Modified Multiple Feedback Scheme for Successive Interference Cancellation based MIMO Detector

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Abstract - Multiple input multiple output (MIMO) systems are becoming very popular day by day. Multiple antenna systems increases the capacity of wireless channel drastically. But, the problem of detecting the transmit vector in MIMO systems is non-deterministic polynomial hard (NP-hard) and becomes impractical when number of antennas increases. Successive interference cancellation (SIC) in a well-known technique used for sequential detection of symbols in multiple input multiple output (MIMO) systems. However, SIC suffers from the problem of error propagation which degrades the bit error rate performance of SIC detector. To overcome this, a multiple feedback scheme is used where the concept of shadow region is used in the decision feedback loop. In this paper, we present a modified multiple feedback scheme for SIC based MIMO detector. In the modified scheme, we vary the radius of shadow region used in the decision feedback loop for different layers of SIC detector. The bit error rate (BER) performance is carried out for different MIMO systems through simulations. We also analyze and discuss the effect of modifications in the multiple feedback SIC algorithm.

Keywords – MIMO, Multiple-Input-Multiple-Output, SIC, Successive Interference Cancellation, BER, Bit Error Rate, QAM, Quadrature Amplitude Modulation.

1. INTRODUCTION

There has been a dramatic increase in requirement for data rate in wireless channel with the rapid growth in technology. To fulfill these data traffic requirements and support more users at the same time, several new techniques such as code division multiple access (CDMA), wideband CDMA (WCDMA), enhanced data rate for GSM evolution (EDGE) and long term evolution (LTE) have been proposed. Recently, systems with multiple antennas are gaining a lot of research attention for being employed in future generation of wireless technology [1]. Multiple antenna systems have been promising in terms of providing diversity and multiplexing gains in wireless channel [2], [3]. In multiple input multiple output (MIMO) systems, multiple antennas are used at the transmitter as well as at the receiver. With the help of these antennas, multiple symbols can be transmitted simultaneously from the transmitter. This is termed as spatial multiplexing i.e. multiplexing the data streams in spatial domain. These data streams are then transmitted to the receiver through wireless channel [4]. At the receiver, multiple replicas are received through the different antennas. Multiple copies of the same transmitted data helps in increasing the link reliability. The main problem in practical implementation of MIMO systems is the complexity of the receiver for reliable detection of the transmitted data.

Maximum likelihood detection (MLD) achieves the minimum bit error rate (BER) performance in MIMO systems. In MLD, an exhaustive search is performed over the set of all the possible data vectors. The likelihood cost corresponding to each possible vector is computed and the vector associated with minimum cost is selected as the best solution. But, the number of solutions available in the search space increases exponentially with increase in the number of transmit antennas and the modulation order. This increases the complexity of performing MLD at the receiver and hence, MLD becomes impractical with increase in number of antennas and modulation order. There are several low complexity MIMO detectors proposed in the literature. These include zero forcing (ZF) detector, minimum mean squared error (MMSE) detector and successive interference cancellation (SIC) detector [5]. Another such detector is sphere decoder (SD) which achieves a near MLD performance with reduced complexity compared to the MLD [6]. Several other algorithms in this context have been proposed in the literature which include [7]–[18].

Successive interference cancellation (SIC) in a well known technique used for sequential detection of symbols in multiple input multiple output (MIMO) systems [7], [8]. However, SIC suffers from the problem of error propagation which degrades the bit error rate performance of SIC detector. To overcome this, a multiple feedback scheme is used where the concept of shadow region is used in the decision feedback loop [9]. In multiple feedback strategy, multiple constellation points are used in the decision feedback loop of the SIC detector whenever a shadow condition occurs. The shadow condition occurs if the distance between estimated value of the decision and the nearest constellation point is above a finite threshold value. However, in multiple feedback scheme the shadow condition is checked for all the symbols which results in an unnecessary increase in computations.

To reduce the computations and get a comparable performance to that of the original multiple feedback scheme, in this paper, we present a modified multiple feedback scheme for SIC based MIMO detector. In the modified scheme, we vary the radius of shadow region used in the decision feedback loop for different layers of SIC detector. The bit error rate (BER) performance is carried out for different MIMO systems through simulations. We also analyze and discuss the effect of modifications in the multiple feedback SIC algorithm. The proposed modifications achieves a comparable bit error performance to that of the multiple feedback strategy.

The rest of the paper is organized as follows. In section 2, we present the systems model of the MIMO system used. In section 3, the traditional MIMO detectors such as maximum likelihood detection, zero forcing detectors, minimum mean squared error detector and the SIC detector. The proposed method is discussed in section 4. In section 5, simulation results on bit error performance are discussed for 10×10, 16×16 and 20×20 MIMO systems. Finally in section 6, we conclude the article.

2. SYSTEM MODEL

In this article, we consider a MIMO system which have multiple antenna transmitter with NT transmit antennas and a multiple antenna receiver with NR receive antennas. Let $x = [x_1, x_2,\ldots, x_{NT}]^T$ represent the transmit vector with symbol x_i being transmitted from the i^{th} transmit antenna. The symbol x_i is taken from a constellation set represented by C (for e.g. BPSK, QPSK and 4-QAM). The symbol transmitted to the receiver through a channel given by H which is assumed to be a Rayleigh flat fading channel. The receiver modified vector r as given by

$$r=Hx+n \qquad (1)$$

where H is an $N_R \times N_T$ MIMO channel matrix and each element of H i.e. h_{kl} for k = 1, 2, ….N_T and l =1, 2,….,N_T represents the channel gain between the l^{th} transmit antenna and the k^{th} receive antenna. The vector n is additive white Gaussian noise vector and each element n_i for i = 1, 2,…,N_R independent and identically distributed (i.i.d.) and $\sim CN(0, \sigma^2)$, σ^2 is the noise variance.

3. TRADITIONAL MIMO DETECTORS

In this section, we present overview of traditional MIMO detectors such as maximum likelihood detector (MLD), zero forcing (ZF) detector, minimum mean squared error (MMSE) detector and successive interference cancellation (SIC) detector.

A. *Maximum Likelihood detector*

The maximum likelihood detection is known to achieve the optimal (minimum) bit error rate performance. In ML, an exhaustive search is performed over all the possible transmit vectors. The ML solution is given by

$$X_{ML} = \arg\min_{x \in C^{NT}} \|r-Hx\|^2 \qquad (2)$$

where C^{NT} denotes the set of all possible symbol vectors which could be transmitted by the transmitter. But, the main drawback of MLD is that the number of computations required for performing the exhaustive search grows exponentially with increase in the number of transmit antennas due to which MLD becomes impractical.

B. *Zero forcing detector*

The zero forcing (ZF) detection is a linear detection method for MIMO systems. In ZF, a transformation matrix is used which removes the effect of channel gain matrix from the received vector by multiplying it with the pseudo inverse matrix as

$$T_{ZF} = (H^H H)^{-1} H^H \qquad (3)$$

where $(.)^H$ denote the Hermitian transpose of the matrix and $(.)^{-1}$ denote the inverse of a matrix. This matrix is then multiplied with the received vector as.

$$z_{ZF} = T_{ZF}\, r \qquad (4)$$

$$z_{ZF} = x + T_{ZF}\, n \qquad (5)$$

Now every entry of the estimated vector is quantized to the nearest constellation point as

$$x_{ZF}(i) = Q[z_{ZF}(i)] \quad \epsilon \; i = 1, 2,\ldots,N_T \qquad (6)$$

where Q[.] is the quantization operator.

C. Minimum mean squared error detector

In minimum mean squared error (MMSE) detection technique, the mean squared distance between the transmitted vector and the esitmated vector is minimized and the transformation matrix T_{MMSE} is found which is given by

$$T_{MMSE} = (H^H H + \sigma^2 I_{NT})^{-1} H^H \qquad (7)$$

Similar to the ZF detection, in MMSE also the transformation matrix is multiplied with the received vector followed by the quantization.

D. Successive interference cancellation detector

In successive interference cancellation (SIC), the symbols are detected sequentially for corresponding to each transmit antenna. After every successful decision about a symbol, its interference from the received vector is canceled and the decision about next symbol in the sequence is taken accordingly. The steps involved in the SIC detection technique are

Step 1 : Initialize the parameters such as H_0 = H and the received vector as

$$r = (h_1x_1 + h_2x_2 + \ldots.. + h_{Nt}\, x_{Nt}) + n \qquad (8)$$

Step 2 : A filter such as ZF or MMSE is then used to detect the symbol corresponding to a transmit antenna. Let us assume that (i-1) symbols have been detected so far and the MMSE filter is used, then the filter matrix for detecting the i^{th} symbol is.

$$w_i = (H_{i-1} H^H_{\ i-1} + \sigma^2/ E_s\, I_{Nr})^{-1} h_i \qquad (9)$$

where H_{i-1} is the matrix with its columns taken from the i^{th} to $N^{th}_{\ t}$ columns of the matrix H.

Step 3 : After detecting the symbols their interference is cancelled as

$$\mathbf{r}_i = \mathbf{r} - \sum_{j=1}^{i-1} \mathbf{h}_j x_j \qquad (10)$$

Step 4 : The i^{th} symbol x_i can now be detected as

$$z_i = w^H_{\ i}\, r_i \qquad (11)$$

$$x_i = Q[z_i] = Q[w^H_{\ i}\, r] \qquad (12)$$

where x_i is estimated value of the transmitted symbol x.

5. PROPOSED DETECTION SCHEME

In this section, we first discuss the multiple feedback strategy for SIC based detection algorithm and then propose the modifications i.e. MOD 1 and MOD 2 in the multiple feedback SIC algorithm. The multiple feedback (MF) strategy [9] is based on the concept of shadow area constraint. In MF scheme, if a decision in any layer of SIC falls in the shadow region i.e. if the difference between the estimated value and the nearest constellation point is above a finite threshold. If such condition occurs then multiple constellation points are used in the decision feedback loop followed by the SIC. This generates multiple solutions corresponding to each feedback symbol. The best symbol from the multiple symbols in the feedback loop is then selected using the maximum likelihood cost rule. The steps involved in the multiple feedback SIC algorithm are

Step 1 : Initialize the parameters such as H0 = H, i = 1 and

the received vector as.

$$r = (h_1x_1 + h_2x_2 + \_\,\_\,\_ + h_{Nt}\, x_{Nt}) + n \qquad (13)$$

Step 2 : A filter such as ZF or MMSE is then used to detect the symbol corresponding to a transmit antenna. Let us assume that (i-1) symbols have been detected so far and the MMSE filter is used, then the filter matrix for detecting the i^{th} symbol is.

$$w_i = (H_{i-1} H^H_{\ i-1} + \sigma^2/ E_s\, I_{Nr})^{-1} h_i \qquad (14)$$

where H_{i-1} is the matrix with its columns taken from the i^{th} to $N^{th}_{\ t}$ columns of the matrix H.

Step 3 : After detecting the symbols their interference is cancelled as

$$\mathbf{r}_i = \mathbf{r} - \sum_{j=1}^{i-1} \mathbf{h}_j x_j \qquad (15)$$

Step 4 : The i^{th} symbol x_i can now be detected as

$$z_i = w^H_{\ i}\, r_i \qquad (16)$$

Compute d = | z_i - Q[z_i] | and check if d < d_{th} then the decision is reliable and go to Step 2 and declare x_i = Q[z_i] else if d > d_{th} then the decision falls in the shadow region and is declared unreliable and go to Step 4.

Step 4: Use N nearest neighbors of the decision z_i in the feedback loop as $x^{(j)}_i = N_j$ where N_j is the j^{th} element of the neighborhood set N = {v1, v2,….., v_N}. Generate different solutions corresponding to each neighbor symbol using SIC as $\{x^{(1)},x^{(2)},\ldots,x^{(N)}\}$.

Step 5: Select and update the best symbol by using the ML rule on the generated solution set as

$$\hat{x}_i = \arg \min_{j=1,2,\ldots,N} \|r - H\tilde{\mathrm{x}}^{(j)}\|^2 \qquad (17)$$

Terminate if $i = N_T$ else $i = i + 1$ and go to Step 2.

MOD 1 : In MOD 1, the reliability criteria (shadow region criteria) is checked only up to $N_T/2$ layers. After $N_T/2$ layers the conventional SIC algorithms is followed for the remaining N_T /2 layers.

MOD 2 : In MOD 2, the reliability criteria (shadow region criteria) is checked only upto $3N_T$ /4 layers. After $3N_T$ /4 layers the conventional SIC algorithms is followed for the remaining N_T /4 layers.

6. SIMULATION RESULTS

In this section, we present the simulation results of the proposed modified strategies and compare them with the performance of the SIC and the multiple feedback SIC algorithms. We have performed the simulations in MATLAB software. We have used 10×10, 16×16, 20×20 antenna MIMO systems with 4 QAM modulation scheme. In figure 1, we present the bit error performance with respect to the signal to noise ratio (dB) for 4-QAM modulated 10×10 MIMO system. In figure 2 and figure 3 the bit error performance is simulated for 4-QAM modulated 16×16 and 20×20 MIMO systems respectively. The bit error performance of the proposed modifications MOD 1 and MOD 2 are simulated and compare with the SIC and multiple feedback strategy aided SIC algorithms. The bit error performance of the proposed modified schemes are comparable with the existing multiple feedback aided SIC algorithms. In MOD 1 and MOD 2 the multiple feedback search is not performed for all the antennas whereas in multiple feedback SIC it is performed for all the antennas and hence the complexity in the proposed modified schemes is less compared to the multiple feedback SIC algorithm.

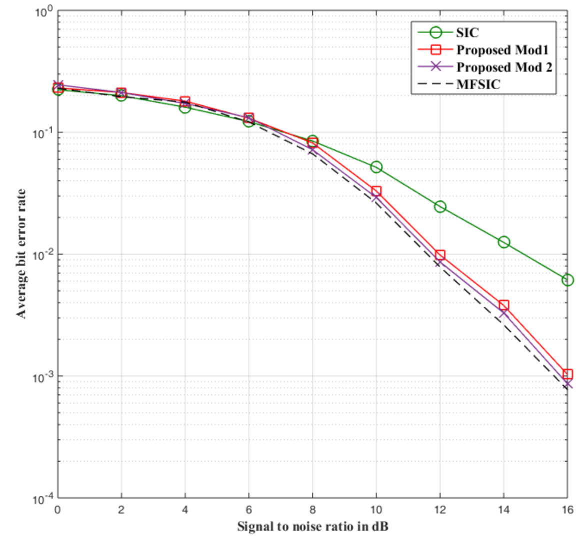

Fig. 1. Bit error rate performance of 10×10 multiple-input multiple-output system versus signal to noise ratio (dB).

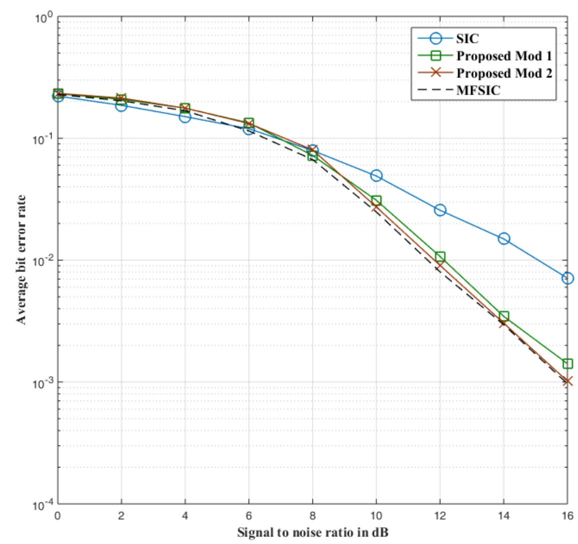

Fig. 2. Bit error rate performance of 16×16 multiple-input multiple output system versus signal to noise ratio (dB)

7. CONCLUSION

In this paper, a modified approach for multiple feedback strategy aided successive interference cancellation (SIC) based detectors is proposed for detecting the symbols in multiple input multiple-output systems. Two different modified schemes MOD 1 and MOD 2 have been proposed. In MOD 1 the multiple feedback search is performed only up to $N_t/2$ antennas and for the remaining symbols SIC is used. In MOD 2 the multiple feedback search is performed for $3N_t/4$ antennas and for the remaining symbols SIC is used. Simulation results for bit error rate versus signal to noise ratio have been performed for 10×10, 16×16, 20×20 MIMO systems. The bit error rate performance of the proposed modifications is comparable to the original multiple feedback SIC performance but the reduction in complexity can be achieved by our approaches (MOD 1 and MOD 2).

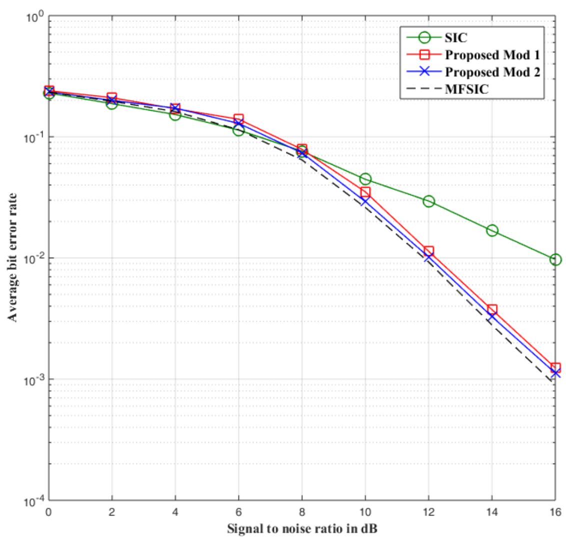

Fig. 3. Bit error rate performance of 20×20 multiple-input multiple output system versus signal to noise ratio (dB)

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