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Analysis of Equalization in MIMO System with Optimal Ordering in Rayleigh flat fading channel

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ABSTRACT: Due to advancement in recent years, wireless communication system has become integral part of our life during the last decade. Because of rapid popularity of wireless system, there has been tremendous demand in data rates leading to development of higher bandwidth over existing cellular networks. But due to limitations in power transmission and implementation complexity, its designing becomes main challenge. Various wireless channel impairments such as fading of signals, interference and noise addition during data transmission creates further problems. Multiple Input Multiple Output (MIMO) is one such wireless technology which increases the efficiency of data transmission along with improved reliability and wide coverage. When data is transmitted at higher rate, channel impulse can create ISI (Inter-symbol interference). Equalization is a well-known technique to eradicate ISI. This paper analyzes the performances of equalization techniques like Zero-forcing (ZF), Minimum mean square error (MMSE), ZF-Successive interference cancellation (ZF-SIC), MMSE-SIC, ZF-SIC & MMSE-SIC with Optimal Ordering, Maximum likelihood (ML) and Sphere decoder (SD) considering 2x2 MIMO over a flat fading Rayleigh multipath channel.

Keywords: Binary Phase Shift Key (BPSK), Minimum mean-squared error (MMSE), Maximum likelihood (ML), Bit error rate (BER), Inter-symbol interference (lSI), Successive- interference cancellation (SIC), Sphere Decoder (SD), Zero Forcing (ZF).

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) exploits the space dimension to improve wireless systems capacity, range and reliability. MIMO is a method for multiplying the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation [5].

Developments in the field of coding and signal processing marks the commencement of equalization strategies in wireless communication systems. The large number of parameters signalize the channel impulse response. The need for high data rates results in ISI which stress the use of suitable equalization strategies. Hence, the Multiple Input Multiple Output (MIMO) which provides higher data rates required by high data demanding applications, paired along with an equalizer, lowers the Bit Error Rate of the transmitted data. Because of the features of MIMO systems, it became an important part of modern wireless communication [4]. MIMO has become an essential element of wireless communication standards such as WLAN – WiFi 802.11n, Mesh Networks (e.g., MuniWireless), WMAN – WiMAX 802.16e, 4G, RFID (Radio frequency identification) and Digital Home.

II. MIMO SYSTEM MODEL

A MIMO system with MT as transmit antennas and MR receive antennas is shown in Fig.1, the MIMO channel [3] at a given time instant may be represented as MT x MR matrix as shown in fig.1 below.

$$\mathrm{H} = \begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,MT} \\ H_{2,1} & H_{2,2} & \cdots & H_{2,MT} \\ \vdots & \vdots & \ddots & \vdots \\ H_{MR,1} & H_{MR,2} & \cdots & H_{MR,MT} \end{bmatrix}$$

Fig. 1. MIMO Matrix.

In a 2x2 MIMO channel, with a transmitted signal sequence x_1, x_2, x_3, x_4 will be transmitted as shown in Fig. 2 below.

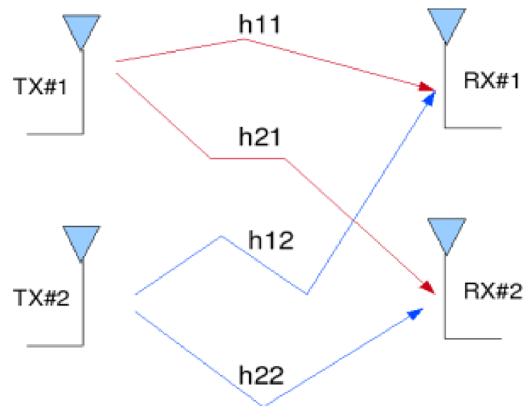

Fig. 2. 2x2 MIMO Channel.

MIMO system provide a unique solution to this challenge by requiring multiple signal paths. MIMO systems uses combination of multiple antennas and multiple signal paths to gain knowledge of the communications channel. Signal in MIMO system travels along multiple paths.
-MIMO makes use of multi-path.
-MIMO uses multiple antennas to transmit multiple parallel signals from the transmitter end.
-In our surrounding, transmitted signals will bounce off from different obstacles and reach the destination following different directions.
-“Multi-path” occurs when the different signals arrive at the receiver at various times.
-Various signals are reach the destination at various because of Multi-path,
-With MIMO, the receiving side uses an algorithm or special signal processing to sort out the multiple signals to produce one signal/data which was originally send from the receiver side.

III. EQUALIZATION TECHNIQUES

A 2x2 MIMO channel with a transmitted signal sequence x_1, x_2, x_3, x_4 is shown in Fig. 2.
In the first-time slot, the received signal at the first receive antenna takes the following form [7]

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = \begin{bmatrix} h_{1,1} & h_{1,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \quad (1)$$

In the second-time slot, the received signal at the second receive antenna takes the following form

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = \begin{bmatrix} h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \quad (2)$$

The above equation can be represented in matrix notation as follows

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (3)$$

Hence, $y = Hx + n$ (4)

To solve for x, we know that we need to find a matrix W which satisfies

$WH = I$ (5)

A. Zero Forcing

The Zero-Forcing Equalizer applies the inverse of the channel frequency response to the received signal, to restore the signal after the channel [1]. To find the transmitted signal matrix x an equalizationmatrix W must satisfy to the following condition $WH = I$, where I is an identity matrix. The ZF equalization matrix [3] can be defined as follows:

$$W = (H^H H)^{-1} H^H \quad (6)$$

B. Minimum Mean Square Error (MMSE)

The MMSE detector tries to maintain balance the interference cancellation and noise amplification. The MMSE estimator minimizes the mean square error (MSE). It chooses either the output SNR, mean square error between transmitted signal or the output of detected signals as parameters. The MMSE equalization [3] can be defined as follows

$$W = [H^H H + N_0 I]^{-1} . H^H \quad (7)$$

C. Zero Forcing with Successive Interference Cancellation

In the Zero Forcing with Successive Interference Cancellation (ZF-SIC) equalization technique the output of the already detected signals can be used to affect the output of the incoming signals.

The main purpose of using successive interference cancellation (SIC) is to reduce the noise amplification. The ZF-SIC equalization [3] can be defined as follows

$$\begin{bmatrix}\widehat{x_1}\\ \widehat{x_2}\end{bmatrix} = (H^H H)^{-1}.H^H \begin{bmatrix}y_1\\ y_2\end{bmatrix} \quad (8)$$

D. MMSE with Successive Interference Cancellation

MMSE with Successive Interference *Cancellation*extends the concept of Successive Interference Cancellation of ZF to the MMSE equalization by adapting shift keying modulation in flat fading Rayleigh multipath channel. The MMSE-SIC equalization [7] can be defined as follows

$$\begin{bmatrix}\widehat{x_1}\\ \widehat{x_2}\end{bmatrix} = (H^H H + \sigma_n^2 I)^{-1}.H^H \begin{bmatrix}y_1\\ y_2\end{bmatrix} \quad (9)$$

E. ZF-SIC and MMSE-SIC with Optimal Ordering

In Successive Interference Cancellation technique, the receiver takes onesymbols and subtract its effect from the received symbol y_1 and y_2. However, we will get better results if we decide whether we should subtract x_1 first or x_2 first by finding out the power of the transmitted symbol at the receiver. Hence, the receivedpower at transmitting and receiving antennas corresponding to the transmitted symbol $x_1$is [7]

$$Px_1 = |h_{1,1}|^2 + [h_{1,2}]^2 \quad (10)$$

the received power at transmitting and receiving antennas corresponding to the transmitted symbol $x_2$is

$$Px_2 = |h_{2,1}|^2 + [h_{2,2}]^2 \quad (11)$$

If $Px_1 > Px_2$ then the receiver decides to remove the effect of $\widehat{x_1}$ from the received vector y_1 and y_2 and re-estimate $\widehat{x_2}$.

$$\begin{bmatrix}r_1\\ r_2\end{bmatrix} = \begin{bmatrix}y_1 - h_{1,1}\widehat{x_1}\\ y_2 - h_{1,2}\widehat{x_1}\end{bmatrix} = \begin{bmatrix}h_{1,2}x_2 + n_1\\ h_{2,2}x_2 + n_2\end{bmatrix} \quad (12)$$

$$r = hx_2 + n \quad (13)$$

The equalized symbol is

$$\widehat{\widehat{x_2}} = \frac{h^H r}{h^H h} \quad (14)$$

Similarly,

$$\widehat{\widehat{x_1}} = \frac{h^H r}{h^H h} \quad (15)$$

F. Maximum Likelihood (ML)

Maximum likelihood detection calculates the Euclidean distance between received signal vector and the product of all possible transmitted signal vectors with the given channel *H*, and finds the one with minimum distance [9]. Equalizer based on ML is the optimal method to estimate the transmitted signals in MIMO system using linear space time coding. By using ML equalizer [8], we find an estimator $\hat{x}$ which minimizes

$$J = |y - H\hat{x}|^2$$

$$J = \left\| \begin{bmatrix}y_1\\ y_2\end{bmatrix} - \begin{bmatrix}h_{1,1} & h_{1,2}\\ h_{2,1} & h_{2,2}\end{bmatrix}\begin{bmatrix}\widehat{x_1}\\ \widehat{x_2}\end{bmatrix}\right\|^2$$

The MLdetector chooses the message $\hat{x}$ which yields thesmallest distance between the received signal vector*y* and hypothesized message $H\hat{x}$.

G. Sphere Decoder (SD)

The main idea behind sphere decoding is to limit the number of possible codewords by considering only those codewords that are within a sphere centered at the received signal vector [10]. By considerthe following equation [11] of the sphere with radius of R_{SD}.

$$(\bar{x} - \hat{\bar{x}})^T \bar{H}^T \bar{H} (\bar{x} - \hat{\bar{x}}) \le R_{SD}^2$$

SD method considers only the vectors inside a sphere defined by Equation (10). If we were fortunate to choose the closest one among the four candidate vectors; we can reduce the radius in Equation (10) so that we may have a sphere within which a single vector remains.

The main advantage of using sphere decoder over ML is that the complexity is significantly reduced. The complexity of sphere decoder depends upon how well the initial radius is chosen.

IV. SIMULATION AND RESULTS

The simulation results has been obtained using the Octave. The results shown in different graphs provides the comparison of the BER performance for BPSK modulation of different equalizers with 2x2 reciever for Rayleigh Flat Fading channel.

"Fig. 3(a)" shows the comparison of BER for BPSK modulation of ZF equalizer with theoritical 2x2 reciever in Rayleigh Flat Fading channels . It has been observed that in Rayleigh Flat Fading Channel with the BPSK modulation we get the same results as compared to the theoritical reciever. So the order of performance is ZF-BPSK = theoritical 2x2 reciever.

"Fig. 3(b)" shows the better performance of MMSE with the BPSK modulation in comparison to 2x2 reciever in Rayleigh Flat Fading Channel. So the order of performance is MMSE-BPSK >2x2 reciever.

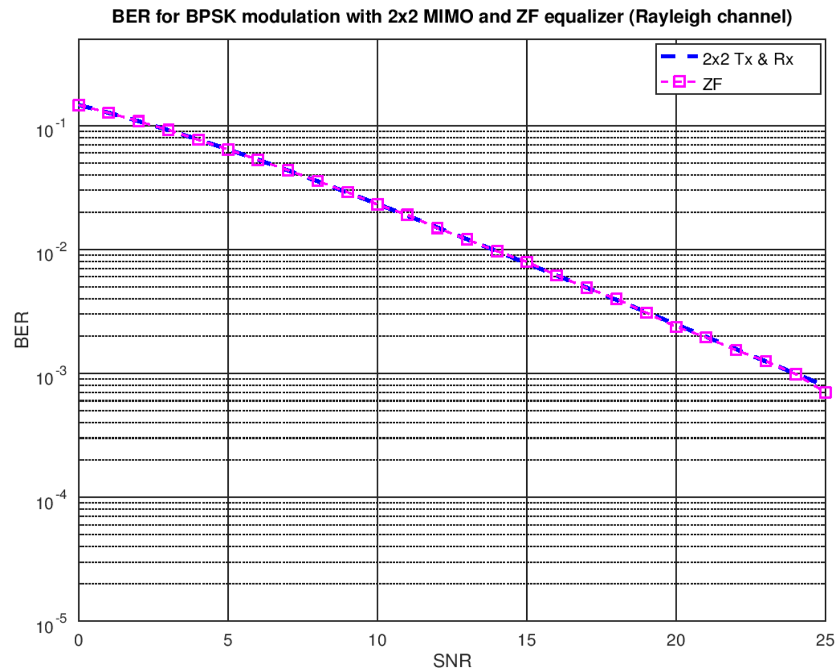

Fig. 3(a). ZF Equalizer.

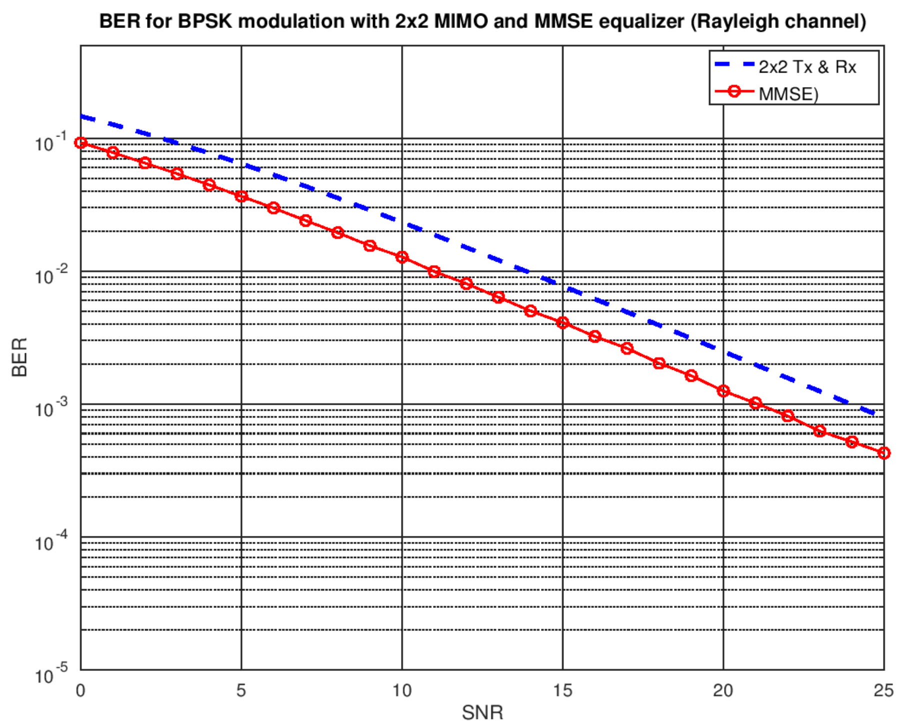

Fig. 3(b). MMSE Equalizer.

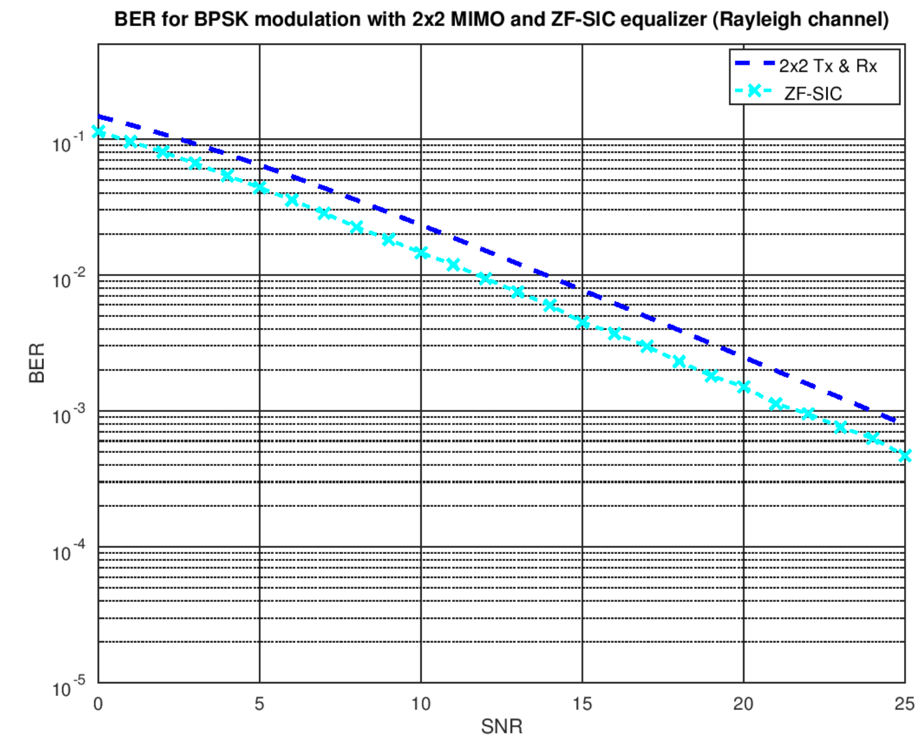

Fig. 4(a). ZF-SIC Equalizer.

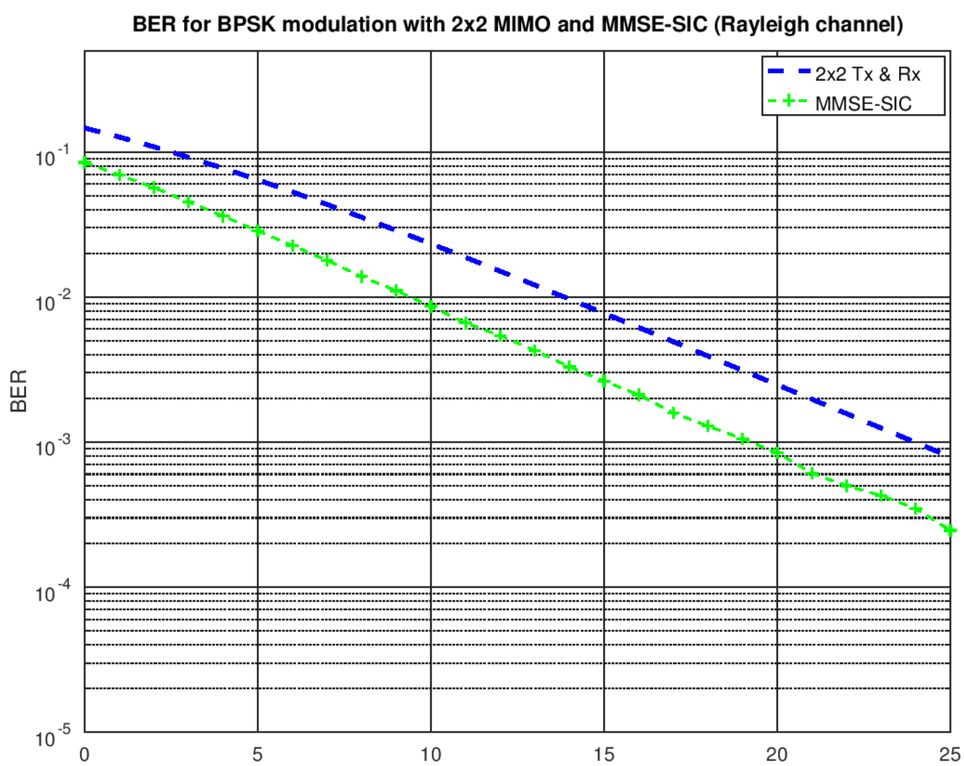

Fig. 4(b). MMSE-SIC Equalizer.

"Fig. 4(a)" shows the comparison of BER for BPSK modulation of ZF-SIC equalizer with theoritical 2x2 reciever in Rayleigh Flat Fading channels . It has been observed that in Rayleigh Flat Fading Channel with the BPSK modulation, we get better performance as compared to ZF and the theoritical reciever. So the order of performance is ZF-SIC-BPSK> ZF-BPSK(2x2 reciever).

"Fig. 4(b)" shows the better performance of MMSE with the BPSK modulation in comparison to 2x2 reciever in Rayleigh Flat Fading Channel.We can observe that MMSE-SIC is better even with MMSE and ZF-SIC both. So the order of performance is MMSE-SIC-BPSK > MMSE-BPSK > ZF-SIC-BPSK.

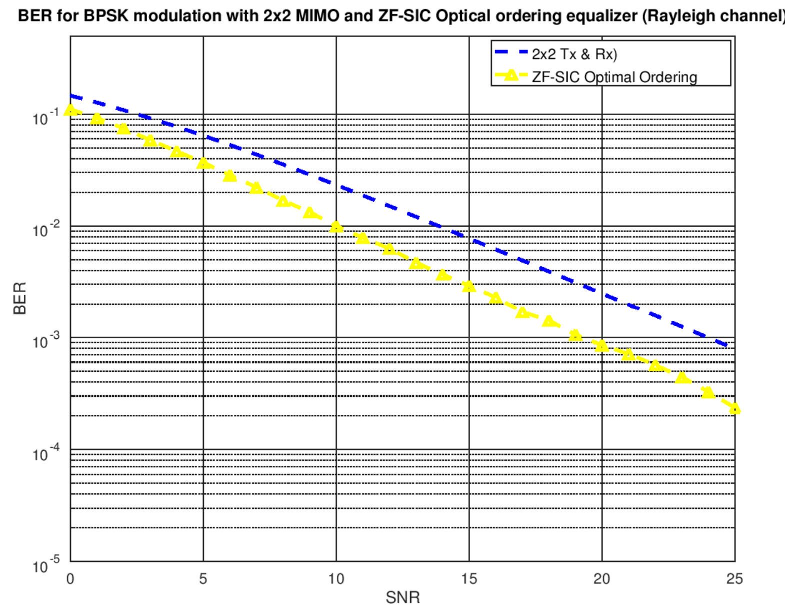

Fig. 5(a). ZF-SIC with Optimal Ordering Equalizer.

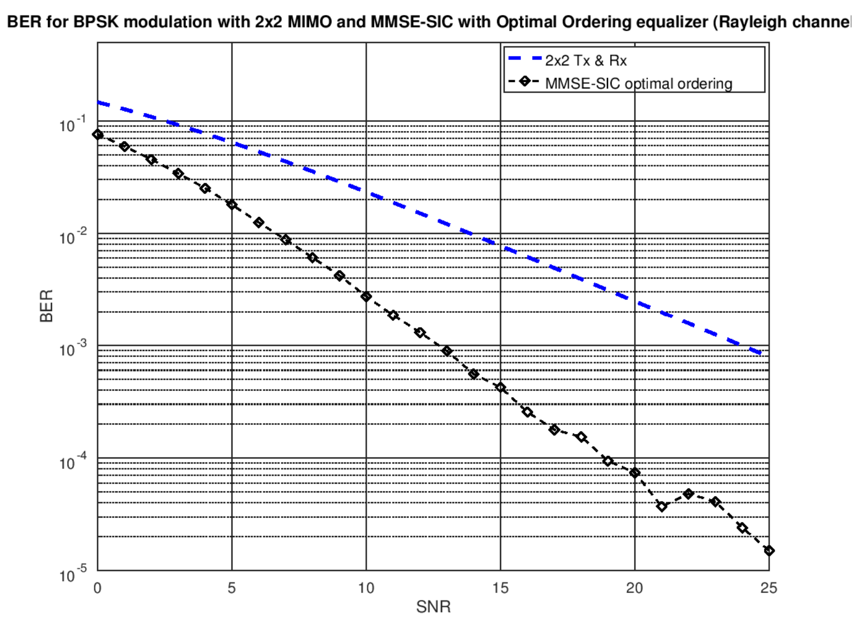

Fig. 5(b). MMSE-SIC with Optimal Ordering Equalizer.

"Fig. 5(a)" shows the comparison of BER for BPSK modulation of ZF-SIC with Optimal Ordering equalizer with 2x2 reciever in Rayleigh Flat Fading channels . It has been observed that in Rayleigh Flat Fading Channel with the BPSK modulation, we get better performance with ZF-SIC with Optimal Ordering. So the order of performance is ZF-SIC with Optimat Ordering-BPSK > MMSE-BPSK.

"Fig.5(b)" shows the performance of MMSE-SIC with Optimal Ordering in comparison to 2x2 reciever in Rayleigh Flat Fading Channel. So the order of performance is MMSE–SIC with Optimal Ordering-BPSK > MMSE-SIC-BPSK> ZF-SIC with Optimal Ordering-BPSK.

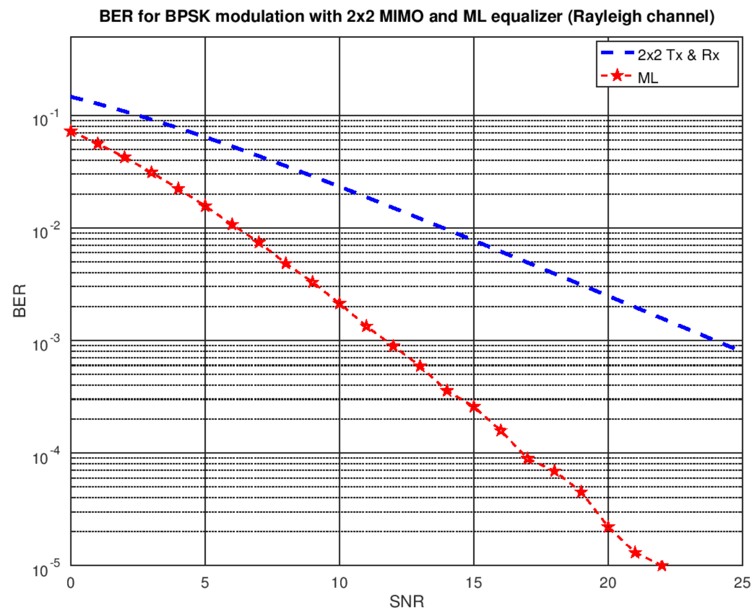

Fig. 6(a). ML Equalizer.

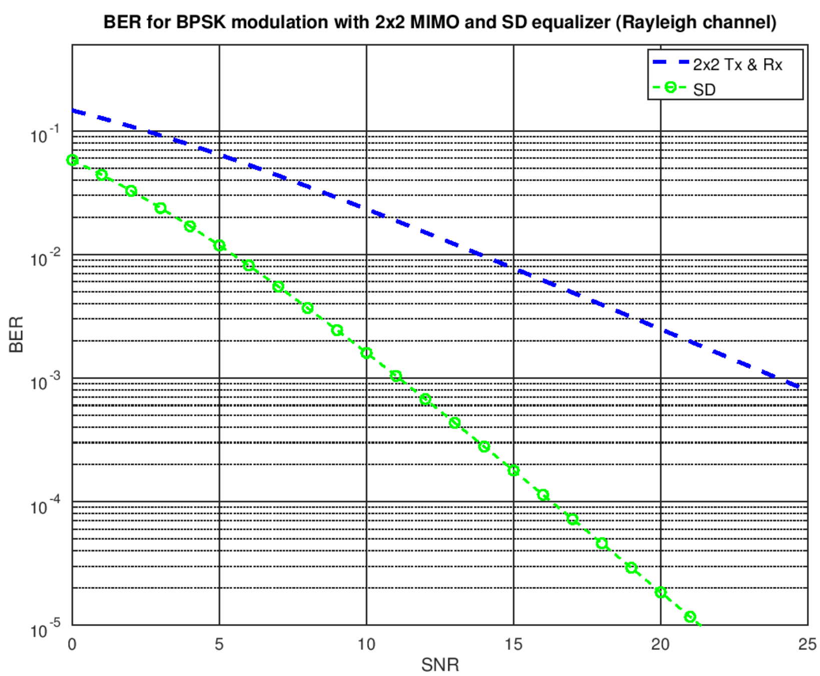

Fig. 6(b). Sphere Decoder.

"Fig. 6(a)" shows the comparison of BER for BPSK modulation of Maximum Likelihood equalizer with 2x2 reciever in Rayleigh Flat Fading channels . It has been observed that in Rayleigh Flat Fading Channel with the BPSK modulation, we get better performance with ML. So the order of performance is ML > MMSE-SIC with Optimal Ordering-BPSK.

"Fig. 6(b)" shows the performance of Sphere Decoder in comparison to 2x2 reciever in Rayleigh Flat Fading Channel. So the order of performance is SD > ML.

"Fig. 7" shows the comparisions of BER for BPSK modulation of all the equalizers in Rayleigh Flat Fading channel. The order of performance is SD > ML > MMSE-SIC with Optimal Ordering > MMSE-SIC > ZF-SIC with Optimal Ordering > MMSE > ZF-SIC > ZF.

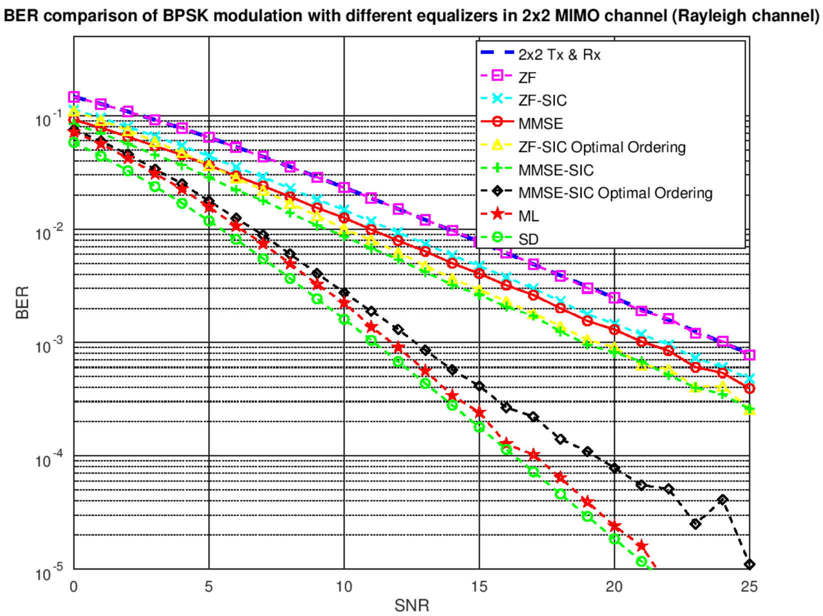

Fig. 7. Comparison of Equalization Techniques.

V. CONCLUSIONS

In this paper, the comparison of different equalizer techniques in 2x2 MIMO is analyzed. We are proposing optimal ordering in Zero Forcing with Successive-interference cancellation and Minimum mean-squared error with Successive- interference cancellation. Rayleigh fading channel is taken as communication channel and noise is added to it. ML and SD gives the best results, but detector entails an exhaustive searching, which results in high computational complexity. Higher computational complexity means more time and money. Therefore, optimal ordering algorithms have been studied. This will decrease the computational complexity and get approximately the similar performance. ZF and MMSE performed better with successive interference cancellation with optimal ordering method respectively. Hence, the BER performance in order from lowest to highest is ZF < ZF-SIC < MMSE < ZF- SIC with optimal ordering < MMSE-SIC < MMSE-SIC with optimal ordering < ML < SD.

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