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Maximum Likelihood Equalizer with Spatial Multiplexing and QPSK Modulation in NLOS Conditions

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Abstract— ***Wireless communication is very vast and having lot of ideas for increasing capacity and BER performance of equalizers. It has shown tremendous increase in capacity with easy handling and portability. Multiple Inputs Multiple Output (MIMO) systems have recently emerged as a key technology in wireless communication systems for increasing both data rates and system performance. There are many schemes that can be applied to MIMO systems. This paper proposes a signal detector scheme called MIMO detectors to enhance the performance in MIMO channels. We have used spatial multiplexing technique along with the optimum detector (ML detector) to increase the gain and to recover the corrupted data. The ML equalizer has proved that it is optimum and provides recovery of data better than MMSE and ZF equalizers. Rayleigh fading channel with BPSK and QPSK modulation is used in this paper.***

Key Words: MIMO, Spatial Multiplexing, ML, MMSE and ZF.

1. Introduction

Wireless telecommunication, is the transfer of information between two or more points that are physically not connected. Distances can be short, as a few meters as in television remote control; or long ranging from thousands to millions of kilometers for deep-space radio communications [1]. It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistant (PDAs), and wireless networking. Other examples of wireless technology

include GPS units, Garage door openers or garage doors, wireless computer mice, keyboards and Headset (telephone/ computer), headphones, radio receivers satellite television, broadcast television and cordless telephones[2].

Wireless Communications Is Enjoying Its Fastest Growth Period In History, Due To Enabling Technologies Which Permit Widespread Deployment. Historically, Growth In The Mobile Communications Field Has Come Slowly, And Has Been Coupled Closely To Technological Improvements. The Ability To Provide Wireless Communications To An Entire Population Was Not Even Conceived Until Bell Laboratories Developed The Cellular Concept In The 1960s And 1970s. With The Development Of Highly Reliable, Miniature, Solid-State Radio Frequency Hardware In The 1970s, The Wireless Communications Era Was Born. The Recent Exponential Growth In Cellular Radio And Personal Communication Systems Throughout The World Is Directly Attributable To New Technologies Of The 1970s, Which Are Mature Today [3]. Thefuture Growth Of Consumer-Based Mobile And Portable Communication Systems Will Be Tied More Closely To Radio Spectrum Allocations And Regulatory Decisions Which Affect Or Support New Or Extended Services, As Well As To Consumer Needs And Technology Advances In The Signal Processing, Access, And Network Areas.

The Following Market Penetration Data Show How Wireless Communications In The Consumer Sector Has Grown In Popularity. Wireless Communication Is Severely Affected By The Interference Present In The Form Of Noise And Disturbances.[4] Therefore Spatial Multiplexing Is Such A Technique That Transmits Multiple Streams From The Transmitter And At The Receiver Data Are Recovered Using Different Equalizers. Optimum Equalizer Is An Equalizer That Tries Up To The Last Error To Correct. Therefore Ml Equalizer Is Used Here.

2. Equalizers

2.1 ZF-SIC

We will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK. Brief description of 2×2 MIMO transmission, assumptions on channel model and the noise are detailed in the post on Zero Forcing equalization with successive interference cancellation

[5]Let us now try to understand the math for extracting the two symbols which interfered with each other. In the first time slot, the received signal on the first receive antenna is,

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

The received signal on the second receive antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2$$

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

where, y_1, y_2 are the received symbol on the first and second antenna respectively, $h_{1,1}$ is the channel from 1^{st} transmit antenna to 1^{st} receive antenna, $h_{1,2}$ is the channel from 2^{nd} transmit antenna to 1^{st} receive antenna, $h_{2,1}$ is the channel from 1^{st} transmit antenna to 2^{nd} receive antenna, $h_{2,2}$ is the channel from 2^{nd} transmit antenna to 2^{nd} receive antenna, x_1 , x_2 are the transmitted symbols and n_1, n_2 is the noise on $1^{st}, 2^{nd}$ receive antennas.

[6]For convenience, the above equation can be represented in matrix notation as follows: Equivalently

$$y = hx + n \quad (3)$$

To solve for x , The Zero Forcing (ZF) linear detector for meeting this constraint $WH = I$. is given by,

$$W = (H^H H)^{-1} H^H \quad (4)$$

Using the Zero Forcing (ZF) equalization, the receiver can obtain an estimate of the two transmitted symbols x_1 , x_2 , i.e.

$$\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = (H^H H)^{-1} H^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \quad (5)$$

2.2. MMSE-SIC [7]

We assume that the receiver knows $h_{1,1}$ $h_{1,2}$, $h_{2,1}$ and $h_{2,2}$. The receiver also knows y_1 and y_2 . For convenience, the above equation can be represented in matrix notation as follows, equivalently,

$$Y = Hx + n \quad (6)$$

The Minimum Mean Square Error (MMSE) approach tries to find a coefficient W which minimizes the criterion,

$$E\left\{[W_y - x][W_y - x]^H\right\} \quad (7)$$

Solving,

$$W = [H^H H + N_0 I]^{-1} H^H \quad (8)$$

Using the Minimum Mean Square Error **(**MMSE**)** equalization, the receiver can obtain an estimate of the two transmitted symbols x_1 , x_2 , i.e.

$$\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = (H^H H)^{-1} H^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \quad (9)$$

2.2.1 Successive Interference Cancellation

(A) Simple

In classical Successive Interference Cancellation, the receiver arbitrarily takes one of the estimated symbols (for example the symbol transmitted in the second spatial dimension, $\hat{x}_2$), and subtract its effect from the received symbol y_1 and y_2 .

(B) with optimal ordering

However, we can have more intelligence in choosing whether we should subtract the effect of $\hat{x}_1$ 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 x_1 is,

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

The received power at the both the antennas corresponding to the transmitted symbol x_2 is,

$$Px_1 = |h_{1,2}|^2 + |h_{2,2}|^2 \qquad (11)$$

If $Px_1 > Px_2$ then the receiver decides to remove the effect of $\hat{x}_1$ from the received vector y_1 and y_2 $\hat{x}_2$. Else if $Px_1 \leq Px_2$ the receiver decides to subtract effect of $\hat{x}_2$ from the received vector y_1 and y_2, and then re-estimate $\hat{x}_1$.

2.3. ML Equalizer or Maximum Likelihood (ML) Receiver

The Maximum Likelihood receiver tries to find $\hat{x}$ which minimizes,

$$J = |y - Hx|^2 \qquad (12)$$

$$J = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \right|^2 \qquad (13)$$

Since the modulation is BPSK, the possible values of x_1 is +1 or -1 similarly x_2 also take values +1 or -1. So, to find the Maximum Likelihood solution, we need to find the minimum from the all four combinations of x_1 and x_2.[7]

$$J_{+1,+1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} +1 \\ +1 \end{bmatrix} \right|^2 \qquad (14)$$

$$J_{+1,-1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} +1 \\ -1 \end{bmatrix} \right|^2 \qquad (15)$$

$$J_{-1,+1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -1 \\ +1 \end{bmatrix} \right|^2 \qquad (16)$$

$$J_{-1,-1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -1 \\ -1 \end{bmatrix} \right|^2 \qquad (17)$$

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 $J_{-1,+1} = [0\ 1]$ and if the minimum is $J_{-1,-1} = [0\ 0]$.

3. Simulation Results and Discussion

From the simulation of single input single output antenna system at the transmitter and receiver with the Binary phase shift keying modulation and with MMSE, ML, ZF, equalizers and using spatial multiplexing technique we find that the performance of considered equalizers show the same performance. Therefore there must be some modification in antenna strategy to improve the performance of the considered equalizers

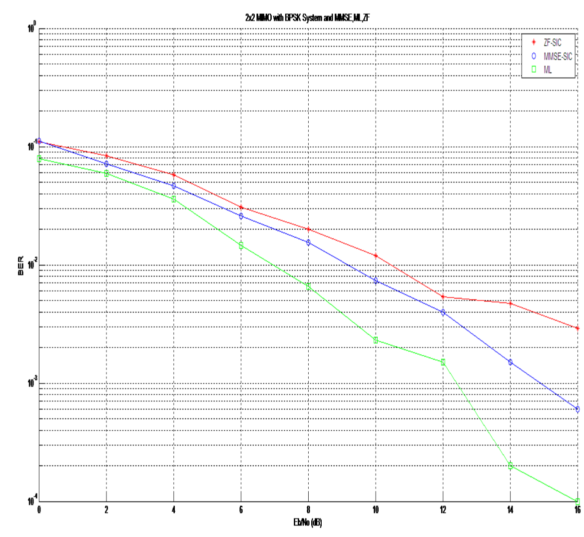

Figure 1: 2x2 MIMO with BPSK system and MMSE, ML, ZF

Now if we consider MIMO system at the transmitter and receiver with 2 transmitting antennas at the transmitter and 2 receiving antennas at the receiver we get drastic change in the performance of different equalizers. Therefore we are now able to distinguish among the performance of equalizers. The ZF equalizer is considered as the basic equalizer and its role is to detect the errors as well as correct the errors. That means we are able to get the performance of ZF equalizer up to some extent. And ZF appears to be the low performer among considered equalizers. While ML equalizer shows the high gain also in comparison with MMSE equalizer and the approximate gain achieved using spatial multiplexing is still not so high because the modulation technique is BPSK, can be seen from the above figure no: 1

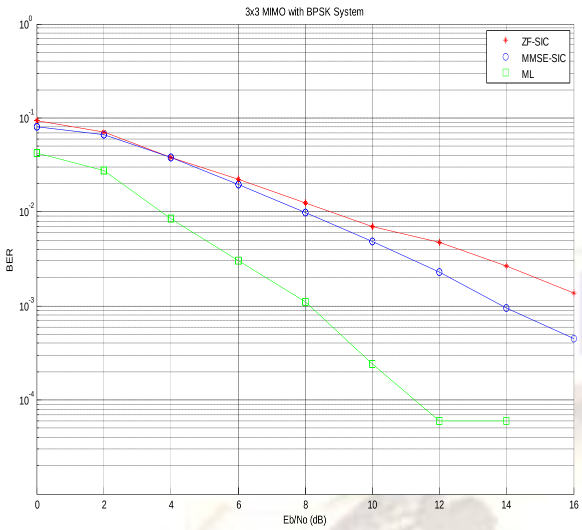

Figure 2: 3x3 MIMO with BPSK System

Let us now change the MIMO strategy by considering 3 transmit and 3 receive antennas at the receiver. More better performance of ML equalizer is achieved in this case in comparison with the MMSE and ZF equalizers, as visible from above figure no. 2

If we consider the MIMO technique at the transmitter and at the receiver then we can improve the error correction capabilities as well as the performance of the considered equalizers. In the following figure no. 3, with 2 transmit and 2 receive antennas and with QPSK modulation and with the spatial multiplexing technique we find the better response. Here we also find that the ML equalizer is showing very good performance in comparison with the MMSE and ZF equalizers. But we have to wait for one hour to get complete simulation of this code.

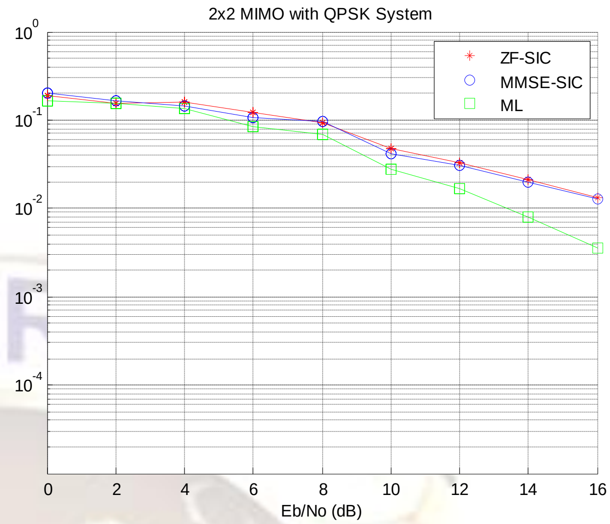

Figure 3 2x2 MIMO with QPSK and MMSE, ML, ZF (Simulation time 1 hour)

A drastic improvement in the gain can be achieved if we increase the number of antennas at the transmitter and at the receiver. Let us consider 3 transmit and 3 receive antennas at the transmitter and at the receiver. (figure 4) Better performance and higher error correction is possible by using ML equalizer in comparison with the other considered equalizers. Now we have to keep passion for the simulation of this code because it will take around 6 hours of time.

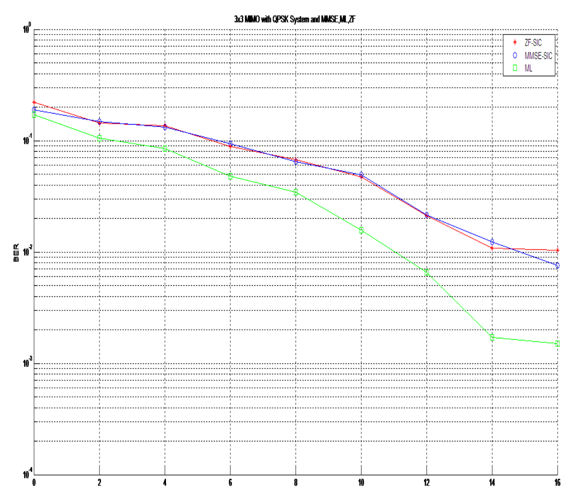

Figure 4 3x3 MIMO with QPSK and MMSE, ML, ZF (Simulation time 6 hours)

4. Conclusion

Spatial Multiplexing schemes provide a multiplexing gain and do not require explicit orthogonalization as needed for space-time block coding. The paper compared two nonlinear interference cancellation methods Zero Forcing and Minimum-Mean-Square-Error with symbol cancellation and compares their performance with the

Maximum Likelihood optimum receiver.

We have used two modulation schemes- first BPSK and second QPSK. Three equalizers we considered in our thesis are ZF, MMSE and ML. The ZF equalizer is simple and always considered as reference with the other equalizers. The other equalizer is the MMSE equalizer, is best among other equalizers. The third equalizer is the ML equalizer that is optimum equalizer with high complexity and high error detection and correction capabilities.

From the above simulation results and discussion we conclude that data recovery is much important then the time therefore spatial multiplexing techniques with QPSK modulation are suitable for high gain and for higher performance as compared to BPSK.

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