Efficient Method for SBI Estimation in Iterative Coded MIMO Systems

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Summary
In this research article, we exhibit a low complexity method for a multiple-input-multiple-output (MIMO) system with forward error correction (FEC) through soft interference cancellation minimum mean-squared error (SIC-MMSE) linear detecting method, which has improved performance compared with the existing methods. In traditional SIC-MMSE detector, the complexity of performing the inverse operation grows as we increase antenna size and number of iterations if we employ iterative MIMO system, where information is shared amongst FEC channel decoder and soft MIMO detector which is commonly called joint iterative detection and decoding (JIDD) system. One other issue in SIC-MMSE is the extraction of soft information whose complexity depends on extraction approach. The traditional SIC-MMSE method uses the maximum a posteriori (MAP) method to find the soft information. We propose a hybrid method to reduce its complexity. This hybrid method is based on an evaluation of soft information by checking its reliability and switching between the simple soft information calculation method which is known as the hard decision threshold (HDT) and traditional MAP method. Furthermore, the over-estimation of extracted soft information can reduce the performance of the system, therefore we introduce a scaling technique which can reduce the over-estimated values of the soft information and improve the error rate performance. Simulation results are produced to compare the performance of the proposed methods with the traditional.

Key words:
MIMO, forward error correction, SIC-MMSE, JIDD, maximum a posteriori, hard decision threshold

1. Introduction

The performance of wireless networks can be enhanced by utilizing the well-recognized method of introducing multiple antenna at the transceivers which is known as a multiple-input-multiple-output (MIMO) system. They are able to improve the reliability and spectral effectiveness of wireless technologies. The channel encoding strategies with the iterative rule can be utilized to accomplish the performance objectives in unsuitable channel situation. Famous channel encoding methods are turbo codes and low-density parity check (LDPC) are capable to accomplish the capability constraining outcomes [1]–[3]. Both turbo encoding and LDPC encoding require soft information to produce better performance so they are normally called soft-input and soft-output (SISO) method [1]–[3]. The wireless network overall performance can additionally be upgraded through utilizing the iterative processing approach in which soft-information is shared amongst SISO channel decoder and MIMO detector which can result in the performance of MIMO system approaching single antenna systems [2]. However, the computational complexity problem is hindering its practical implementation.

The sphere detector (SD) detecting method can deliver the performance near to maximum likelihood (ML) technique with lower complexity by lowering the search space through tree search approach. Another advantage of the SD method is that it can be used to build a list of possible solution which is called as list-sphere detection (LSD) technique [2]. The LSD method involves a high complexity which increases with list size. It is not necessary to build a list of possible solutions, the single tree search (STS) method can find the best solution with its counter hypothesis in a single tree [4]. Similar to LSD, the STS method has higher complexity which varies with channel conditions. Lattice reduction (LR) aided approach has a better performance which reduces the channel space [5]. However, all above-mentioned methods require a lot of computational efforts to produce better performance.

The linear detecting such as minimum mean squared error (MMSE) and zero-forcing (ZF) methods have considerably lower complexity. The suitable method for MIMO systems with the iterative principle is soft interference cancellation based MMSE (SIC-MMSE) scheme [6]–[12]. There are mainly three steps to extract the complete soft-information from a SIC-MMSE detector. The main problem with SIC-MMSE detector is the complex method of extracting soft-information using maximum a posteriori (MAP) method which can be solved by using a simple method of distance calculation [12], [13].

Manuscript received June 5, 2019
Manuscript revised June 20, 2019

In this article, we observe the level of reliability of soft data traded by turbo decoding. Based on the level of reliability, the soft-information calculation method is applied. The dependability is explored in every MIMO scheme. Furthermore, the overestimation of extracted soft-information can reduce the performance, so, we address this issue by introducing the scaling technique which can reduce the values for overestimated soft-information and improve the error rate performance.

2. MIMO System Based on Iterative Detection Encoding

A. System Model

The block diagram of the system model is shown in Fig. 1, that comprises a transceiver of $M \times N$ antenna size over MIMO framework having applied iterative principle. Firstly, bit matrix enclosing data bits **u,** is produced then those bits are coded by utilizing FEC encoding strategy to develop the codeword, **c,** along with i_{th} size represented as n. At that point $M \bullet N$ code-words are gathered, where K shows the extent of bits containing in each transmitted information, cumulated codewords are bit-interleave to create **x.** The subsequent interleave and encoded data is utilized to build the MIMO data structure, and extent of a solitary MIMO plan is of $M \bullet N$ bits.

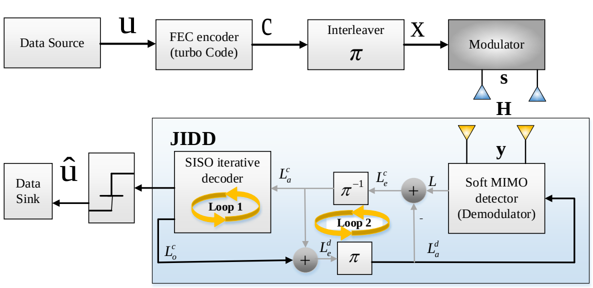

Fig. 1. Block diagram of MIMO Transceiver system model with the iterative standard.

The MIMO data frames comprising of bit matrix that is represented as:

$$\mathrm{X} = \left[x_{1,1},\ ...,\ x_1,\ K,\ x_{2,1},\ ...,\ x_{M,K} \right], \tag{1}$$

where $x_{(m,k)}$ explains the *kth* encoded an interleave bit of the m_{th} transmitting symbol. The transmitting data symbols matrix, $s = \left[s_1, s_2,\ ...,\ s_M \right]^T$, comprised of data symbols that are freely selected from the constellation, C. The data matrix, y comprises the transmitting data symbols matrix x, composite channel matrix, $\mathbf{H}$ of a size $M \times N$, and a $N \times 1$ composite Gaussian Noise matrix, $\mathbf{n}$, is showed as:

$$y = H_s + n. \tag{2}$$

B. MAP Selecting

As shown in Fig. 1, at the receiving side, MIMO detection evaluates the soft data, L, for entirely bits comprised in every MIMO frame as of y. The optimum MAP depends upon approximation strategy, the soft data of the k_{th} bit comprised through the m_{th} data symbols, $L(x_{m,k})$, can be initiated by exploiting

$$L\left(x_{m,k}\right) = \ln\left(\frac{P\left(x_{m,k} = +1 \mid y\right)}{P\left(x_{m,k} = -1 \mid y\right)} \right). \tag{3}$$

The bits in every transmitting data symbols matrix of MIMO frames are measurably autonomous that is finished with the assistance of error correction coding with interleaving the loglikelihood ratio (LLR) data in (3) under max-log estimation is illustrated by utilizing [2]:

$$L\left(x_{m,k}\right) = \ln\left(\frac{\sum_{s \in X_{m,k}^{(+1)}} P\left(y \mid s\right) \cdot P\left(s\right)}{\sum_{s \in X_{m,k}^{(-1)}} P\left(y \mid s\right) \cdot P\left(s\right)} \right) \approx \max_{s \in X_{m,k}^{(+1)}} d_s - \max_{s \in X_{m,k}^{(-1)}} d_s \tag{4}$$

where $X_{m,k}^{(+1)}$ is set per size of $2^{M \cdot K - 1}$ encoded bits consuming $X_{m,k} = \pm 1$ and d_s is assessed as:

$$d_s = -\frac{1}{N_o} \left\| y - H_s \right\| + \frac{1}{2} \sum_{m,k} x_{m,k} L_a^d \left(x_{m,k} \right). \tag{5}$$

The data, $L_e^c = L - L_a^d$, , is resubmitted to the turbo decoder, where L is known as the newly found data in (3) and L_a^d is the data traded by the FEC channel encoder.

The BER performance is shown in Fig. 2 for 2×2 and 4×4 MIMO frameworks with different inward iterations (i.e., MIMO detecting iterations). Overall numbers of MIMO detecting iterations demonstrate the information shared amongst the soft FEC channel decoder and soft MIMO detection methods. The total iterations inner channel decoder iteration is 8. The overall suitability of the proposed approach was assessed over a Rayleigh fading channel.

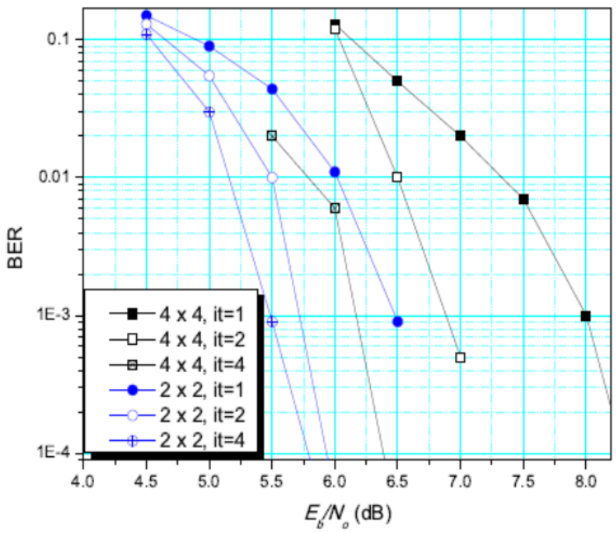

Fig. 2 $M = N = 2$ and $M = N = 4$ antenna size of MIMO system with 16-QAM modulator for BER performance of MAP detector.

The turbo code with $1/3$ encode rate was used and the information size of 378 bits was used in each data block. The recursive systematic convolutional (RSC) element code having a restrained size of 3 is utilized. It is shown in Fig. 2, it increases the performance of MIMO systems drastically. Therefore, the iterative principle can be used in future MIMO systems such as 5G technology to meet the demands of future systems.

3. Traditional SIC Based MMSE Detector Methods

The traditional SIC-MMSE detector method has 3 significant stages to estimate the LLR for transmitting data [9]– [12]. The traditional SIC-MMSE detector method has 3 significant stages to estimate the LLR for transmitting data [9]–[12]. To begin with, the SIC-MMSE method estimates the soft symbol $\tilde{s}_i$ for $i = 1, ..., M$ over every transmitting symbol s_i as:

$$\tilde{s}_i = E[s_i] = \sum_{q \in C} q \prod_{k=1}^{k} \frac{1}{2}\left(1 + \tilde{x}_{i,k} \tanh\left(L_a^d(x_i, k)\right)\right), \quad (6)$$

where $\tilde{x}_{i,k}$ is set to be an estimation of ± 1 that is drew in the view of the symbols occupied through the constellation of picked modulation method. The $Var[i]$ denotes variance and it is found in [9]-[12] as:

$$Var[i] = \sum_{q \in C} |q|^2 \prod_{k=1}^{k} \frac{1}{2}\left(1 + \tilde{x}_{i,k} \tanh\left(L_a^d(x_i, k)\right)\right) - |\tilde{s}_i|^2. \quad (7)$$

After finding soft symbols from feedback information given by FEC channel decoder, the subsequent stage cancels the interference from others layer by utilization of that soft symbol for the i_{th} layer is specified as:

$$\hat{y}_i = y = H\tilde{s}_i = y - \sum_{j, j \neq 1} h_j \tilde{s}_j = h_i s_i + \tilde{n}_i \quad (8)$$

where $\tilde{n}_i = \sum_{j, j \neq 1} h_j e_j + n$ and $\tilde{s}_i = [\tilde{s}_1, ..., 0, \tilde{s}_{i+1}, ..., \tilde{s}_M]^T$, and $\tilde{s}_j$ is the soft data at the j_{th} layers, where $j = 1, ..., M\text{-}1, j \neq i$.

Next, we find the filtering matrix based on MMSE method as:

$$w_i = \left(H \sum_i H^{?} + \alpha I_N\right)^{-1} h_i, \quad (9)$$

In (9), $\sum_i$ is a vector comprises diagonal entries of variance as:

$$\sum_i = diag\left(Var[1], .., Var[i-1], 1, Var[i+1], .., Var[M]\right), \quad (10)$$

The filtering matrix is multiplied with the interference canceled version of the received symbol $\hat{y}_i$ in order to find the i_{th} symbols, $\hat{s}$ as:

$$\hat{s}_i = (w_i)^{\dagger} y_i. \quad (11)$$

Afterward symbol detecting procedure, the noise variation is found based on the fact that found symbol can be written as:

$$\hat{s}_i = \mu_i s_i + \eta_i, \quad (12)$$

where $\mu_i = (w_i)^{\dagger} \hat{y}_i$. and η_i is the noise term having Gaussian distribution with variance value which can be calculated as:

$$(\tilde{\sigma}_i)^2 = \mu_i - |\mu_i|^2. \quad (13)$$

Finally, LLR data representing soft information for each bit is found by reflecting FEC channel information to improve the reliability of each bit LLR information and it calculated based on the Max-log MAP estimate strategy given as:

$$L\left(x_{i,k}\right) \approx \max_{s \in X_{i,k}^{(+1)}} \left[-\frac{\left|\hat{s}_i - \mu_i s\right|^2}{(\tilde{\sigma})^2} + \frac{1}{2}\sum_{i,k} x_{i.k} L_a^d\left(x_{i,k}\right) \right] - \max_{s \in X_{i,k}^{(-1)}} \left[-\frac{\left|\hat{s}_i - \mu_i s\right|^2}{(\tilde{\sigma})^2} + \frac{1}{2}\sum_{i,k} x_{i.k} L_a^d\left(x_{i,k}\right) \right]. \quad (14)$$

4. SIC-MMSE Method with Low Complexity

Figure 3 explains the receivers block diagram portraying iterative detector with special emphasize on the proposed method of low complexity estimation of soft information by dividing the process into several steps. The proposed method first checks the reliability level of the information feedback by the FEC channel decoder. In order to decide the level of reliability of the information, we fix the threshold variable. If feedback information exceeds the set threshold then it is observed as reliable while lesser is considered as unreliable.

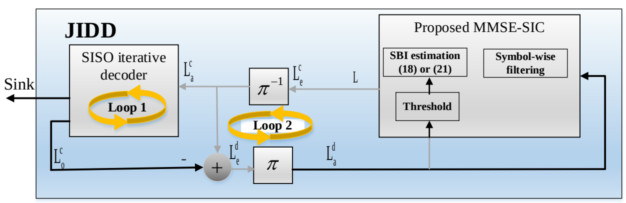

Fig. 3 Block diagram of a MIMO receiver system with low complexity SIC-MMSE detector scheme.

The calculation of LLR information for each bit is done with the less complex method known as single distance calculation approach. If the reliability of feedback infor mation is lower than the set threshold then MAP method is followed for LLR calculation for each bit. Additionally, to reduce further complexity, we also exclude the use of channel decoder feedback information during the LLR calculation process. It is because the impact of reflecting channel decoder information has very small improvement on performance which is negligible. By adopting simple distance scheme, the found symbol can be normalized using:

$$\hat{s}_i = \frac{(\omega_i)^H \hat{y}_i}{\mu_i} \quad (15)$$

with the help of HDT technique, the SBI data can be calculated for the i_{th} symbol by applying [12]

$$L\left(x_{i,k}\right) = -2\alpha\rho_i \tilde{b}_k, \quad (16)$$

where α is a scaling aspect, $0 < \alpha \le 1$, the α variable can be adjusted by using a trial and error approach to find the best threshold value which can differ for every system [12]–[14]. While the iterations rise, the JIDD framework won't result in performance change because of the over assessed SBI. In this manner, an optimum weighting variable can be utilized to diminish the over evaluated SBI variables. ρ_i is the ratio for signal strength and noise, and $\tilde{b}_k$ is the distance related to the filtered symbol, $\hat{s}_i$ and the HDT link for the k_{th} bit. The ρ_i can be defined as:

$$\rho_i = \frac{\mu_i}{1-\mu_i}. \quad (17)$$

The M-array QAM modulation, $\sim b_k$ variable can be st ated as given [13]

$$\begin{aligned} \tilde{b}_1 &= \Re\left(s_i\right), \\ \tilde{b}_2 &= \Im\left(s_i\right), \\ \tilde{b}_{2b+1} &= \left(\left|\tilde{b}_{2b-1}\right| - \left(2^{\left(\frac{k}{2}\right)-A} \right) A \right), \\ \tilde{b}_{2b+2} &= \left(\left|\tilde{b}_{2b}\right| - \left(2^{\left(\frac{k}{2}\right)-A} \right) A \right), \end{aligned} \quad (18)$$

where $0 < b \le \frac{k}{2} - 1$, $\Re(\bullet)$ and $\Im(\bullet)$ signify real and imaginary parts of symbols. A is the lowermost amplitude of $\Re(s)$ and $\Im(s)$. The soft information is calculated for less reliable feedback information can be found by using the MAP method using:

$$L\left(x_{i,k}\right) \approx \max_{s \in X_{i,k}^{(+1)}} \left[-\frac{\left|s_i - \mu_i s\right|^2}{(\tilde{\sigma})^2} \right] - \max_{s \in X_{i,k}^{(-1)}} \left[-\frac{\left|s_i - \mu_i s\right|^2}{(\tilde{\sigma})^2} \right] \quad (19)$$

A posteriori data without reflecting the data given by turbo decoder can directly be calculated by using equation (16) OR (19), in this way $L_e^c = L$.

The performance of BER was assessed over a Rayleigh channel. We used a turbo decoder as FEC channel decoder with a code rate of 1/3. The reason we used a turbo decoder is that it is known for iterative processing. The information size of 378 bits was used in each data block. The recursive systematic convolutional (RSC) element code with a constraint length of 3 was used.

In Fig. 4, we evaluate the performance of the MIMO system having antenna size of 2 at both transmitter and receiver $(M = N = 4)$ with the 16-QAM modulator.

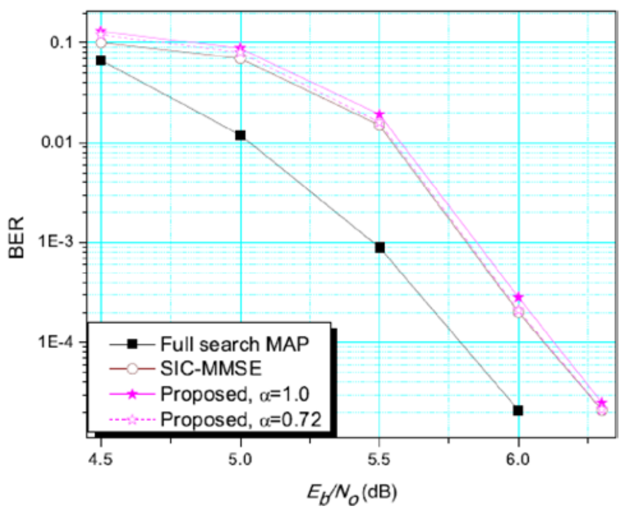

Fig. 4 Performance evaluation of MIMO system having antenna size of 2 at both transmitter and receiver (M = N = 4) with 16-QAM modulator.

The data trade between MIMO detecting and turbo encode is done 4 times, so the MIMO detecting iterations variable is set as 4. However, total iterations in the turbo decoder were set as 8. The performance evaluation of the proposed low complexity method is performed, and it is compared with the conventional schemes. The MAP method has the best performance, but it is impractical to use due to the nature of complexity. The threshold value used here is set as 2.5 which gave the 40% information calculated using a simple distance calculation method. While the performance lost was overcome by setting $\alpha = 0.72$, which resulted as the same performance of the proposed method as a conventional method.

The bit error rate performance demonstrated in Fig. 5 is of the low complexity proposed strategy and it is compared with the traditional SIC-MMSE technique utilizing α 4×4 MIMO framework with a 16-QAM modulation method. The recommended method with $\alpha = 0.68$, offers the good performance of error rate over the traditional technique. The threshold variable by using trial and error method was set as 3.0 that brought about 30% of soft data calculated using a simple distance calculation method.

The bit error rate performance is shown in Fig. 6 for the lower complexity proposed strategy with the traditional SIC-MMSE technique having antenna size of ($M = N = 4$) for MIMO system with a QPSK modulation method. The $\alpha = 0.68$ value for the proposed technique generates better performance in terms of computational complexity with minor bit error rate performance degradation compared to the traditional strategy. In this case, the threshold variable was set as 1.5 that results in about 24% complexity reduction by omitting the soft information calculation for reliable information.

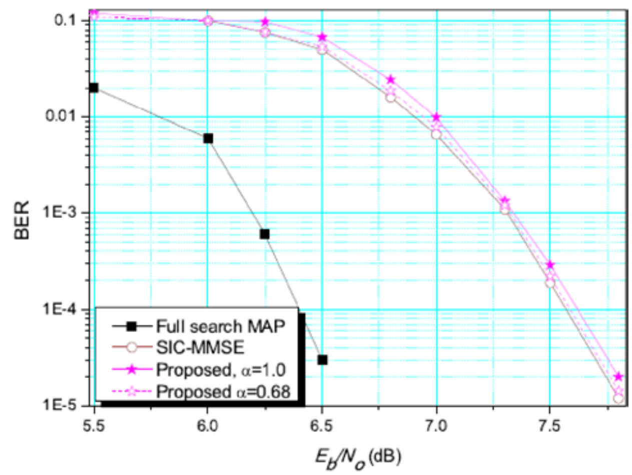

Fig. 5 Performance evaluation of MIMO system having antenna size of 4 at both transmitter and receiver (M = N = 4) with 16-QAM modulator.

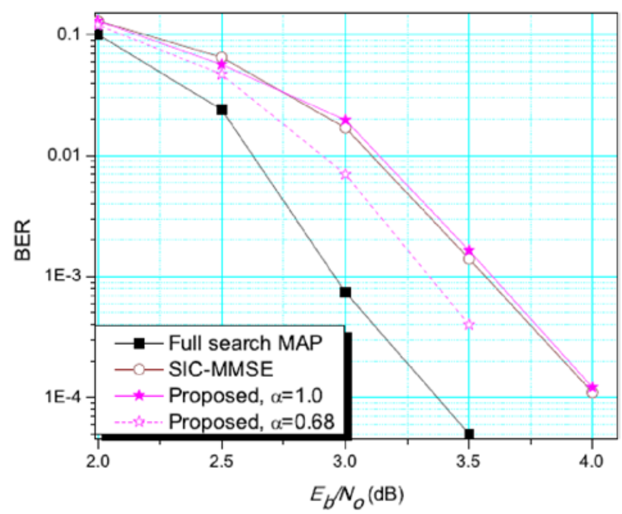

Fig. 6 Performance evaluation of MIMO system having antenna size of 4 at both transmitter and receiver (M = N = 4) with QPSK modulator.

5. Conclusion

This article shows the bit error rate performance of a proposed low complexity method based on SIC-MMSE depends upon soft data evaluation procedure. Firstly, we check the reliability of data feed-back by FEC turbo decoder. By looking at the level of reliability we utilize simple distance calculation technique information with higher reliability and we utilize MAP based information extraction for the data with less reliability. Moreover, the over evaluated SBI data can be decreased by employing a weighting element that results in over-all BER performance upgrading. The simulation results examined in this article demonstrated that the complexity of the soft data calculation procedure in SIC-MMSE method may be decreased without losing BER performance.

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