7] "Techniques for adaptive equalization of digital communication systems," *Bell Syst. Tech. I.,* vol. 45, pp. 255-286,Feb. 1966.

[8] "Adaptive Equalization" by SHAHID U. H. QURESHI, SENIOR MEMBER, IEEE Vol.4, No.4, October, 2010.

[9] "Zero-Forcing Equalization For Time-Varying Systems With Memory " by Cassio B. Ribeiro, Marcello L. R. de Campos, and Paulo S. R. Diniz.

[10]Zero-Forcing Frequency Domain Equalization For Dmt Systems With Insufficient Guard Interval by Tanja Karp , Martin J. Wolf , Steffen Trautmann , and Norbert J. Fliege.

[11]*Digital Communications.* New York: McCraw-Hill,1983.

[12] Wireless communications and networks : second edition, by Theodore S. Rappaport

[13] G. Leus, S. Zhou, and G. B. Giannakis, "Orthogonal multiple access over time- and frequency-selective channels," IEEE Transactions on Information Theory, vol. 49, no. 8, pp. 1942–1950, 2003.

[14]Anuj Kanchan, Shashank Dwivedi, "Comparison of BER Performance in OFDM Using Different Equalization Techniques", International Journal of Engineering and Advanced Technology(IJEAT) ISSN: 2249 – 8958, Volume-1, Issue-6, August 2012, pp. no.-139-143.

[15] Amit Kumar Sahu, Sudhansu Sekhar Singh, "BER Performance Improvement Using Mimo Technique Over Rayleigh Wireless Channel With Different Equalizers", International Journal of Engineering and Technology (IJET), ISSN No.- ,333-340.