CHANNEL NORM BASED IMPROVED MULTIPLE FEEDBACK SUCCESSIVE INTERFERENCE CANCELLATION DETECTION FOR MIMO SYSTEMS

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ABSTRACT

With the rapid development in wireless technology, multiple-input multiple-output (MIMO) systems are becoming very demanding. They are the key to bring in several advantages in terms of diversity and multiplexing gains over the conventional single antenna systems. However, one of the major challenge in MIMO systems is the complexity of the receiver when detecting the transmitted vector. In this article, we present an improved technique based on the multiple feedback successive interference cancellation (SIC) detection in MIMO systems. In the proposed work, we use the channel norm based metric to update the radius of the reliability region in multiple feedback SIC. The simulations on bit error performance are performed for different MIMO systems and compared with the SIC and MF-SIC algorithms.

KEYWORDS: *MIMO, Multiple-Input-Multiple-Output, SIC, Successive Interference Cancellation, BER, Bit Error Rate, QAM, Quadrature Amplitude Modulation*.

I. INTRODUCTION

Owing to the ever fast growth in mobile technology, there has been continuous increase in the requirement for higher data rates due to increase in number of users and several wireless based applications such as online gaming and video calling. To serve these requirements and satisfy the data rates for each user, the wireless community has seen a dramatic change from first generation (1G) to the fourth generation (4G) wireless technology where 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 an increased research attention for as a key technique for future generation (5G) wireless technology [1]. Multiple input multiple output (MIMO) systems provides gains in terms of 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]. The MIMO fading channel modifies the transmitted data which is then corrupted by the additive white Gaussian noise (AWGN) as well. The main challenge is to extract the transmitted data from the corrupted signal received at the receiver through multiple antennas. The practical implementation of MIMO systems depends on the computational complexity of the receiver which detect the transmitted symbol reliably.

Through maximum likelihood detection (MLD) minimum bit error rate (BER) performance can be achieved in MIMO systems. But in MLD, an exhaustive search is performed over the set of all the possible data vectors where 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 problem with the MLD is that as the number of transmit antennas or the modulation order increase, the set of possible vectors grows exponentially which increase the complexity of performing MLD at the receiver which makes MLD impractical in MIMO systems having sufficiently high antennas. Several low complexity algorithms in the literature 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) is a well known technique used for detection of symbols in MIMO systems [7], [8] where the symbol corresponding to each transmit antenna is detected sequentially. But, the main problem associated with SIC is that it suffers from the problem of error propagation which degrades the BER performance of SIC detector. In order 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.

In this paper, we present the channel norm based improvement in the MFSIC algorithm. In channel norm based MFSIC (CH-MFSIC), the radius of the reliability region depend on the channel norm metric. Higher channel norm represent the better channel conditions and hence the radius of the reliability region can be kept more and for low value of channel norm, the radius can be reduced. The bit error rate (BER) performance of the proposed method is carried out for different MIMO systems through simulations and compared with the SIC and MF-SIC schemes. The proposed method performs better and achieve good BER performance.

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.

II. SYSTEM MODEL

Consider a MIMO system having multiple antenna at the transmitter and at receiver, respectively. Let the number of transmit antennas be denoted by N_T and the number of receive antennas be denoted by N_R. Let $s = [s_1, s_2, \ldots, s_{NT}]^T$ represent the transmit vector with symbol s_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 symbols from the transmitter are transmitted to the receiver through a MIMO channel which is given by H and it is assumed to be a Rayleigh flat fading MIMO channel. The receiver receives the modified form of the transmitted vector which is given by

$$\mathbf{y} = \mathbf{Hs} + \mathbf{n} \qquad (1)$$

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 ~ $\mathcal{CN}(0, \sigma^2)$, σ^2 is the noise variance.

III. 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

$$\hat{\mathbf{s}}_{ML} = \arg \min_{\mathbf{s} \in \mathbb{C}^{N_T}} \|\mathbf{y} - \mathbf{H}\mathbf{s}\|^2 \qquad (2)$$

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

$$\mathbf{T}_{ZF} = (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H \qquad (3)$$

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

$$\mathbf{z}_{ZF} = \mathbf{T}_{ZF} \mathbf{r} \qquad (4)$$

$$\mathbf{z}_{ZF} = \mathbf{x} + \mathbf{T}_{ZF} \mathbf{n} \qquad (5)$$

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

$$s_{ZF}(i) = \mathcal{Q}[z_{ZF}(i)] \quad \forall i = 1, 2, \ldots, N_T \qquad (6)$$

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 estimated vector is minimized and the transformation matrix T_{MMSE} is found which is given by

$$\mathbf{T}_{MMSE} = (\mathbf{H}^H \mathbf{H} + \sigma^2 \mathbf{I}_{N_T})^{-1} \mathbf{H}^H \qquad (7)$$

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

$$\mathbf{y} = (\mathbf{h}_1 s_1 + \mathbf{h}_2 s_2 + \cdots + \mathbf{h}_{N_t} s_{N_t}) + \mathbf{n} \qquad (8)$$

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

$$\mathbf{w}_i = (\mathbf{H}_{i-1}\mathbf{H}_{i-1}^H + \frac{\sigma^2}{E_s}\mathbf{I}_{\mathbf{N_r}})^{-1}\mathbf{h}_i \qquad (9)$$

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 canceled as

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

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

$$\tilde{z}_i = \mathbf{w}_i^H \mathbf{y}_i \qquad (11)$$

$$\hat{s}_i = \mathcal{Q}[\tilde{z}_i] = \mathcal{Q}[\mathbf{w}_i^H \mathbf{y}_i] \qquad (12)$$

where $\hat{s}_i$ is estimated value of the transmitted symbol s_i.

IV. Proposed Detection Scheme

In this section, we first discuss the multiple feedback strategy for SIC based detection algorithm and then proposed channel norm based improved MFSIC algorithm is discussed. The multiple feedback (MF) strategy [10] 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 H_0 = H and the received vector as

$$\mathbf{r} = (\mathbf{h}_1 x_1 + \mathbf{h}_2 x_2 + \cdots + \mathbf{h}_{N_t} x_{N_t}) + \mathbf{n} \qquad (13)$$

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

$$\mathbf{w}_i = (\mathbf{H}_{i-1}\mathbf{H}_{i-1}^H + \frac{\sigma^2}{E_s}\mathbf{I}_{\mathbf{N_r}})^{-1}\mathbf{h}_i \qquad (14)$$

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 canceled 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

$$\tilde{z}_i = \mathbf{w}_i^H \mathbf{r}_i \qquad (16)$$

Compute $d = |z_i - Q[z_i]|$ and check if $d \le d_{th}$ then the decision is reliable and declare $x_i = Q[z_i]$ else if $d > d_{th}$ then the decision falls in the shadow region and is declared unreliable.

A: *Proposed Work*

In this section, we present the proposed channel norm based update for the threshold radius of the reliability region in MFSIC. To start with, we assume the complete knowledge of channel gain matrix H at the receiver end. Following steps are involved in the proposed method

Step 1: Consider each column hi for i = 1, 2,….,N_t of the channel gain matrix H.

Step 2: Compute the 2-norm of each column h_i of the channel matrix as

$$g_i = (\mathbf{h}_i^H \mathbf{h}_i) = \|\mathbf{h}_i\|^2 \qquad (17)$$

Step 3: Arrange the values g_i for i = 1, 2,….,N_t in decreasing order and compute the ordering pattern p which is used to order the detection sequence.

Step 4: For each layer compute the threshold distance of the reliability region as

$$d_{th}(i) = 0.1 + \frac{2 * g_i}{\sum_{k=1}^{N_t} g_k}. \qquad (18)$$

Step 5: Use the threshold radius values computed in *Step 4* in the MF-SIC with the ordering sequence given by p and generate the output solution.

As shown in the steps that the if the channel norm is higher i.e. the channel quality is good then the radius of the reliability region is more, i.e. the chances of getting good decision are higher whereas when the channel quality is poor, the channel norm reduces and hence reduces the radius of reliability region.

V. Simulation Results

In this section, we present the simulation results of the proposed channel norm based MFSIC algorithm and compare the results with the performance of SIC and the multiple feedback SIC algorithms. The simulations were performed in MATLAB software. We have used 10×10, 16×16; 20×20 MIMO systems with the modulation as 4-QAM modulation scheme. In figure 1, the bit error performance for 4-QAM modulated 10×10 MIMO system is performed with respect to the signal to noise ratio (dB). 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 channel norm based improved MFSIC are better when compared with the multiple feedback aided SIC algorithms. The performance of proposed algorithm for 10 _×10 MIMO is better as compared to the other MIMO setups i.e. 16 ×16 and 20×20 MIMO.

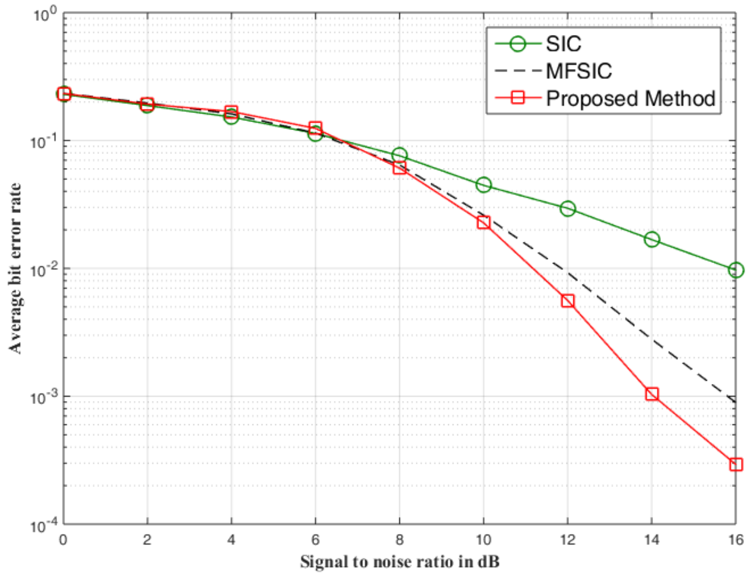

Fig. 1. Bit error rate performance of 10×10 multiple-input multiple-output system versus signal to noise ratio (dB)

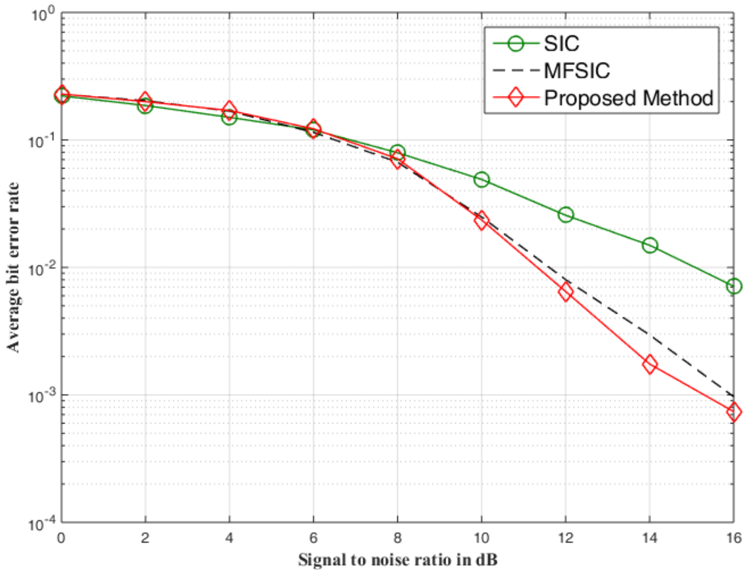

Fig. 2. Bit error rate performance of 16×16 multiple-input multiple-output system versus signal to noise ratio (dB)

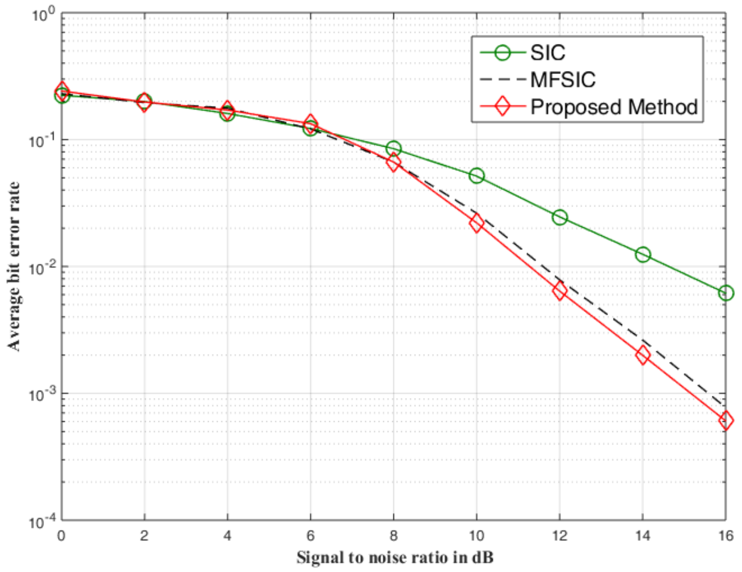

Fig. 3. Bit error rate performance of 20×20 multiple-input multiple-output system versus signal to noise ratio (dB)

VI. CONCLUSIONS

In this paper, a channel norm based improved multiple feedback strategy aided successive interference cancellation (SIC) detector is proposed for detecting the symbols in multiple-input multiple-output systems. In the proposed work, the radius of the reliability region in MFSIC is computed according to the norm of the column of the channel gain matrix. To detect the symbol for each transmit antenna, a different radius is used depending upon the channel quality. If the channel quality is good then the radius is higher and if the quality of the channel is bad then the radius is less. Simulation results for bit error rate versus signal to noise ratio have been performed for 10×10, 16×16, and 20×20 MIMO systems. The bit error rate performance of the proposed modifications is better when compared to the SIC and the MFSIC performance.

VII. FUTURE WORK

In this paper, an effective channel norm based feedback strategy is proposed so as to detect symbols in MIMO systems. As an extension to the work in future one may consider other algorithms to enhance the system performance. While proposing new algorithm performance enhancement from the previous methods can be compared for the effective work.

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