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Data Recovery Using ML Equalizer in NLOS Communication Environment

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Abstract— ***Wireless communication has become very important in this world due to easy handling of equipments and installation of operating software's. The capacity and gain of these equipments depend on the channel conditions therefore we have to take care of channel noise, delay, gain, signal propagation and processing equipments. At the receiving end, receiver is responsible in inverting the effect of channel, therefore equalizers are required. A single input single output antenna system at the transmitter and receiver cannot show the better recovery of original transmitted data sequence, therefore we need multiple inputs multiple output antenna systems in our equipment. We have used different equalizers to improve the BER performance at the receiver and also the QPSK modulation is used at the transmitter. The spatial multiplexing has shown very good performance at the receiver and improves the gain of our system however complexity of the algorithm returned in time consumption. Finally the optimum performance is achieved by maximum likelihood equalizer.***

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

1. Introduction

Wireless communications is one of the most active areas of technology development of our time. This development is being driven primarily by the transformation of what has been largely a medium for supporting voice telephony into a medium for supporting other services, such as the transmission of video, images, text, and data. Thus, similar to the developments in wire line capacity in the 1990s, the demand for new wireless capacity is growing at a very rapid pace. Although there are, of course, still a great many technical problems to be solved in wire line communications, demands for additional wire line capacity can be fulfilled largely with the addition of new private infrastructure, such as additional optical fiber, routers, switches, and so on. On the other hand, the traditional resources that have been used to add capacity to wireless systems are radio bandwidth and transmitter power [1], [2]. Unfortunately, these two resources are among the most severely limited in the deployment of modern wireless networks: radio bandwidth because of the very tight situation with regard to useful radio spectrum, and transmitter power because mobile and other portable services require the use of battery power, which is limited. These two resources are simply not growing or improving at rates that can support anticipated demands for wireless capacity. On the other hand, one resource that is growing at a very rapid rate is that of processing power. Given these circumstances, there has been considerable research effort in recent years aimed at developing new wireless capacity through the deployment of greater intelligence in wireless networks. A key aspect of this movement has been the development of novel signal transmission techniques and advanced receiver signal processing methods that allow for significant increases in wireless capacity without attendant increases in bandwidth or power requirements [3].

Multipath fading is the biggest problem of these wireless scenarios. The fading will decrease the power level per bit because of the interference mixed due to channel. Therefore the processing time of these bits will get increased and also the equipments will be ready for the additional time [4].

These fading effects can be controlled or balanced by using the proper equalizer and the algorithms to recover the original transmitted sequence.

We are using spatial multiplexing to increase capacity of the system and its effects will improve the gain and saving of the bandwidth.

The optimum equalizer is one which uses viterbi algorithm to recover or refine the bit patterns received. Therefore based on the property of maximum likelihood, we have to wait for the recovery of each correct symbol [5], [6].

2. Equalizers

2.1 ZF-SIC

We will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is QPSK. 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

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,

$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1$

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

the received signal on the second receive antenna is,

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

$= [h_{2,1} h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$ (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[7]. For convenience, the above equation can be represented in matrix notation as follows: Equivalently,

$Y = Hx + n$ (3)

To solve for x, The Zero Forcing (ZF) linear detector for meeting this constraint

$WH = I$. Is given by,

$W = [H^H H + N_0 I]^{-1} H^H$ (4) Using the Zero Forcing (ZF) equalization, the receiver can obtain an estimate of the two transmitted symbols x_1, x_2 i.e.

$\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = [H^H H + N_0 I]^{-1} H^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$ (5)

2.2 MMSE-SIC

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,

$y = hx + n$ (6)

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

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

Solving,

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

$\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = [H^H H + N_0 I]^{-1} H^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$ (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 $\hat{x}_1$ is,

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

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

$Px_2 = |h_{1,2}|^2 + |h_{2,2}|^2$ (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. 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 $\hat{x}_1$ [8].

2.3 Maximum Likelihood (ML) Receiver

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

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

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

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.

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

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

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

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

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 $J_{-1,-1} = [0\ 0]$ Based on above discussion we can modify equations for 4-PSK or QPSK.

3. Spatial Multiplexing

Spatial multiplexing is a transmission technique in MIMO wireless communication to transmit independent and separately encoded data signals, so-called streams, from each of the multiple transmit antennas. Therefore, the space dimension is reused, or multiplexed, more than one time.

If the transmitter is equipped with N_t antennas and the receiver has N_r antennas, the maximum spatial multiplexing order (the number of streams) is

$$N_s = \min(N_t - N_r) \quad (18)$$

if a linear receiver is used. This means that N_s streams can be transmitted in parallel, ideally leading to an N_s increase of the spectral efficiency (the number of bits per second and per Hz that can be transmitted over the wireless channel)[9].

4. Simulation Results

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. 1, 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.

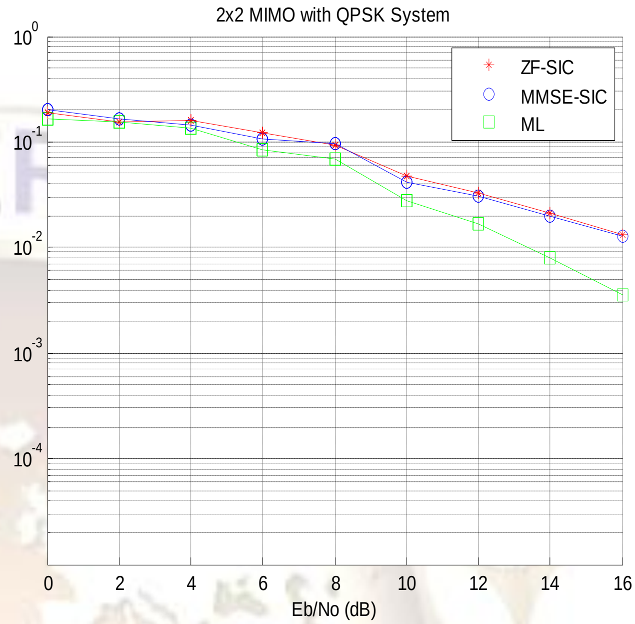

Figure 1: 2x2 MIMO with QPSK and MMSE, ML, ZF (Simulation time 1 hour)

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. 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. Now let us again think about the recovery of data, if correction of the data is very important then we can again increase the size of MIMO, see figure no 2.

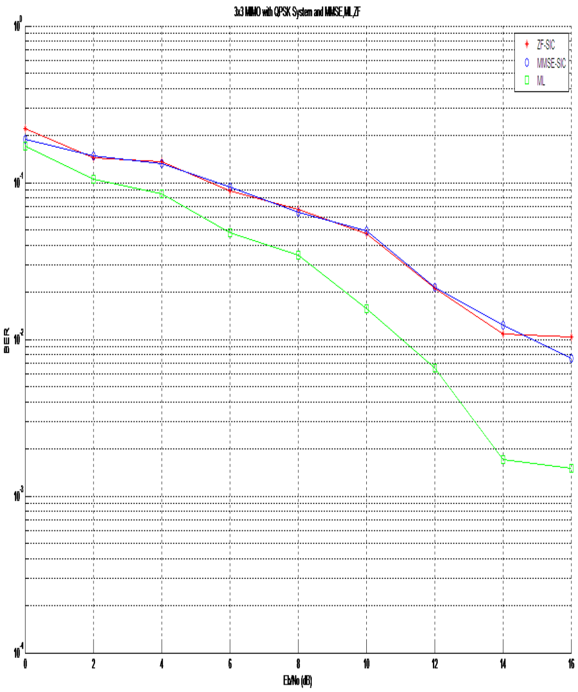

Figure 2: 3x3 MIMO with QPSK and MMSE, ML, ZF (Simulation time 6 hours)

Let us now consider 4 transmit and receive antennas at the transmitter and at the receiver. Keep passion and wait for minimum of 15 hours on latest system configuration with 4GB RAM and minimum I3 processor. Here we achieve very high gain and good error performance of ML equalizer with spatial multiplexing technique. Around 6db of gain is achieved by ML equalizer. Therefore we may state that the ML equalizer is the optimum performer and very good in correcting errors. Please see the following figure no.3

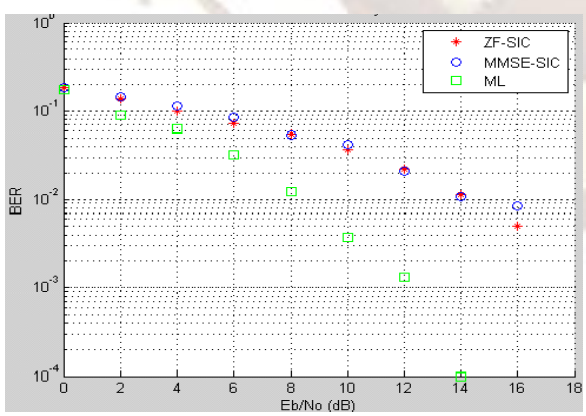

Figure 3: 4x4 MIMO with QPSK and MMSE, ML, ZF (Simulation time 15 hours)

5. Conclusion

MIMO along with the spatial multiplexing is wonderful because it improves the capacity and also the gain of the receiver. Therefore the system can recover the original symbols or bits transmitted from the transmitter using wireless channel.

The MMSE, ZF and ML equalizers are the equalizers having correct capabilities and complexities. MMSE equalizer is the most preferred one in communication. But the recovery of the images and original data is also important. The ML Equalizer is one such equalizer which has showed the optimum performance in recovery of such corrupted images and data.

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.

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.

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