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Research paper

Performance of MIMO detection techniques with spatial multiplexing

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Abstract

MIMO system plays a vital role in the field of wireless communications due to the high data rates with spatial multiplexing operation and increased reliability with space time coding. It can be employed for a variety of standards such as 802.11n(modern Wi-Fi Routers),802.16e(Wi-Max), LTE (4G) etc. The major challenge to exploit the full potential of MIMO systems, is in the design of a detection scheme with high throughput and low complexity. In this paper, various liner and non linear MIMO detection schemes that have optimal spectral efficiency with enhanced reliability of wireless links were studied. Out of all these schemes, Maximum Likelihood detection has optimal performance theoretically. However, ML detection is practically infeasible particularly for high dimensional MIMO systems with higher order modulation schemes. Linear detection algorithms such as ZF,MMSE and SIC can reduce the computational complexity very much compared to ML but have poor BER performance. Simulation results shows the BER performance of Linear MIMO detection schemes with various modulation schemes.

Keywords: *MIMO; ZF; MMSE; ML and BER.*

1. Introduction

Wireless communications has become one of the fastest growing markets worldwide[1]. Several technical challenges were raised with the development of mobile wireless devices such as real time teleconferences, online-video games and streaming of videos. Hence, the modern wireless standards such as 802.16e(Wi-Max) [2] and LTE-A [3] were extensively studied. However, existed systems requires a high QoS (i.e reliable links with higher throughputs).

Linear detectors cannot exploit the full potential of receive diversity for spatial multiplexing operation. However, SIC based detectors only realize the coding gain [15], [16]. As, ML detectors are practically infeasible, sphere decoders were investigated in depth to exploit the full potential of MIMO systems and achieved the optimum tradeoff between BER performance and computational complexity. Several decades multi antenna systems have been studied and have capability to provide higher spectral efficiency with improved reliability. Many wireless standards adopted the MIMO systems successfully in several countries and achieved the higher spectral efficiencies. In this section, MIMO system with spatial multiplexing operation with various linear detection schemes were discussed. These MIMO systems provides higher data rates by simultaneously transmitting independent data bits through multiple transmitting antennas. Thus, a high capacity MIMO channels may be achieved with SM operation.

Rest of this paper is organized as follows: MIMO system model and related detection algorithms were introduced in section-II. In section III, simulation results were presented and in section IV, concluding remarks are given.

2. MIMO system model & detection schemes

MIMO system with four transmit antennas (i.e N_t =4) and four receive antennas (i.e N_r= 4) is considered in Fig.1. . The system can be modeled as

$$y = Hs + n \tag{1}$$

Where

$y = [y_1, y_2 .... y_{N_r}]^T$ Denotes the received signal vector of dimension (Nr x 1), $s = [s_1, s_2 .... s_{N_t}]^T$ denotes the transmitted signal vector of dimension (Nt x1), H denotes the frequency flat fading channel matrix of the dimension (Nr x Nt) and $n = [n_1, n_2 .... n_{N_r}]^T$ denotes AWGN vector with zero mean circular symmetric complex Gaussian of dimension (Nr x1).

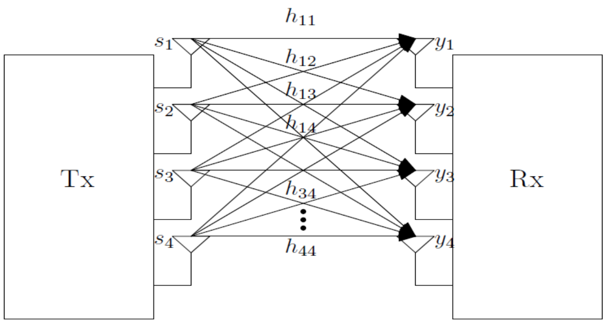

Fig. 1: 4xfour MIMO System Model.

3. ZF Detection

It is the simplest one among all the MIMO detection algorithms. Which applies, inverse of the frequency response of the channel to the received signal. Thus the combination of the channel and ZF detector gives a flat frequency response with linear phase. It can be implemented by following expression.

$$W_{ZF} = \left(H^H H\right)^{-1} H^H \quad (2)$$

Therefore, symbol estimation using ZF detection is given as

$$\hat{s}_{ZF} = W_{ZF}\, y = s + \left(H^H H\right)^{-1} H^H n = s + \tilde{n}_{ZF} \quad (3)$$

From the equation (3), it is obvious that error performance of ZF detector is directly related to $\hat{s}_{ZF}$.

Post detection noise power using SVD can be evaluated as

$$E\left\{\left\|\tilde{n}_{zF}\right\|^2\right\} = \sum_{i=1}^{N_t} \frac{\sigma_z^2}{\sigma_i^2} \quad (4)$$

Where

σ_i^2 represents the equivalent signal power at the receiver of ith transmit antenna. When this parameter becomes small, noise component will be enhanced, thereby decreasing the performance. However ZF algorithm removes the effect of the ISI from the received signal. So that which is ideal when channel is noiseless. It removes the co channel interference.

In subsequent section, linear MMSE detection will be presented which reduces the enhancement of noise by adopting statistical information of noise.

4. MMSE detection

This algorithm suppresses the total power of both interference and noise components in the output, hence improves the SINR. In order to maximize the post detection SINR, the MMSE filter matrix is given as

$$W_{MMSE} = (H^H H + \sigma_z^2 I)^{-1} H^H \quad (5)$$

By using above weight matrix , the expression for output of MMSE detector will be given as

$$\hat{s}_{MMSE} = W_{MMSE}\, y = \left(H^H H + \sigma_z{}^2 I\right)^{-1} H^H y$$

$$= \tilde{s} + \left(H^H H + \sigma_z{}^2 I\right)^{-1} H^H z$$

$$\hat{s}_{MMSE} = \tilde{s} + \hat{z}_{MMSE} \quad (6)$$

The post detection noise power of MMSE detector using SVD is given as

$$E\left\{\left\|\hat{z}_{MMSE}\right\|_2^2\right\} = \sum_{i=1}^{N_t} \frac{\sigma_z^2 \sigma_i^2}{(\sigma_z^2 + \sigma_i^2)^2} \quad (7)$$

From the above equation. [7] it is obvious that effect of noise is very much reduced. However, in the course of filtering , when the channel matrix is large, enhancement of noise is significant. Anyhow, effect of noise enhancement in MMSE filtering is less critical than ZF filtering.

5. SIC detection

SIC technique was initially adopted by V-BLAST system. In contrast to the linear detectors such as ZF and MMSE, this algorithm detects the received streams sequentially. Accordingly at first it chooses the largest SNR sub stream for detection then removes the interference of each detected stream, before continuing the detection process. That means, SIC detection process similar to the ZF detection. However streams are processed sequentially one after another. This allows slicing the estimate $\hat{y}_i$ to $\hat{s}_i$ immediately after it's computation. Using this result, it's influence on the subsequent stream will be nullified. So that once a data stream is successfully recovered it can be subtracted from the received vector and hence reduces the burden on the receivers of the remaining data streams. (5). SIC can be visualized as a single tree traversal from top to bottom and always selects the node with smallest PED. The symbol vector leaving to the leaf node is referred to as SIC estimate. SIC performance is superior than ZF and MMSE detection. An alternative detection approach is nulling and cancellation based on linear estimation methods, can be divided into two categories such as Parallel Interference Cancellation and Successive Interference Cancellation. ZF with SIC detects the data stream s_1(m) and then subtract it from received vector. ALL other ZF with SIC detectors treat all other data steams as interference. This process continues until the final ZF detector does not have to deal with any interference from other data streams.

The conventional SIC algorithm can be given by following expression.

$$y_k = y - \sum_{j=1}^{k-1} h_j \hat{s}_j \quad (8)$$

Where

y_k Represents the received symbols after the (k-1) th cancellation, subscript k gives kth cancellation order, hj represents jth column of vector H. The MMSE detection (for kth data stream) can be given as

$$W_k = (H_{\bar{k}}{}^H \, \mathrm{H}_{\bar{k}} + \sigma_z^2 \, \mathrm{I})^{-1} \quad (9)$$

Where

$H_{\bar{k}}$ gives remaining columns of H after (k-1)th cancellation. Therefore, the expression for estimated stream from the transmitting antenna(kth) is

$$\hat{s}_k = W_k\, y_k \quad (10)$$

Where

W_k represents the kth row vector of MMSE matrix in the expression (9).

6. ML detection

ML detection is optimal detection technique among all other algorithms, which exploits the full potential of MIMO communication systems., due to it's exhaustive search. It estimates the transmit signal vector S , as per the Maximum likelihood principle, where the received vector is compared with entire possible transmit vector s and selects a lattice point that is closest to the received signal will be estimated as optimal solution ($\hat{s}$). Hence it has optimal performance among all MIMO detection algorithms. Mathematical model for ML detection can be expressed as

$$\hat{s}_{ML} = \arg.\min_{s \in M^{N_t}} \left\| y - Hs \right\|_2^2 \quad (11)$$

Where

M denotes constellation size, N_t denotes No. of transmit antennas and M^{N_t} denotes total possible transmit vectors. However practically ML detection is almost infeasible due to its exhaustive search, particularly for high dimensional MIMO systems with higher order modulation schemes. That means complexity increases exponentially w.r.t no. of transmit antennas and order of modulation.

7. Simulation results

BER performance of SIC detection for 4x4 MIMO systems with 8 PSK using different ordering techniques is shown in Fig.2. A plot for MMSE detection can be used as a reference to compare its performance with SIC detection also shown in Fig.2. Performance of SIC detection can be enhanced with SINR ordering technique at the cost of implementation computational complexity. However, this technique may be infeasible with high dimensional MIMO systems. On the other hand SIC detection with channel norm based ordering focused only on the transmitted powers instead of considering SINR. That means, for detection it can choose a signal with max. norm among different transmit antennas. Hence complexity of such ordering can be less at the cost of performance degradation. However, SINR ordering has superior performance particularly with 4x4 MIMO system with 8PSK modulation.

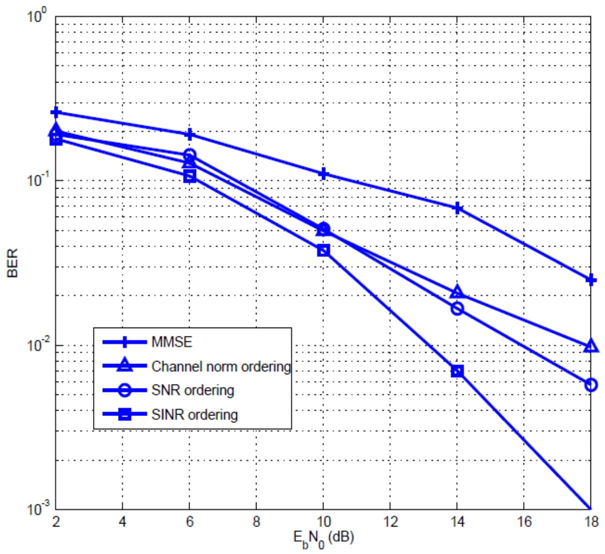

Fig. 2:.BER Performance of SIC Detection for 4x4 MIMO with Different Ordering Techniques Using eight PSK.

BER performance of Linear and non linear detection techniques such as MMSE, SIC and ML respectively for 4x4 MIMO using 16-QAM can be shown in Fig.3. Out of all MIMO detection algorithms, ML detection outperforms as shown in Fig.4. However, it's complexity increases exponentially with order of modulation and No. of antennas.

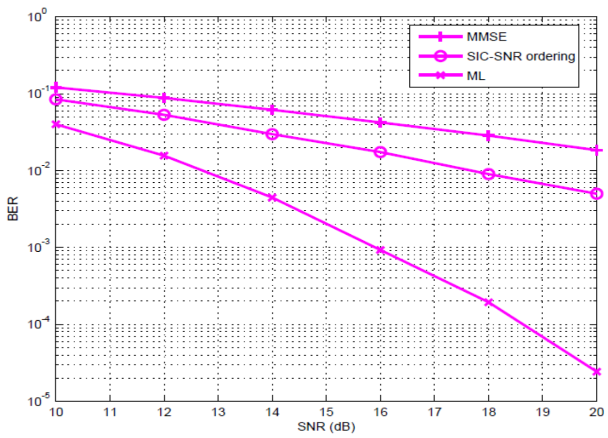

Fig. 3: BER Performance of MMSE, SIC and ML Detection for 4 × 4 MIMO with 16QAM.

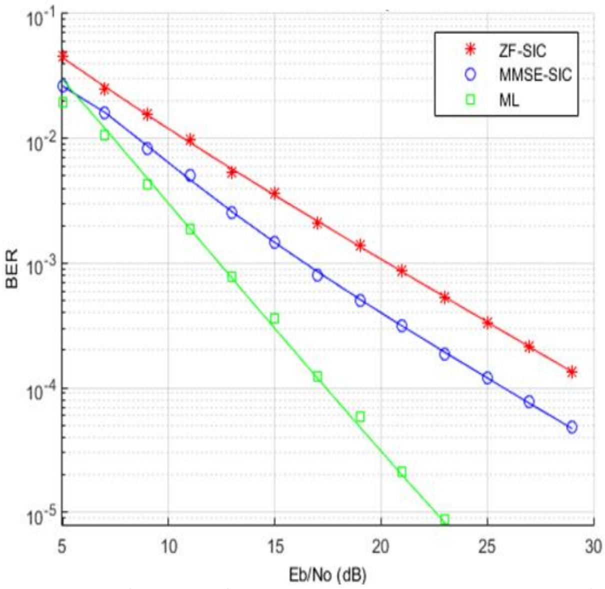

Fig. 4: BER Performance of ZF-SIC, MMSE-SIC and ML Detection for 2 × 2 MIMO with QPSK.

8. Conclusions

Both linear and non linear MIMO detection algorithms were discussed. ML detection has optimal performance among all algorithms, however for high dimensional MIMO systems these are practically infeasible due to their increased computational complexity. In this regard the main challenge in the exploitation of full potential of MIMO is in the design of detection algorithm which has near ML performance with very much reduced computational complexity. Also presented BER performance of ZF,MMSE,SIC detection schemes.

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