ISSN 2277 – 5528
Impact Factor- 3.145

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & MANAGEMENT

Analysis of Equalization Techniques for MIMO Systems in wireless communication

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ABSTRACT

A detail analysis of the performance of 2X2 Multiple Input Multiple Output (MIMO) antenna system with STBC multiplexing and Alamouti coding and BPSK modulation for high data rate transmission has been carried out assuming flat fading Rayleigh channel. Combining different linear and non-linear detection techniques, Bit Error Rate (BER) performance have been studied in comparison to the optimally equalized 1X2 antenna Maximal Ratio Combining (MRC) techniques of receive diversity. The combination of linear techniques such as Zero Force (ZF) equalization methods and non-linear techniques such as Successive Interference Cancellation (SIC) shows that for BER ~10-3 there is an improvement of SNR by ~2.2 dB compared to ZF case. The combination of ZF, SIC and non-linear techniques such as optimal ordering showed further improvement in the SNR ~2dB. The combination of linear techniques such as Minimum Mean Square Equalization (MMSE) methods with SIC and optimal ordering indicates that for BER by 10-3 significant improvement in SNR ~ 5 dB over ZF case.

Keywords: *Multiplexing, MIMO, ML, QAM, MMSE, V-BLAST.*

I. INTRODUCTION

Narrowband MIMO detectors are used to reduce complexity in fast Rayleigh fading channels. MIMO techniques offer the promise of high spectral efficiency and robustness to fading. Key to their success is the MIMO detector at the receiver, whose job it is to recover the symbols that are transmitted simultaneously from multiple antennas. They are categorized into linear and non-linear receivers. Linear receivers are ZF receiver which implements matrix (pseudo)-inverse (ignores noise enhancement problems) and MMSE receiver optimizes the noise and offers a compromise between residual interference between input signals and noise enhancement [2]. Non-linear receivers are ML and SIC. ML is exhaustive optimum detection receiver uses complexity exponential in QAM. This paper coverage ranges from simple linear detectors based on the zero-forcing and MMSE criteria to the optimal maximum-likelihood detector [1]. The successive-cancellation or decision-feedback detectors are described. The performance-complexity tradeoff for a variety of detection strategies are quantified.

II. IMPLEMENTATION

A MIMO detector for detecting receive symbols, which correspond to symbols transmitted through transmit antennas from receive signals, when the transmit data transmitted by the terminal group are received through receive antennas.

A terminal identifier for identifying the receive symbols detected by the MIMO detector as symbols which correspond to respective terminals in the terminal group; a symbol de-mapper for de-mapping the receive symbols identified by the terminal identifier to binary data which correspond to a modulation method used by the terminal.

The Fig. 1 shows the probable MIMO transmission schemes with 2 transmit antennas and 2 receive antennas.

ISSN 2277 – 5528
Impact Factor- 3.145

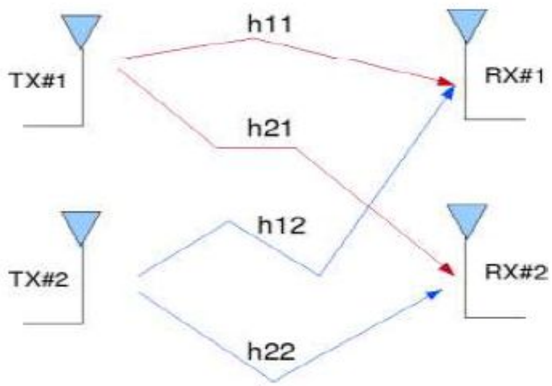

Fig. 1 Transmit 2 Receive (2×2) MIMO channel

An attempt is made to improve the bit error rate performance by trying out Successive Interference Cancellation (SIC). We will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK. To do the SIC, the receiver needs to perform the following.

Using the ZF equalization approach described above, the receiver can obtain an estimate of the two transmitted symbols *x1, x2* , i.e.

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

Take one of the estimated symbols (for example $\hat{x}_2$) and subtract its effect from the received vector y1 and y2, i.e.

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{pmatrix} y_1 - h_{1,2} & \hat{x}_2 \\ y_2 - h_{2,2} & \hat{x}_2 \end{pmatrix} = \begin{pmatrix} h_{1,1} & x_1 + n_1 \\ h_{2,1} & x_1 + n_2 \end{pmatrix}$$

Expressing in matrix notation,

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{pmatrix} h_{1,1} \\ h_{2,1} \end{pmatrix} x_1 + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix}$$

$$r = h\, x_1 + n$$

The equalized symbol is,

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

This forms the explanation for ZF Equalizer with Successive Interference Cancellation (ZF-SIC) approach.

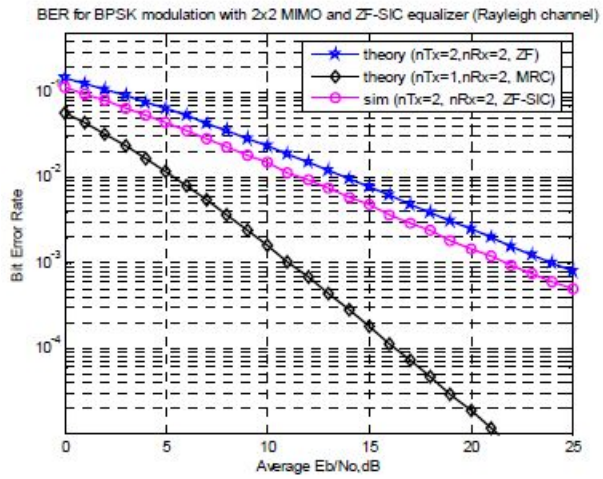

Fig. 2: BER plot for BPSK in 2×2 MIMO channel with Zero Forcing

Successive Interference Cancellation equalization

A. *MIMO with ZF-SIC and optimal ordering*

In the variant of ZF-SIC optimal ordering, assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK. Using the ZF equalization, the receiver can obtain an estimate of the two transmitted symbols *x1, x2, i*.e.

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

B. *Successive Interference Cancellation with optimal ordering*

In classical SIC, the receiver arbitrarily takes one of the estimated symbols, and subtract it effect from the received symbol y1 and y2. However, we can have more intelligence in choosing whether we should subtract the effect $\hat{x}_1$ of first or $\hat{x}_2$ first. To make that decision, let us find out the transmit symbol (after multiplication with the channel) which came at higher power at the receiver. The received power at the both the antennas corresponding to the transmitted symbol x1 is,

$$Px_1 = |h_{1,1}|^2 + |h_{2,1}|^2$$

The received power at the both the antennas corresponding to the transmitted symbol x2 is,

$$Px_1 = |h_{2,1}|^2 + |h_{2,2}|^2$$

Optimal way of combining the information from multiple copies of the received symbols in receive diversity case is to apply MRC. The equalized symbol is,

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

Doing SIC with optimal ordering ensures that the reliability of the symbol which is decoded first is guaranteed to have a lower error probability than the other symbol. This results in lowering the chances of incorrect decisions resulting in erroneous interference cancellation. Hence gives lower error rate than simple successive interference cancellation.

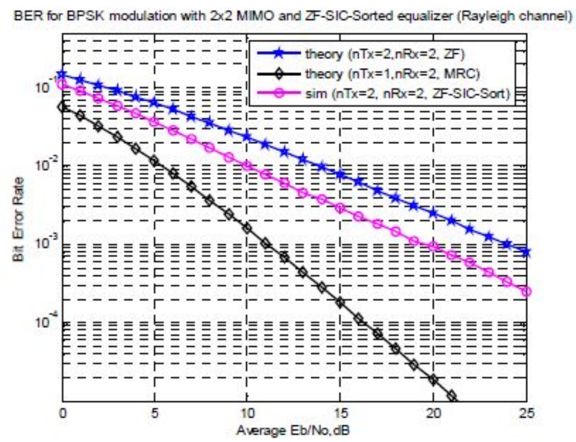

Fig. 3: BER plot for BPSK in 2×2 MIMO equalized by ZF-SIC with optimal ordering

The MIMO- ZF equalization with SIC detection is compared with optimal ordering and shown in figure 3 along with 1X2 transmit diversity scheme. It can
be seen from the figure the performance of BER decreases with the SNR in all the cases. The figure indicates that for BER of 10^{-3} the transmit diversity SNR~11 dB. For the same BER values the figure shows different SNR for the two cases. The SNR for optimal ordering is ~20 dB and for ZF-SIC the SNR ~24dB. The figure indicates that there is a marked difference in SNR > 9 dB between the transmit diversity and MIMO receiver diversity. The figure also suggests that between ZF-SIC and optimal ordering there is an improvement ~4 dB performance at BER of 10^{-3}

C. *Minimum Mean Square Error (MMSE) equalizer for 2×2 MIMO channel*

The MMSE approach tries to find a coefficient W which minimizes the criterion,

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

Solving,

$$W = \left[H^H H + N_0 I\right]^{-1} H^H$$

When comparing to the equation in ZF equalizer, apart from the No I term both the equations are comparable. When the noise term is zero, the MMSE equalizer reduces to ZF equalizer.

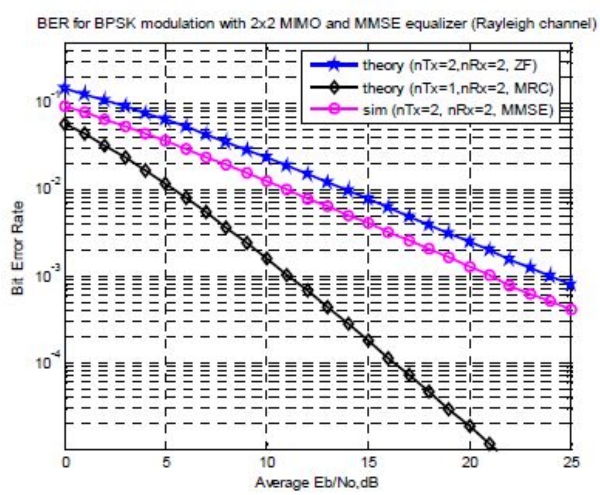

Fig.4 BER plot for 2×2 MIMO with MMSE equalization for BPSK in Rayleigh channel

ISSN 2277 – 5528
Impact Factor- 3.145

The simulated results for the MIMO - ZF equalizer and MMSE detectors are shown in figure 4 along with 1X2 transmit diversity scheme. The figure indicates that at BER of 10-3 the transmit diversity SNR ~11 dB. The figure shows that at 10-3 BER, the MMSE equalizer the SNR ~22 dB and for ZF equalizer the SNR ~ 25 dB.

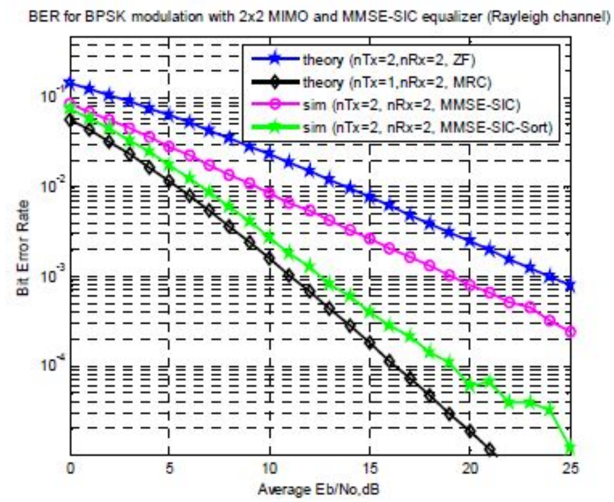

Fig. 5: BER plot for 2×2 MIMO channel with MMSE-SIC equalization with and without optimal ordering

From the above receiver structures, we saw that MMSE equalization with optimally ordered SIC gave the best performance. Here we are discussing another receiver structure called ML decoding which gives us an even better performance [6]. We will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK.

D. ***Maximum Likelihood (ML) Receiver***

The ML receiver tries to find $\hat{x}$ which minimizes

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

$$\left[\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} - \begin{pmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{pmatrix} \begin{pmatrix} \hat{x}_1 \\ \hat{x}_2 \end{pmatrix} \right]^2$$

The simulation mainly includes finding the minimum among the four possible transmit symbol combinations, based on the minimum chose the estimate of the transmit symbol and repeat for multiple values of E_b/N_0 and plot the simulation and theoretical results.

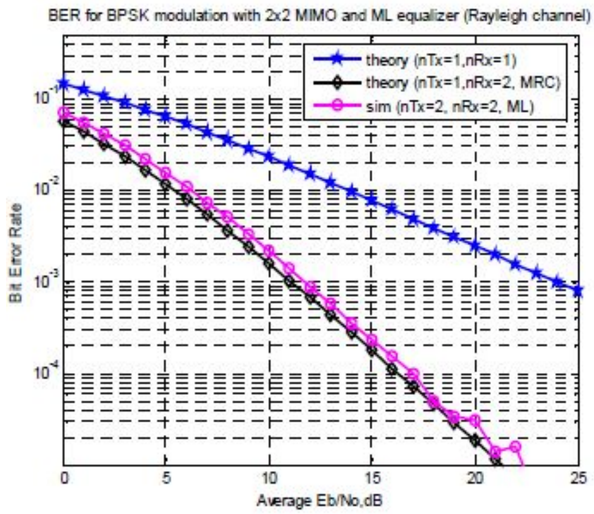

Fig.6: BER plot 2×2 MIMO Rayleigh channel with ML equalization

The figure 6 shows the BER performance for different SNR for MIMO-ML equalization detection and 1x2 transmit diversity system. The BER decreases with increase with SNR and indicates that at BER ~10^{-3}, the SNR values ~11 dB for both the cases and shows that the MIMO detection with ML equalization shows same performance as those of 1x2 transmit diversity system.

III. CONCLUSION

From the results and discussions presented above we conclude the following,

1. The combination of linear and non linear detection techniques can improve the BER performance of MIMO systems.
2. When Compared to various MIMO linear and non linear detection techniques, the maximum BER performance very close to 1x2 transmit diversity can be achieved for MIMO-Maximum Likelihood detection (ML) scheme with receiver diversity.

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