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Efficient SIC-MMSE MIMO detection with three iterative loops

Saleem Ahmed [a], Sooyoung Kim [b,*]

[a] Dawood University of Engineering and Technology, Pakistan
[b] IT Convergence Research Center, Division of Electronics Engineering, Chonbuk National University, 567 Baekjae-daero, Jeonju, Republic of Korea

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ABSTRACT

In this paper, we propose an efficient joint iterative detection and decoding (JIDD) scheme with a soft interference cancellation minimum mean squared error (SIC-MMSE) based method for a turbo coded multiple-input multiple-output (MIMO) system. In the proposed method, we activate a loop inside the SIC-MMSE based MIMO detection process in addition to the iterative loop between the MIMO detector and turbo decoder, so that the iteration inside the SIC-MMSE detection can be performed in parallel to the iterations inside the turbo decoder. Subsequently, soft outputs from each loop is exchanged for next further iteration, and this makes three iterative loops in total. In comparison with the conventional JIDD schemes, employing additional loop inside the MIMO detection process largely contributes to enhance the performance. In addition, the additional loop speeds up the performance convergence and eventually requires smaller overall computational complexity at the same performance.

1. Introduction

Joint iterative detection and decoding (JIDD) method which iteratively exchanges soft information between the detector and decoder can achieve impressive performance gains, approximating to a single antenna system [1]. The complexity and performance of the detection method plays a vital role in overall performance of JIDD systems. In particular, the computational complexity of the optimum multiple-input multiple-output (MIMO) detection method known as maximum likelihood (ML) detection increases exponentially with the number of antennas and the modulation order. Hence, research has mainly focused on the development of low-complexity detection algorithms including their efficient implementation in terms of hardware.

For example, MIMO detection based on the sphere-decoding (SD) algorithm and lattice reduction (LR)-aided scheme are able to achieve near optimal error-rate performance [1–6], but they are very inefficient for hardware implementation due to variable computational complexity depends on the channel and the noise. On the other hand, the soft interference cancellation (SIC) minimum mean square error (MMSE) MIMO detection method can be economically reasonable for very large scale integration (VLSI) implementation in the future MIMO systems [7]. Even though the SD algorithms like the single tree search (STS) outperforms the SIC-MMSE scheme, the STS algorithm requires 8 times higher computational complexity than the SIC-MMSE scheme [4]. For this reason, this paper focuses a JIDD system based on a SIC-MMSE scheme.

There have been attempts to apply and enhance the performance of SIC-MMSE schemes for JIDD systems [7–15]. In these schemes, SIC methods were combined with MMSE detections for symbol-level detection. Subsequently, the estimation of soft bit information (SBI) from a detected symbol was performed. The concern in a decision-feedback equalization (DFE) scheme like MMSE-based detection is an error propagation (EP) effect. The EP problem may arise when the reliability of the feedback information is not sufficient enough. In order to solve the EP problem, *a posteriori* information was additionally utilized in [13]. In [14], EP problem was further addressed and complexity of soft bit estimation was reduced by employing simple distance calculation method.

In this paper, we propose a method to further improve the performance of the SIC-MMSE based JIDD system, by employing three iterative loops. In addition to the loops inside the turbo decoder and the loop between the decoder and SIC-MMSE detector, another loop is activated inside the SIC-MMSE detector. By adding this additional loop inside the SIC-MMSE detector, three kinds of soft information can be utilized during the detection process; we utilize *a priori* information from the channel decoder, *a posteriori* information from the previous SIC-MMSE loop and *a posteriori* information from the current SIC-MMSE loop. Subsequently, the soft bit extraction is performed by using either a MAP based or a simple hard

* Corresponding author.
E-mail addresses: saleem3714@gmail.com (S. Ahmed), sookim@jbnu.ac.kr (S. Kim).

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decision threshold (HDT) based method without reflecting the *a priori* information from the channel decoder.

The outline of remainder of the paper is as follows. In Section 2, we will describe the operational principles of the optimal MAP-based detection scheme and JIDD system model. Section 3 presents the proposed JIDD system with three iterative loops based on a SIC-MMSE detection. The performance of the proposed method is analysed in Section 4, and the complexity issues are discussed in Section 5. Finally, the paper is concluded in Section 6.

2. JIDD for coded MIMO system

We consider a MIMO system with M transmit antennas and N receive antennas with a JIDD scheme as shown in Fig. 1. In the conventional JIDD system, there are two loops; Loop 1 is for the iterations inside the channel decoder and Loop 2 is for exchanging information between the channel decoder and soft MIMO detector which produces soft bit information. Initially, the information bit vector, $\mathbf{u}$, is passed through the encoder yielding the codeword $\mathbf{c}$, of length n. After accumulating $M \cdot K$ codewords, the bit-interleaving is performed to produce $\mathbf{x}$, where K represents the number of bits per transmit symbol. The resulting interleaved coded bits are partitioned into the MIMO frames with a length of $M \cdot K$ bits for each frame. The bit vector in each MIMO frame is represented as $\mathbf{x} = [x_{1,1}, \ldots, x_{1,K}, x_{2,1}, \ldots, x_{M,K}]$, where $x_{m,k}$ is the kth bit mapped onto the mth transmit symbol. The mapped transmitted symbol vector, $\mathbf{s} = [s_1, s_2, \ldots, s_M]^T$, is independently chosen from a complex constellation alphabet, $\mathcal{C}$. The received symbol vector $\mathbf{y} = [y_1, y_2, \ldots, y_N]^T$, can be represented as follows:

$$\mathbf{y} = \mathbf{H}\mathbf{s} + \mathbf{n}, \tag{1}$$

where $\mathbf{H}$ is an $N \times M$ complex channel matrix, and $\mathbf{n}$ is an $N \times 1$ complex Gaussian noise vector with variance of σ^2.

A JIDD receiver computes the SBI, L, for each transmitted bit by employing a MAP detector which can provide exact log-likelihood ratio (LLR) information for each transmitted bit. By employing the MAP detection under the max-log approximation, the LLR value, $L(x_{m,k})$ of the kth bit of the mth symbol is given as follows [1]:

$$L(x_{m,k}) = \ln\left(\frac{P(x_{m,k} = +1|\mathbf{y})}{P(x_{m,k} = -1|\mathbf{y})}\right) = \ln\left(\frac{\sum_{\mathbf{s}\in\mathcal{X}_{m,k}^{(+1)}} P(\mathbf{y}|\mathbf{s}) \cdot P(\mathbf{s})}{\sum_{\mathbf{s}\in\mathcal{X}_{m,k}^{(-1)}} P(\mathbf{y}|\mathbf{s}) \cdot P(\mathbf{s})}\right)$$
$$\approx \max_{\mathbf{s}\in\mathcal{X}_{m,k}^{(+1)}} d_s - \max_{\mathbf{s}\in\mathcal{X}_{m,k}^{(-1)}} d_s, \tag{2}$$

where $\mathcal{X}_{m,k}^{(\pm 1)}$ is the set of $2^{M \cdot K-1}$ coded bits for which the kth bit of the mth symbol is ± 1, and d_s can be computed as:

$$d_s = -\frac{1}{2\sigma^2}\|\mathbf{y} - \mathbf{H}\mathbf{s}\|^2 + \frac{1}{2}\sum_{m,k} x_{m,k} L_a^d(x_{m,k}), \tag{3}$$

where L_a^d is the *a priori* information provided by a channel decoder. The soft information delivered to the channel decoder by MIMO detector is the extrinsic information, L_e^c. After passing L_e^c through the deinterleaver, it is delivered to the channel decoder which utilizes it as the *a priori* information, L_a^c, to estimate the information sequence, and generate its soft output, L_o^c. Subsequently, the extrinsic information for the MIMO detector, L_e^d, is computed to produce L_a^d [2].

3. Proposed scheme for JIDD system

3.1. Performance enhancement using additional loop inside the SIC-MMSE detector

As a suboptimal detection method, a linear detection scheme such as a SIC-MMSE method can be used with lower complexity [7–15]. However, a SIC-MMSE method does not provide higher gain as MIMO detector iterations increases. It was shown that the performance of the conventional SIC-MMSE schemes could be enhanced by incorporating the *a posteriori* information from the already detected layers during the interference cancellation and MMSE detection process, in addition to the *a priori* information from the turbo decoder [13,14]. This additional utilization of the *a posteriori* information contributed to increasing the reliability of the estimated soft information, and thus the EP problem could also be reduced [14].

The issue arise that the method of utilizing the *a posteriori* information from the already detected layers gives higher impact to the later layers. As the detector goes through more layers, that much of the *a posteriori* information is accumulated. This means that the last layer is detected with the most reliable information. Motivated by this, the proposed method utilizes additional iterative loop inside the SIC-MMSE detector, so that the earlier layers which is detected with less reliable information can be re-detected with full *a posteriori* information from other layers. Therefore, this loop is a simple double iteration purpose.

Fig. 2 represents the block diagram of the proposed JIDD system. The detection is performed by utilizing three iterative loops, Loop 1 to Loop 3. Loops 1 and 2 are usually operated in the conventional JIDD system, as the loop for the turbo decoder and that between the turbo decoder and SIC-MMSE detector. Loop 3 is additionally employed in the proposed system. Due to this addition, there are three kinds of feedback information inside the

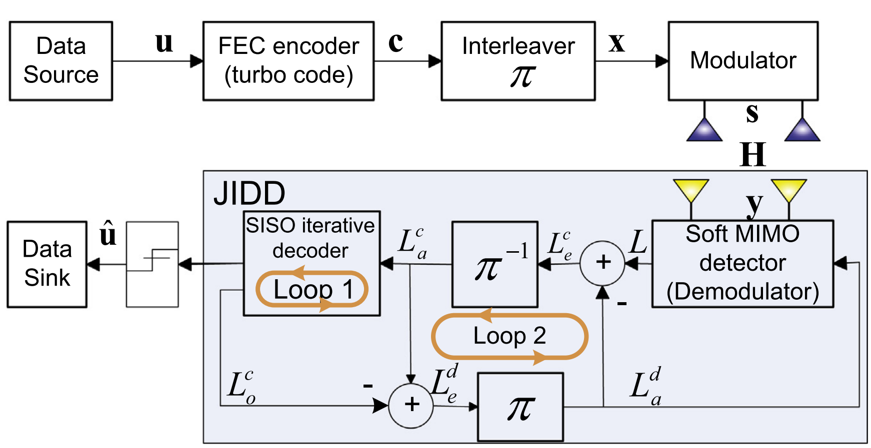

Fig. 1. Block diagram of a MIMO system with JIDD.