Wireless Detections in MIMO System

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Abstract – Multiple-Input Multiple-Output (MIMO) communication technology has received a significant attention in the area of wireless communication systems. MIMO provide reliable transmission and increasing data rate than traditional single input single output system. Increasing the number of transmit or receive antennas increases channel throughput. In this paper linear and non-linear detection techniques are analyzed. The linear detection techniques such as Zero Forcing (ZF) Minimum Mean Square Error (MMSE) are tested and results are analyzed. In linear MIMO wireless detection schemes, pre-coding at the transmitter is provided. It is observed that this detection scheme is sensitive to the impact of spatial correlation caused by mutual coupling between antenna elements and the spatial propagation conditions of the wireless channel. Also, the non-linear MIMO wireless detection techniques which include Maximum Likelihood (ML), Minimum Mean Square Error-Successive Interference Cancellation (MMSE-SIC) are tested and results are analyzed. The results depicts how to apply non-linear detection, which can help mitigating the impact of correlated signals, in a closed-loop MIMO system and compare the average rates achieved with different detection schemes.

Keywords: MIMO, Wireless detections, MMSE, Zero-Forcing, Maximum Likelihood, MMSE-SIC, Wireless communication.

I. Introduction

Wireless communication system uses antennas on transmitter and receiver side for transmission of radio waves. The frequency spectrum is the scarce resource for wireless communication systems and the rapid increase of wireless applications has demanded the new techniques to achieve higher spectral efficiency. The availability of spectrum has been an influential factor impeding a rapid and efficient convergence of technologies.

The multiple-input multiple-output (MIMO) system utilizes the spatial diversity to increase the data rate and spectral efficiency. MIMO is considered to be the potential solution in combating the challenges of bandwidth constraints and high data rate demands. MIMO systems are regarded as one of the most promising research areas of wireless communications. This is due to the fact that a MIMO channel can offer a significant capacity gain over a traditional Single Input Single Output (SISO) channel. This provides a fundamental limit on data throughput in MIMO systems. MIMO systems improve data transmission reliability without increasing transmits power and bandwidth. The spatial diversity obtained from transmit and receive antennas can be combined with channel coding. This combined process leads to space-time coding in a coded system [1].

MIMO Detectors

MIMO detectors consist of different linear and non-linear detections techniques which include:

a) Zero Forcing (ZF)

Zero Forcing (ZF) is a linear detection method which treats all the transmitted signals as interferences except for the desired stream from the target transmit antenna. Therefore, interference signals from other transmit antennas are minimized or nullified in the course of detecting the desired signal from the target transmit antenna. ZF receiver works...
best with high SNR level. Zero forcing method is based on the calculation of pseudo inverse of channel matrix $H$ i.e. facilitate the detection of desired signals from each antenna, the effect of the channel is inverted by a weight matrix $W$ [3] [8]. In simple form,

$$Y = HX + N$$

To solve the ‘$X$’ the weight matrix $W$ is to solved out which satisfies $WH=I$. The Zero Forcing (ZF) linear detector for $d$ antennas got more to consider $|M|$ transmitted symbols are received power at the transmitted symbols are

$$W = (H^HT + N_0I)^{-1}H^H$$

Where, $H^H$ is the Hermitian transpose.

b) MMSE Signal Detection

Minimum Mean Square Error (MMSE) is linear detection method in which mean squared error (MSE) is minimized between the transmitted signals. MMSE equalizer does not usually eliminate ISI completely but, minimizes the total power of the noise and ISI components in the output [3]. In order to obtain the unknown transmitted signal MMSE use a weight matrix given by $W = (H^HT + N_0I)^{-1}H^H$…………………………(3)

where $I$ is the identity matrix.

In the classical approach, the Minimum Variance Unbiased Estimator (MVUE) is derived by first considering minimization of the mean square error i.e., $\hat{\theta}_1 = \arg\min\theta\ m\se(\theta)$ where:

$$m\se(\theta) = E[|\theta_1 - \theta|^2] = \int (\theta_1 - \theta)^2 p(\theta; \theta) \, d\theta$$

and $p(\theta; \theta)$ is the PDF of $\theta$ parameterized by $\theta$.

c) MMSE-SIC Signal Detection

Minimum Mean Square Error Successive Interference Cancellation (MMSE-SIC) is signal detection method where weight matrix is used same as linear detector MMSE. The receiver can obtained an estimate of the two transmitted symbol $x_1$, $x_2$ as:

$$\hat{x}_1 = (H^HT + N_0I)^{-1}H^H y$$

This method is similar to that of ZF-SIC except the weight matrix used to identify the unknown transmitted symbols. In classical SIC an approach, the receiver arbitrarily takes one of the estimated symbols and subtracts its effect from the received symbols. Instead of choosing random estimated symbols, another intelligent way is optimal ordering in which received power at the transmitted symbols are determined [3] [8].

d) ML Signal Detection

Maximum Likelihood (ML) is optimal decoding method that compares between the received signal and possible transmitted signal. As the transmitted signal is modified by channel matrix, we need to estimate transmit symbol by using maximum likelihood detection algorithm.

$$\hat{x} = \arg\min x \in \{x_1, x_2, \ldots, x_N\} ||r - Hx||^2$$

Where $||r - Hx||^2$ is ML metric which achieve maximum performance when transmitted vectors are equally likely [1],[4]. $r$ be the received signal and $h$ be the channel matrix. Since the receiver has to consider $|M|^{nTX}$ possible symbols so it has complexity issues as the number of transmitter increases. Here $M$ defines the ‘modulation constellation’ and $nTX$ defines the no of transmitted antenna system. For example $2 \times 2$ MIMO system and QPSK system, the total possible symbol is 16.

II. Related Work

Several research works have already been done and many research papers have been published regarding detection algorithms. Since, each of the papers has focused on different detection technique being implemented in MIMO with their resulted output in simulation tools as well. However, the comparative analysis is very rare and proposed research is crucial in today’s time in order get the de-facto standard for efficient detection techniques implementation. Some of the related works that are closely related to proposed work are highlighted below along with their scope of research.

The research work done by Xiaoqing Peng, Weimin Wu, Jun Sun, and Yingzhuang Liu [1] put forward about the detection of symbols via compressive sensing algorithms, to reduce the original MIMO system to a new one, whose input dimension is much less than the output dimension. Also, the research done by Max Scharrenbroich, Michael Zatman and et.al [2] explain about non-linear detection and requires a prior knowledge of the target SNR and it depicts more result for the stationary case only. Similarly, the research completed by Gurpreet Singh, Rahul Vij and Priyanka Mishra[3] put an approach for spatial multiplexing technique with various decoding techniques got more optimal result specifically for $1 \times 4$ antennas. Besides, the result obtained by Shreedhar. A. Joshi Dr. Rukmini T S, Dr. Mahesh H M[4] on V-BLAST technique with MIMO exhibits better bit error rates.
**III. Methodology**

This chapter deals with the explanation of observed system model. Here, the binary data generator generates the random binary data with equal probability of being 1 and 0. The binary data are created as they were easy to analyze, and they are matched to the real digital communication world. The encoder encodes the data using the Convolution Encoder. If the encoder takes \( k \) input bit streams (that is, it can receive \( 2^k \) possible input symbols), the block input vector length is \( L*k \) for some positive integer \( L \). To solve the problem, systematic steps are needed which is better to explain in the flow chart form:

![Flowchart of the system](image)

**IV. Simulation Results and Discussions**

To verify the proposed method, MATLAB simulation is done. Parameters which are necessary for the simulation are taken from the standards in the MIMO communication system. The simulation results are obtained, after the MATLAB programming by using the parameters as shown below:

**Table 1: Simulation Parameters**

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of bits</td>
<td>( 10^6 )</td>
</tr>
<tr>
<td>Encoder</td>
<td>Convolutional Encoder</td>
</tr>
<tr>
<td>MIMO configuration</td>
<td>2x2</td>
</tr>
<tr>
<td>Modulation type</td>
<td>QPSK</td>
</tr>
<tr>
<td>No. of transmitter/ receiver</td>
<td>2</td>
</tr>
<tr>
<td>Channel</td>
<td>Rayleigh, Rician fading channels</td>
</tr>
<tr>
<td>Noise type</td>
<td>AWGN</td>
</tr>
<tr>
<td>Detection Scheme</td>
<td>ZF, MMSE,ML and MMSE-SIC</td>
</tr>
</tbody>
</table>

The fig. 3 shows that the capacity of channel increases as the value of SNR increases i.e. lower most line has lowest capacity compared to other. Although the capacity increases as the value of SNR increases (here from 2 to 20), it is least compared to MIMO system which has 2x2, 3x3 or 4x4 antennas. SNR value 18dB corresponds to the capacity of 6 bit/Sec/Hz for SISO, but for the same SNR value the capacity for \([2 \times 2], [3 \times 3], \text{and} [4 \times 4] \) antennas are 10.5, 15.5 and 21 respectively. It can be analyzed that for the fixed SNR the capacity of system increases as the number of antennas increases. From this it can be said that any system can increase its channel capacity by increasing the number of antennas at both transmitter and receiver side without increasing SNR value.
ZF detection algorithm for MIMO is the most simple and basic algorithm, and the basic idea of ZF algorithm is kept of MIMO-channel interference by multiplying received signal and the inverse matrix of channel matrix.

Here, over Rayleigh channel for $10^{-2}$ BER, there exist 12 dB of SNR value of ZF detection technique as in fig. 4. The fig. 5 depicts the MIMO case of 2x2 in the Rician fading channel using ZF as a linear detecting technique.

The simulated results with a 2x2 MIMO system using QPSK modulation in Rayleigh/Rician fading channel shows matching results as obtained in for a 1x1 system for same modulation in Rayleigh/Rician channel. The ZF equalizer helps us to achieve the data rate gain, but not take advantage of diversity gain (as there is two receiving antennas). It might not be able to achieve the two fold data rate improvement here.

A MMSE estimator is a method in which it minimizes the mean square error (MSE), which is a universal measure of estimator quality. The most important characteristic of MMSE equalizer is that it does not usually eliminate ISI totally but instead it minimizes the total power of the noise and ISI components in the output.
The fig. 8 is the case of 2x2 MIMO, which uses the MMSE equalizer at the receiver. This depicts the analysis of various cases, performance, and comparison of the simulated and theoretical bit error rate of the MMSE with that of the ZF.

In fig. 9, for $10^{-2}$ BER there is 5.8 dB of SNR for ML equalizer for Rayleigh Channel. In fig. 10 for $10^{-2}$ BER, there is 7.5dB of SNR. Comparing the results of ML and MMSE-SIC of Rayleigh fading channel for same BER i.e. $10^{-2}$, SNR of MMSE-SIC gets improved than that of ML signal detection. The result of fig.10 is obtained after average of 10 times of MATAB simulation for MMSE-SIC.

In fig. 11, for $10^{-2}$ BER there is 8 dB of SNR for MMSE-SIC Rayleigh of 2X2 MIMO with QPSK Modulation.

This shows that the performance of the MMSE is highly impressive compared to that of the ZF. Equalization techniques can combat for ISI even in mobile fading channel with high efficiency. MMSE equalizer uses LMS to compensate ISI. The MMSE equalizer results in around 3dB of improvement when compared with Zero Forcing equalizer. From the simulation result as shown in fig. 8, it can be summarized that, ZF equalization in addition of noise gets boosted up and thus spoils the overall signal to noise ratio. Hence it is considered good to a receiver under noise free conditions. The multiple antennas are used to increase data rates through multiple antennas to improve performance through diversity. This technique offers higher capacity to wireless systems and the capacity increases linearly with the number of antennas and link range without additional bandwidth and power requirements.

The SNR is 0.5 dB more in MMSE-SIC of Rician Fading. The result of fig. 11 is obtained after average of 8 times of MATAB simulation.
V. Conclusion and Future Work

Conclusion:
The Rician channel has the good SNR value than the Rayleigh in all detections and in varying configuration of the MIMO system. MMSE-SIC is much better than MMSE. It can be concluded that wireless MIMO receiver with ML detection has the least BER for a given SNR and ZF detector has a greater BER. Also, the simulation results obtained shows that by combining SIC with MMSE provide better BER performance characteristics than normal receiver consisting simple MMSE or ZF respectively. And, MMSE-SIC provides better overall system performance than MMSE, ZF and ML the increasing diversity order.

Future Work
The different modulation schemes and antenna configurations can be used to analyze the performance of the MIMO system. Detections techniques can be used for designing of adaptive channel estimation with beam forming antenna and MIMO-OFDM.

References

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