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BER Comparison of MIMO Systems using Equalization Techniques in Rayleigh Flat Fading Channel

Gurpreet Singh* and Pardeep Sharma**

* (Department of Electronics and Communication, Shaheed Bhagat Singh State Technical Campus Moga Road (NH-95), Ferozepur-152004)

** (Department of Electronics and Communication, Shaheed Bhagat Singh State Technical Campus Moga Road (NH-95), Ferozepur-152004)

ABSTRACT

Multiple Input Multiple Output (MIMO) technology is one of the most promising wireless technologies that can efficiently boost the data transmission rate, improve system coverage, and enhance link reliability. By employing multiple antennas at transmitter and receiver sides, MIMO techniques enable a new dimension– the spatial dimension – that can be utilized in different ways to combat the impairments of wireless channels. While using MIMO techniques, there is intersymbol interference present between the symbols. This paper will focus on Equalization techniques, for Rayleigh Flat fading. Equalization is a well known technique for combating intersymbol interference. In this paper, we will discuss different types of equalizer like ZF, MMSE, DFE and ML. In this paper, we will compare different equalizers with different modulations techniques like BPSK,QPSK,16-QAM.We will find out which modulation techniques is better than others and then we will compare ZF,MMSE, ML with the best modulation technique .Furthermore, we will conclude which type of equalizer will provide us better BER performance.

Keywords- Decision Feedback Equalization (DFE), Interference Intersymbol (ISI), Multiple Input Multiple Outpue (MIMO), Minimum Mean Square Error (MMSE) and Zero Forcing (ZF)

1. INTRODUCTION

The use of multiple antennas at the transmitter and receiver in wireless systems is known as MIMO. Communication [1] is wireless channels are impaired predominantly by multi-path fading. Multipath is the arrival of the transmitted signal at an intended receiver through differing angles and/or differing time delays and/or differing frequency shifts due to scattering of electromagnetic waves in the environment. The received signal power fluctuates in space and/or frequency and/or time through the random variations of the signals. This random fluctuation in the signal level is known, as fading. Fading can affect the quality and reliability of wireless communication. Additionally it is very difficult task of designing with high data rate and highly reliable wireless communication systems due to limited power and frequency bandwidth. MIMO [2] technology constitutes a breakthrough in wireless communication system design. The technology offers a number of benefits that help meet the challenges posed by both the impairments in the wireless channel as well as resource constraints. The benefits of MIMO technology that help achieve significant performance gains are array gain, spatial diversity gain, spatial multiplexing gain and interference reduction.

Due to multi-path fading, there is a distortion of a signal, where one symbols interference with subsequent symbols, is known as Intersymbol interference (ISI). Therefore, Equalization ideas to remove intersymbol interference (ISI) can be used. A linear equalizer usually tries to separate the symbols without enhancing the noise. The equalization methods that we consider in the design of MIMO receiver are ZF, MMSE, DFE and ML.

2. MIMO SYSTEM MODEL

We consider single user MIMO communication system [2] with 2 antennas at the transmitter and 2 antennas at the receiver. Consider that we have a transmission sequence is $\{x_1, x_2, \ldots\ldots\ldots\ldots, x_n\}$. In normal transmission, we send x_1 in the first time slot, x_2 in the second time slot and x_n in the n^{th} time slot. Now we have two transmit antennas, we may groups the symbols into groups of two. In the first time slot, send x_1 and x_2 from the first and second antenna. In the second time slot, send x_3 and x_4 from the first and second antenna and in next time slot x_5 and x_6 and so on.

Let us consider for 2 x 2 MIMO System

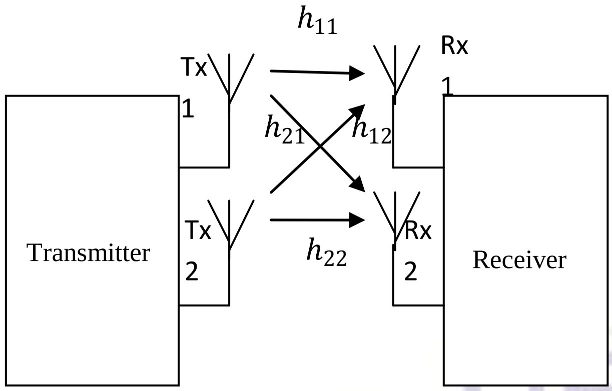

Figure:1. 2 x 2 MIMO system model

The received signal on the first receive antenna is

$$r_1 = h_{11}s_1 + h_{12}s_2 + n_1 \quad (1)$$

The received signal on the second receive antenna is

$$r_2 = h_{21}s_1 + h_{22}s_2 + n_2 \quad (2)$$

where, y_1 *and* y_2 are the received symbol on the first and second antenna respectively,h_{11} is the channel from 1^{st} transmit antenna to 1^{st} receive antenna,h_{12} is the channel from 2^{nd} transmit antenna to 2^{nd} receive antenna,h_{21} is the channel from 1^{st} transmit antenna to 2^{nd} receive antenna, h_{22} is the channel from 2^{nd} transmit antenna to 2^{nd} receive antenna, s_1 *and* s_2 are the transmitted symbols and n_1 *and* n_2 is the noise on 1^{st} *and* 2^{nd} receive antennas respectively.

Eq^n (1) and Eq^n (2) can be represented in matrix form

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (3)$$

Therefore, the received vector can be expressed as

$$y = Hs + n \quad (4)$$

And the complex baseband representation of signal [15] is given by

$$y = \sqrt{\frac{P}{M}} Hx + n \quad (2)$$

where $y \in C^{N \times 1}$ is the received signal vector, $x \in C^{M \times 1}$ is the transmitted signal vector with zero mean and unit variance, P is the total transmit power, $H \in C^{N \times M}$ is the channel response matrix with possibly correlated fading coefficients. In order to access the performance of MIMO System in correlated channel, we adopted a correlation-based channel model which is expressed as [3]

$$H \sim R_{Rx}^{\frac{1}{2}} H_w \left(R_{Tx}^{1\backslash 2}\right)^T \quad (3)$$

where x ~ y denotes that x and y are identical in distribution, R_{Rx} and T_{Tx} are the normal correlation distribution matrices at the Rx and transmitter (Tx) respectively, and $H_W \in C^{N \times M}$ contains i.i.d complex Gaussian entries with zero mean and unit variance.

For a system with M_T transmit antennas and M_R receive antennas, the MIMO channel at a given time instant may be represented as a $M_R \times M_T$ matrix

$$H = \begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,M_T} \\ H_{2,1} & H_{2,2} & \cdots & H_{2,M_T} \\ \vdots & \vdots & \ddots & \vdots \\ H_{M_R,1} & H_{M_R,2} & \cdots & H_{M_R,M_T} \end{bmatrix} \quad (5)$$

3. FADING

Fading is used to describe the rapid fluctuations of the amplitudes, phases or multipath delays of a radio signal over a short period of time or travel distance, so that large scale path loss effect may be ignored [5]. Fading, or equivalently small-scale fading, is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. These signals, called multipath waves, combine at the receiver antenna and the corresponding matched filter and provide an effective combined signal. This resulting signal can vary widely in amplitude and phase. The rapid fluctuation of the amplitude of a radio signal over a short period of time, equivalently a short travel distance, is such that the large-scale path loss effects may be ignored. Multipath in the radio channel creates small-scale fading effects. The three most important effects are:

- Rapid changes in signal strength over a small travel distance or time interval
- Random frequency modulation due to varying Doppler shifts on different multipath signals
- Time dispersion caused by multipath propagation delays

In built up urban areas, fading occurs because the height of mobile antennas are well below the height of surrounding structures, so there is no single line of sight (LOS) the base station [5]. The signal received by mobile at any point in space may consist of large number of waves having randomly distributed amplitudes, phases and angles of arrival. These multipath components combine vectorially at the receiver antenna, and because the signal received by mobile is fade [12]. Due to relative motion between the mobile and the base station, each multipath wave experiences an apparent shift in frequency. The shift in received signal frequency due to motion is called Doppler shift, and is directly proportional to the velocity and direction of motion of the mobile with respect to the direction of arrival of the received multipath wave. If the signal bandwidth is wider than the coherence bandwidth then different frequencies undergo independent fading and the result is inter-symbol-interference (ISI).

4.RAYLEIGH FLAT FADING CHANNEL

The fading effect is usually described statistically using the Rayleigh distribution [7]. The amplitude of two quadrature Gaussian signals follows the Rayleigh distribution whereas the phase follows a uniform distribution. The probability distribution function (PDF) of a Rayleigh distribution is given by [12]

$$p(r) = \begin{Bmatrix} \frac{r}{\sigma^2} exp\left(\frac{-r^2}{2\sigma^2}\right) & (0 \le r \le \infty \\ 0 & (r < 0) \end{Bmatrix} \quad (1.16)$$

where σ is the RMS (amplitude) value of the received signal and σ^2 is the average power.

5. EQUALIZATION TECHNIQUES

5.1 ZERO FORCING

An ISI channel may be modeled by an equivalent finite-impulse response (FIR) filter [5] plus noise. A zero-forcing equalizer uses an inverse filter to compensate for the channel response function. In other words, at the output of the equalizer [4], it has an overall response function equal to one for the symbol that is being detected and an overall zero response for other symbols. If possible, this results in the removal of the interference from all other symbols in the absence of the noise. Zero forcing is a linear equalization method that does not consider the effects of noise. In fact, the noise may be enhanced in the process of eliminating the interference.

Let us assume the case that $M_T = M_R$ and H is a full rank square matrix. In this case, the inverse of the channel matrix H exists and if we multiply both sides of equation (4) by H^{-1}, we have

$$y\mathrm{H}^{-1} = x + n\mathrm{H}^{-1} \quad (6)$$

From above equation we can see that symbols are separated from each other.

To solve for x, we know that we need to find a matrix W_{ZF} which satisfies W_{ZF} H =1. The Zero forcing linear detectors for meeting this constraint is given by

$$\mathrm{W_{ZF}} = (\mathrm{H^H H})^{-1}\mathrm{H^H} \quad (7)$$

The covariance matrix of the effected noise may be calculated as:

$$\begin{aligned} &E[(n\mathrm{H}^{-1})^H . n\mathrm{H}^{-1}] \\ &= (H^{-1})^H . E[n^H . n]. H^{-1} \\ &= n(H.H^H)^{-1} \end{aligned} \quad (8)$$

It is clear from the above equation that noise power may increase because of the factor $(H.H^H)^{-1}$.In general if the number of transmitter and receiver antennas is not same, we may multiply by Moore–Penrose generalized inverse, pseudo-inverse of H to achieve a similar zero-forcing result.In other words, it inverts the effect of channel as [3]

$$\begin{aligned} \tilde{\mathrm{x}}_{\mathrm{ZF}} &= \mathrm{w_{ZF}}\,\mathrm{y} \\ &= x + (\mathrm{H^H H})^{-1} n \end{aligned} \quad (9)$$

The error performance is directly proportion connected to the power of $(\mathrm{H^H H})^{-1} n$ that is, $\|(\mathrm{H^H H})^{-1} n\|_2^2$.

5.2 MINIMUM MEAN SQUARE ERROR (MMSE)

If the mean square error between the transmitted symbols and the outputs of the detected symbols, or equivalently, the received SINR is taken as the performance criteria, the MMSE detector [7] is the optimal detection that seeks to balance between cancelation of the interference and reduction of noise enhancement.

Let us denote MMSE detector as W_{MMSE} and detection operation by [3]

$$\hat{x}_k = sgn\,[\mathrm{W_{MMSE}}\ \mathrm{y}] \quad (10)$$

The W_{MMSE} maximizes the SINR and minimizes the mean square error which is given by:

$$E[(\hat{x}_k - \mathrm{W_{MMSE}}\ \mathrm{y})^T (\hat{x}_k - \mathrm{W_{MMSE}}\ \mathrm{y})] \quad (11)$$

To solve for x, We know that we need to find a matrix W_{MMSE} . The MMSE linear detector for meeting this constraint is given by:

$$\mathrm{W_{MMSE}} = (\mathrm{H^H\ H} + \sigma^2{}_n \mathrm{I})^{-1}\ \mathrm{H^H} \quad (12)$$

Therefore,

$$W_{MMSE} = \left(H^* H + \frac{1}{SNR} I\right)^{-1} H^* \quad (13)$$

MMSE at a high SNR is given by

$$\begin{aligned} W_{MMSE} &= \left(H^* H + \frac{1}{SNR} I\right)^{-1} H^* \\ &\approx (H^H H)^{-1} H^H \end{aligned} \quad (14)$$

At a high SNR MMSE becomes Zero Forcing.

5.3 MAXIMUM LIKELIHOOD (ML)

The Linear detection method and SIC detection methods require much lower complexity than the optimal ML detection, but their performance is significantly inferior to the ML detection [8]. Maximum Likelihood between received signal vector and the product of all possible transmitted signal vector and product of all possible transmitted signal vectors with the given channel H, and finds the one with minimum distance.

Let C and N_T denote a set of signal constellation symbol points and a number of transmit antennas, respectively. Then, ML detection determines the estimate transmitted signal vector x as:

$$\hat{x}_{ML} = \underset{x \in C^{N_T}}{\operatorname{argmin}} \|y - Hx\|^2 \quad (15)$$

where, $\|y - Hx\|^2$ Corresponds to the ML metric. The ML method achieves the optimal performance as the maximum a posterior detection when all the transmitted vectors are likely. However, its complexity increases exponentially as modulation order and/or the number of transmit antennas increases. The required number of ML metric calculation is $|C|^{N_T}$, that is the complexity of metric calculation exponentially increases with the number of antennas.

The ML receiver [8] performs optimum vector decoding and is optimal in the sense of minimizing the error probability. ML receiver is a method that compares the received signals with all possible transmitted signal vectors which is modified by channel matrix H and estimates transmit symbol vector $\hat{C}$ according to the Maximum Likelihood principle, which is shown as:

$$\hat{C} = \min_{C} arg \left[\!\left[y - C'H \right]\!\right]_F^2 \quad (16)$$

where, $_F$,is the Frobenius norm. Expanding the cost function using Frobenius norm given by

$$\hat{C} = \min_{\hat{C}} \arg \left[\mathrm{Tr}[(y - C'H)^H.(y - C'H)] \right] \quad (17)$$

$$\hat{C} = \min_{\hat{C}} \arg \left[\mathrm{Tr}[y^H.y + H^H.C'^H.C'.H - H^H.C'^H.y - y^H.C'.H] \right] \quad (18)$$

Considering $y^H.y$ is independent of the transmitted codeword so can be rewritten as [3]

$$\hat{C} = \min_{\hat{C}} \arg[\mathrm{Tr}[H^H.C'^H.C'.H] - 2\mathrm{Real}(\mathrm{Tr}[H^H.C'^H.y])] \quad (19)$$

where, $.^H$ is a Hermition operator, although ML detection offers optimal error performance, it suffers from complexity issues.

5.4 SUCCESSIVE INTERFERENCE CANCELLATION

When signals are detected successively, the outputs of previous detectors can be used to aid the operations of next ones which leads to the decision directed detection algorithms including SIC, Parallel Interference cancelation (PIC), and multistage detection [8]. ZF SIC with optimal ordering, and MMSE-SIC [10] with equal power allocation approach the capacity of the i.i.d. Rayleigh fading channel. After the first bit is detected by the decorrelator the result is used to cancel the interference from the received signal vector assuming the decision of detection calculates the Euclidean distance [6] the first stream is correct. For the ZF-SIC, since the interference is already nulled, the significance of SIC is to reduce the noise amplification by the nulling vector. The nulling vector w_1 filters the received vector y as:

$$\hat{x}_k = sgn\,[\,w_1^T\,y] \quad (20)$$

Assuming $\hat{x}_k = x_1$, by substituting x_1 from the received vector y, we obtain a modified received vector y_1 given by:

$$y_1 = y - \hat{x}_k(H)_1 \quad (21)$$

where, $(H)_1$ denotes the first column of H. We then repeat this operation until all M_T bits are detected. Once the first stream is detected, the first row of H is useless and will be eliminated. Therefore after the first cancelation the nulling vector for the second stream need only M_r -1 dimensions. For the MMSE detector the significance of SIC is not only to minimize the amplification of noise but also the cancelation of the interference from other antennas. In addition, there is another opportunity to improve the performance by optimal ordering the SIC process. The ordering is based on the norm of the nulling vector. At each stage of cancelation, instead of randomly selecting the stream to detect, we choose the nulling vector that has the smallest norm to detect the corresponding data stream. This scheme is proved to be the globally optimum ordering more complex.

5.4.1 ZERO FORCING WITH SIC

OSIC [11] is basically based on subtraction of interference of already detected elements of **s** from the receiver vector r. This results in a modified receiver vector in which effectively fewer interferers are present. In other words, SIC is based on the subtraction of interference of already detected elements **s** from the received vector **x.** This results in a modified receiver vector in which effectively fewer interferers are present. When Successive Interference Cancellation (SIC) [11] is applied, the order in which the components of **s** are detected is important to the overall performance of the system. To determine a good detection order, the covariance matrix of the estimation error $s - s_{est}$ is used.

We know that the covariance matrix is given by

$$Q = E[\epsilon.\epsilon^H] = \sigma_n^2(H^H H)^{-1} \quad (22)$$

$$Q = E[(s - s_{est})(s - s_{est})^H] = \sigma_n^2(H^H H)^{-1} \equiv \sigma_n^2 P \quad (23)$$

Where P $=H^+(H^+)^H$

Let $(s_{est})_p$ be the p[th] entry of s_{est}, then the "best" is the one for which P_{pp} (i.e., the p-th diagonal element of **P**) is the smallest. Because this is estimate with the smallest error variance. From the eq^n (23) it becomes clear that P_{pp} is equal to the squared length

of row p of H^+. Hence, finding the minimum squared length row of H^+ is equivalent.
Summarizing, the decoding algorithm consist of three parts:

- Ordering: determine the Tx stream with the lowest error variance.
- Interference Nulling: estimate the strongest Tx signal by nulling out all the weaker Tx signals.
- Interference Cancellation: remodulate the data bits, subtract their contribution from the received signal vector and return to the ordering step.

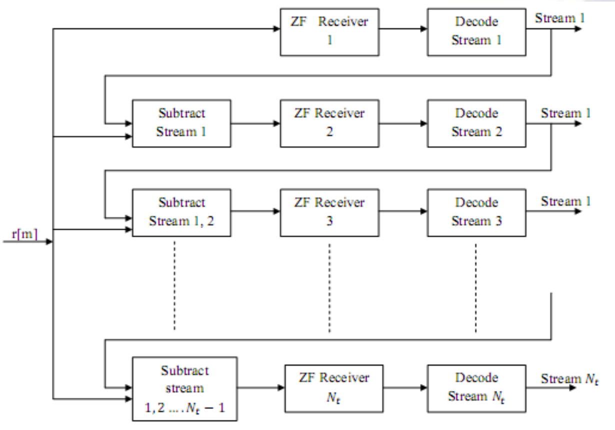

Figure.2 SIC Zero Forcing Detector

We use the first Zero-Forcing detector to detect the data stream $s_1(m)$ decode it and then subtract this decoded stream from the received vector. Assuming the first stream is successfully decoded, and then the second Zero-Forcing detector only needs to deal with $s_3 \ldots\ldots\ldots s_{N_t}$ as interference, since s_1 has been correctly subtracted off. Thus, the second Zero-Forcing detector projects onto a subspace which is orthogonal to $h_3 \ldots\ldots\ldots. h_{N_t}$.This process is continued until the last Zero-Forcing detector does not have to deal with any interference from the other data streams. We assume subtraction is successful in all preceding stages. This SIC (Successive Interference Cancellation) Zero-Forcing detector architecture is illustrated in Figure.2
So we can see here with respect to ZF, the ZF with OSIC algorithm introduces extra complexity.

5.4.2 MMSE WITH SIC

In order to do OSIC with MMSE [11], then the algorithm resulting as follows
Covariance matrix can be written as
$[(s - s_{est})(s - s_{est})^H] = \sigma_n^2(\alpha I + H^H H)^{-1} \equiv \sigma_n^2 P$
Covariance matrix of the estimation error $(s - s_{est})$ will be used to determine good ordering for detection.

1) Compute W (P is obtained while determining W). Find the smallest diagonal entry of P and suppose this is the p-th entry. Permute the p-th column of H to be last column and permute the rows of W accordingly.
2) From the estimate of the corresponding elements of s. In case of MMSE:
$$(S_{est})_p = W^M x$$
Where the weight vector W^M equals row M (number of transmitting antennas) of the permuted W
3) While M-1>0 go back to step 1, but now with:
$$H \longrightarrow H^{(M-1)} = (h_1 \ldots\ldots\ldots h_{M-1})$$

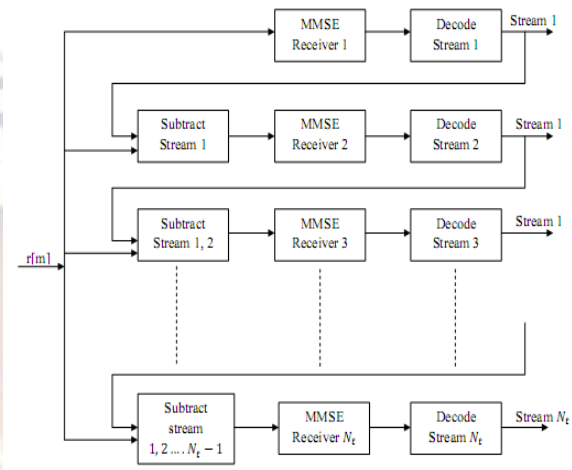

Figure.3 SIC MMSE Detector

So here we can see that we get optimal ordering by using MMSE with OSIC

6. SIMULATION RESULTS

6.1 SIMULATION MODEL

The Matlab script performs the following.Generation of random binary sequences

1. Modulate the binary sequences using BPSK, QPSK and 16 QAM.
2. Group them into pair of two symbols and send two symbols in one time slot.
3. Multiply the symbol with the channel and then add white Gaussian noise.
4. Perform equalization on the received signal and different equalizers are ZF, MMSE and ML [6].
5. Perform hard decision decoding that is demodulating the BPSK, QPSK and 16 QAM.

Repeat for multiple value of SNR and plot the simulation result.

6.2 RESULTS

In Figure.4 We compare a ZF with different modulation and in this we observed that BPSK and QPSK have the almost same results and 16-QAM have worst results than BPSK and QPSK modulation. At BER=0.001, there is approximately 3 dB difference between the BPSK and 16-QAM modulation in Zero Forcing. In Figure.5 we compare the ZF-OSIC with different modulation like BPSK, QPSK and 16-QAM. In this graph we observed that BPSK have an equivalent to the QPSK and 16-QAM have worst results than BPSK and QPSK modulation. At BER=0.001, there is approximately 4 dB difference between the BPSK and 16-QAM modulation in Zero Forcing-OSIC. In Figure.(6) we compare the MMSE with different modulation like BPSK, QPSK and 16-QAM. In this graph we observed that BPSK have better results than QPSK and 16-QAM and 16-QAM modulation have worst results. At BER=0.001, there is approximately 5 dB difference between the BPSK and 16-QAM modulation in MMSE-OSIC. In Fig.(7) we compare the MMSE-OSIC with different modulation like BPSK, QPSK and 16-QAM. In this graph we observed that BPSK have better results than QPSK and 16-QAM and 16-QAM modulation have worst results. At BER=0.001, there is approximately 7 dB difference between the BPSK and 16-QAM modulation in MMSE-OSIC. In Figure. (8) we compare the ML with different modulation like BPSK, QPSK and 16-QAM. In this graph we observed that BPSK have better results than QPSK and 16-QAM and 16-QAM modulation have worst results. At BER=0.001, there is approximately 3dB difference between the BPSK and QPSK modulation in MMSE-OSIC.

In Figure. (9)There is a comparison between the different detectors like Maximum Likelihood (ML), ZF-OSIC, ZF, MMSE and MMSE-OSIC. Here we observed that Maximum Likelihood (ML) have a best performance than other detectors and Zero Forcing (ZF) has a worst performance. If we compare the ZF and ML, performance curve of the two detectors are close to each other at low SNR but the gap gets larger when SNR gets higher. When the SNR gets higher, the post detection of SNR is mainly affected by channel matrix H. If we compare the MMSE-OSIC and. ZF-OSIC, at BER=0.001 there is an approximately 3 dB difference between these two detectors.

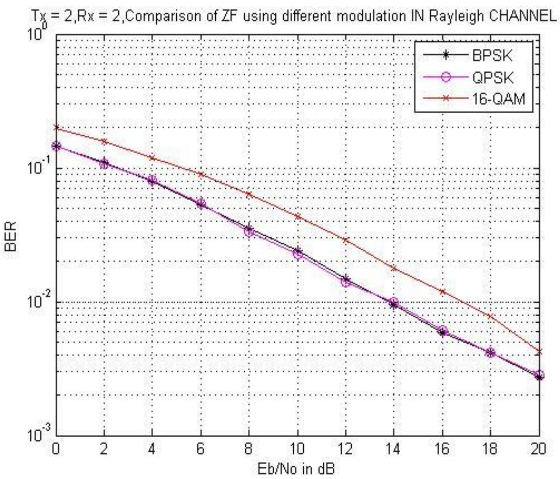

Figure.4 Comparison of ZF using BPSK

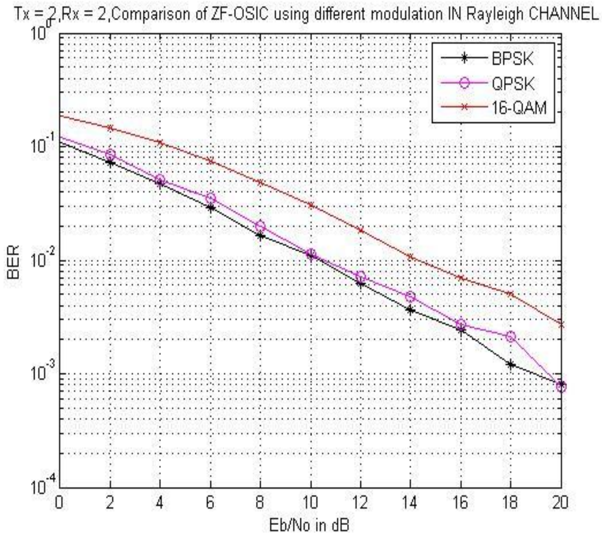

Figure.5 Comparison of ZF-OSIC using BPSK

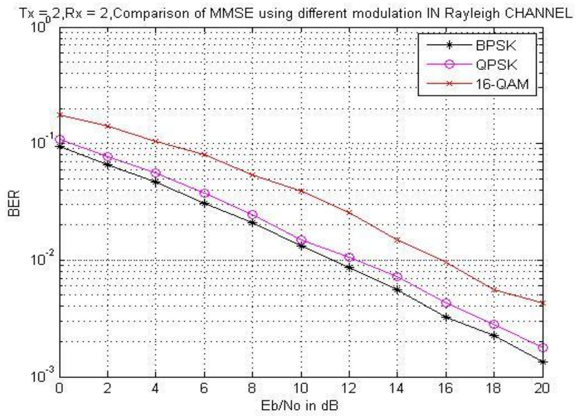

Figure.6 Comparison of MMSE using BPSK

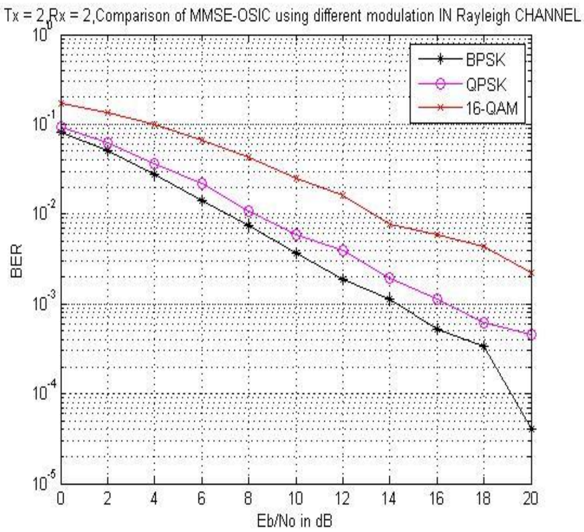

Figure.7 Comparison of MMSE-OSIC using BPSK

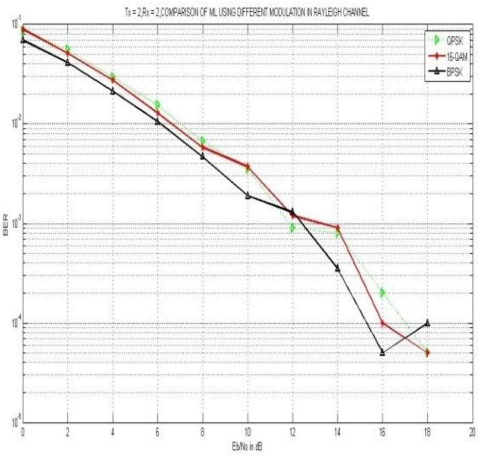

Figure.8 Comparison of ML using BPSK

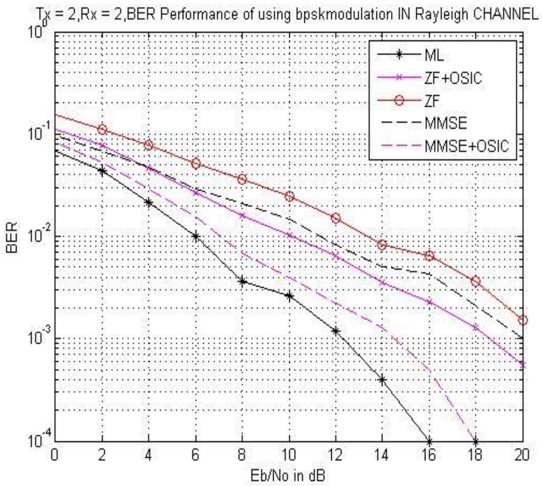

Fig.9 Comparison using different detection technique using BPSK modulation

7. RESULTS

In this paper, we studied MIMO V-BLAST system performance under Flat Fading Rayleigh channel. Further this system is compared with different modulation technique and system gets better result in BPSK modulation and worst result in 16-QAM Fig.(9) shows the simulation results for BPSK modulation with different decoding technique and ML gives the best result and ZF gives the worst result.

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BIOGRAPHY

Mr.Gurpreet Singh received M.Tech degree in Electronics and Communication Engineering degree from Jaypee University of Information and Technology, Solan in 2012 and received B.Tech degree from Lovely Institutes of Technology in Electronics and Communication Engineering from Lovely Institutes of Technology, Phagwara in 2010 with distinction. Currently, he is working as a Assistant Professor in Shaheed Bhagat Singh State Technical Campus, Ferozpur, Punjab. His area of interest is signal processing, MIMO, Wireless Mobile Communication Engineering, high speed digital communications and 4G Wireless Communications


Mr. Pardeep Sharma received M.Tech degree in Electronics and Communication Engineering from Sant Longowal Institute of Engineering & Technology in 2012 and received B.Tech degree in Electronics and Communication Engineering form Swami Vivekanand Institutes of Engineering & Technology, Banur in 2010. Currently, he is working as a Assistant Professor in Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab. His area of interest is Digital Signal processing, VHDL, Wireless Mobile Communication Engineering, Digital Design and Analysis