Performance Analysis of Equalization Schemes in MIMO RF Communication

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Abstract--- The wireless communication has derived to the present scenario after passing through number of stages and generation. From analog communication of 1st generation today we talk about digital communication in 4th generation, from the generation of single transmitting antenna and single receive antenna known as SISO systems, we reached the systems with multiple transmitting and multiple receiving antennas known as MIMO systems going through the systems of Multiple Transmit and single receive antenna systems known as MISO systems and Single transmit and multiple receive systems known as SIMO systems. This paper will present a study of generation from SISO systems to MIMO systems for digital communication under the research work going at Banasthali University, Rajasthan, India.

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

I. INTRODUCTION

The traditional digital communication systems involve BPSK modulation or any other modulation scheme and single transmitting and Single Receive antenna systems. Then come the SIMO systems with single transmitting antennas and multiple receiving antennas. Similar ideas are used in rake receivers for CDMA systems. Different diversity schemes were followed by the systems at the receiving end in order to equalize the receive systems. Same way when MISO systems were in use, different schemes at the transmitting end were employed in order diversifies the transmitting signal and the schemes were known as transmitting diversity schemes. When MIMO systems comes, they somehow combines the concepts from both SIMO and MISO systems and forms MIMO systems [1][2]. The basic block diagram of the wireless communication system has been shown below in the figure 1.

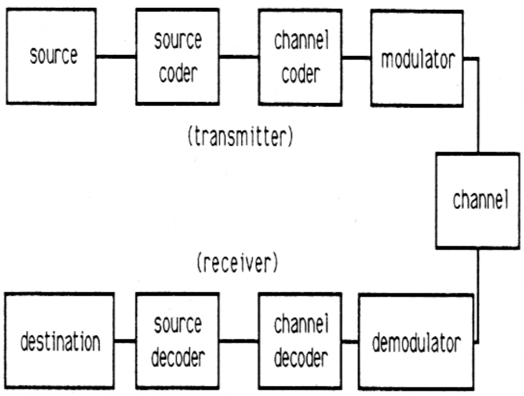


Fig. 1: Wireless Communication System

Diversity scheme in wireless communication is a method for improving the quality and correctness of a message signal in which more than one communication channels which differs in their characteristics are used. This is one important scheme to battle with co channel interference and fading of the signal because individual channels results in the different amount of interference and fading and when a signal is transmitted or received with multiple versions, it is easier to combat such issues. The concept of diversity schemes in transmitted end is first came into an existence in the landmark paper of alamouti which he published in 1998 and laid down the foundation of diversity schemes. Now diversity schemes are used in MISO, SIMO and MIMO systems [2][3][4].

II. MIMO SYSTEMS

MIMO systems involve multiple inputs and multiple outputs or the multiple transmitting antennas and multi receive antennas. This is achieved by spreading the total transmitted power over to achieve the array gain, and hence throughput of the channel increases linearly and thus increases the spectral efficiency and link reliability [7].

A. *Working of MIMO systems*

The entire working of MIMO systems can be divided into three stages:

1) Pre-coding
2) Spatial multiplexing
3) Diversity coding.

1) *Pre-coding*

It is a multi-stream beamforming. In more common terms it was supposed to be all spatial processing which occurs at the transmitter end.

2) *Spatial multiplexing*

It needs MIMO antenna configuration. In this technique a high rate signals is splited into several lower rate signals and each signal is transmitted by a different transmit antenna in a common frequency channel.

3) *Diversity Coding*

This technique is used if there is no channel knowledge at the transmitter end. In diversity methods, a single stream is transmitted, but the signal is coded using techniques called SPACE-TIME CODING.

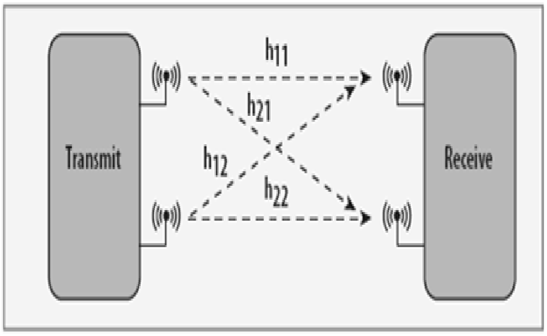


Fig. 2: MIMO Wireless Communication Systems

B. Equalization schemes for MIMO systems

In MIMO systems, equalization is done at the receiving side or at the destination end. There are three different such equalization schemes, we will introduce which are used at the receiver. They are Zero Forcing Equalizer, Minimum Mean Square Error and Maximum Likelyhood Estimator. They are briefly explained below.

1) Zero forcing (ZF) equalizer

Zero Force equalization is a linear equalization process in communication system which inverts the frequency the frequency response of the channel. ZFE restore the transmitted signal by applying the inverse of the channel to the received signal and brings down the ISI. It is a very good scheme to combat ISI when ISI is high as compared to the channel noise [11][12].

Let us define mathematical model for the system, the initial equations will remain same for the three schemes of MIMO systems we will discuss here. Let there be two signals received on antenna 1 and antenna 2, y1 and y2 respectively, h(1,1), h(1,2), h(2,1) and h(2,2) are the channel parameters showing the relation between transmitting and receive antenna as shown by the figure 5, x1 and x2 are the transmitted signals from antenna 1 and antenna 2 respectively and n1 and n2 are the noise on receiving antenna 1 and antenna 2respectively such that[12]:

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

And

$$y_1 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1} \quad h_{2,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

The above equations can be expressed in matrix form as

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

i.e. Y= Hx + n

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

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

The term,

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

$$= \begin{bmatrix} |h_{1,1}|^2 + |h_{2,1}|^2 & h_{1,1}^* h_{1,2} + h_{2,1}^* h_{2,2} \\ h_{1,2}^* h_{1,1} + h_{2,2}^* h_{2,1} & |h_{1,2}|^2 + |h_{2,2}|^2 \end{bmatrix}$$

Fig. 3: The Final matrix of ZFE

For BPSK modulation in Rayleigh fading channel, the bit error rate is derived as,

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{(E_b/N_0)}{(E_b/N_0) + 1}}\right)$$

2) Minimum Mean Square Error

Minimum mean square error (MMSE) is an estimation scheme which minimizes the mean square error and one very common method used for quality estimation. This does not remove the ISI but however it reduces or minimizes the components of noise and ISI in the output. The MMSE finds a coefficient M which minimizes criteria:

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

On solving the above criteria, the mathematical value of M comes out to be:

$$M = [H^H H + N_0 I]^{-1} H^H$$

If we compare the equation of ZFE with MMSE, both the equation seems similar apart from the term NoI that means in the absence of noise, MMSE and ZFE works similar to each other[6][13][14][15].

3) ML Equalization

The ML or maximum Likelihood equalization schemes finds out the term m, such that

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

Can be minimized. This relation can be further expresses in terms of received signal, channel parameters and m

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

As with BPSK modulation, value of x1 and x2 can be either +1 or -1, hence to find the ML solution, all the four combinations below for x1 and x2 need to be minimized[14][15][16].

$$J_{+1,+1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}\begin{bmatrix} +1 \\ +1 \end{bmatrix} \right|^2$$

$$J_{+1,-1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}\begin{bmatrix} +1 \\ -1 \end{bmatrix} \right|^2$$

$$J_{-1,+1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}\begin{bmatrix} -1 \\ +1 \end{bmatrix} \right|^2$$

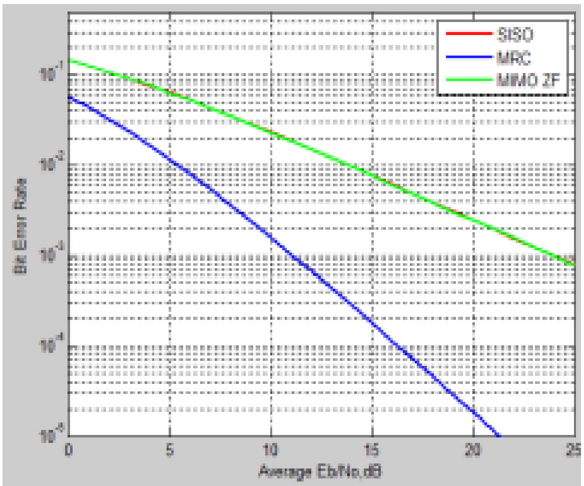
$$J_{-1,-1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}\begin{bmatrix} -1 \\ -1 \end{bmatrix} \right|^2$$

Fig. 4: Cases for ML equalization to be minimized

The estimate of the transmit symbol is chosen based on the minimum value from the above four values i.e.

- 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]

Simulation



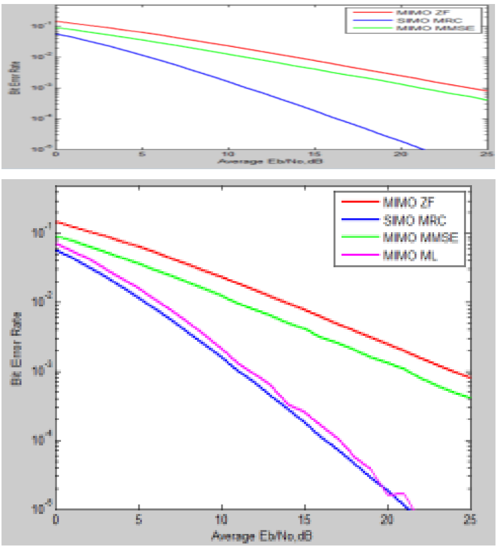


Fig. 5: MIMO with ZL Equalization

III. CONCLUSION

The paper provides a detailed review on different schemes for MIMO systems. The aim of this paper is to compare the various equalization schems ZFE, MMSE and ML schemes for the MIMO receiving end. All the three schemes have been thoroughly studied and simulated. On the simulation performance, the BER and SNR relation for ML equalization schemes is better than that of MMSE and ZFE but still, it is little poorer than MRC scheme. Further research is required to develop an equalization scheme which works better than MRC coding scheme for MIMO systems.

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