Extended-list SQRD-based Decoder for Improving BER performance in V-BLAST systems

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ABSTRACT

In the QR Decomposition-based (QRD) decoding class, the system performance is sensitive to the error propagation. Thus, it is critical to correctly decode the previous layers. One approach to desensitize the error propagation is to propose the optimal decoding order of layers. In this work, we propose a new extended-list Sorted QRD-based (SQRD) decoding approach. In the proposed decoding scheme, the solution of the few first layers is extended as the list of promising possible solutions. By doing so, the diversity of the lowest layer is increased. As a result, the system performance is less sensitive to the error propagation than its counterparts. The proposed approach is verified by the computer simulation results.

Keywords

Space Time Codes (STCs), Multiple-Input Multiple-Output (MIMO) system, V-BLAST, Wireless Communication System.

I. Introduction

Recently, it has been shown that the additionally co-operative usage of STCsin multiple-input multiple-output (MIMO) systems - the systems exploit multiple antennas at both transmitter and receiver side- has the potential to achieve much higher spectral efficiencies and performance reliability as well [1].

One of STCs, which is capable of providing high spectral efficiency and has been released and demonstrated in indoor slow fading channel, is the Vertical Bell Laboratories Layered Space Time (VBLAST) code [2]. In VBLAST, a single data stream is partitioned into sub-streams (layers), which in turn are optionally encoded independently, then modulated and transmitted in different antennas. At the receiver, with the use of interference suppression and interference cancellation, these data streams can be separately decoded using conventional decoding algorithms. As orthogonal space-time block codes (STBCs) or quasi-orthogonal STBCs (QSTBCs), the optimal detection scheme for VBLAST is maximum-likelihood (ML) decoder. Unfortunately, the complexity of ML decoder for VBLAST grows exponentially with the number of transmit antennas. Thus, it makes ML decoder to be infeasible when large number of transmit antennas and/or high-order modulation scheme are employed. A bunch of decoding schemes, which enable to achieve low computational load, are zero-forcing successive interference cancellation (SIC) with optimal order so called ZF-VBLAST [2], QRD-based which combines ZF or MMSE approach with SIC [3]-[5], combination ZF and ML approaches [6]-[7], or combination of ML and decision feedback equalizer (DFE) [8]. It is worth mentioning that, those approaches are sub-optimal algorithms, which obtain low computational load at the cost of the degradation in bit-error-rate (BER) performance.

In this paper, we exploit the sub-optimal decoder called Extended-list SQRD-decoder, which is based on SQRD of the channel matrix.

First, similarly to [6] and [7], the proposed decoder appliesthe zero-forcing approach to get a list of promising possible solutions for the lowest layer - the firstly decoded layer. The list of solutions constitutes nodes which are sorted in ascending order of Euclidean distance. Unlike the decoders in [6], [7] that apply the list decoding for unique first layer, our decoder uses each node as a possible ML solution for the layer to find list of solutions for upper layers. The number of layers chosen for being applied list decoding and the length of the list are set to compromise the system performance and the complexity. With the flexible choice of length of list, the complexity of our decoder can be controlled to be much more smaller than that of [8] with the same number of layers which are being applied ML decoder or list decoding approach. It is undoubted that the proposed decoder has slightly higher complexity than that of [6], [7] while having significant increase of system performance.

The rest of the paper is organized as follows. In section II, the system model used in our consideration is introduced. The detail of the proposed decoding scheme is presented in section III. The simulation results are shown in section IV. Finally, the conclusion is given in section V.

II. System model

We examine the VBLAST system depicted in Figure 1 with M transmit antennas and N receive antennas $(N \geq M)$, denoted as (M,N) system. At the transmitter, the data stream is demultiplexed into M data sub-streams. Each data substream can be optionally encoded, or bit-interleaved independently, then are mapped into a certain modulation scheme symbols such as M-PSK or M-QAM. After that, modulated symbols are transmitted independently on different transmit antennas. For the sake of simplicity, we assume that the uncoded data stream is taken into consideration. It is easy to deduce the similar decoding scheme for coded data stream.

For simplicity of expression, let us examine only one time-slot of the time-discrete complex base band signal denoted as the $M \times 1$ transmit signal vector $s = [s_1 \quad s_2 \quad \cdots \quad s_M]^T$. Then, at the receiver, we have the corresponding

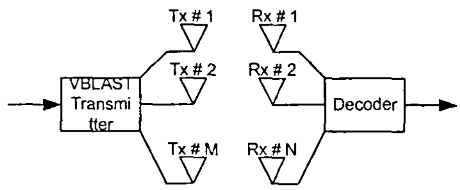

Figure 1: Block diagram of VBLAST system

received signal vector $y = [y_1 \quad y_2 \quad \cdots \quad y_N]^T$ as given by:

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

In the equation (1), H is a $N \times M$ complex channel matrix containing uncorrelated complex Gaussian variables with unit variance. In this work, we assume that the channel is flat fading, i.e. elements of the complex channel matrix H are constant over one data frame duration and changes independently from one frame to the others. The vector n represents white Gaussian noise of variance σ_n^2 observed at N receive antennas.

In general, with the assumption that the channel is perfectly known at the receiver, the optimal maximum-likelihood detection problem of the system becomes:

$$\hat{s} = \arg\min_{s \in S} \|y - Hs\|^2 \tag{2}$$

III. The Extended-list SQRD-based Decoder

We start with the SQR decomposition of the complex channel matrix H as $H = QR$, where the $N \times M$ matrix Q has orthogonal columns with unit norm and the $M \times M$ matrix R is an upper triangular. By multiplying the received signal vector y with Q^H, where $()^H$ denotes the Hermitian transform, we obtain the following equation:

$$\tilde{s} = Q^H y = Rs + \eta \tag{3}$$

In (3), since Q is an unitary matrix, the term noise $\eta = Q^H n$ has the same statistical properties as n. In addition, with the regard of triangular structure of the matrix R, we can express the k^{th} element of $\tilde{s}$ as follows:

$$\tilde{s}_k = r_{k,k}s_k + \sum_{i=k+1}^{M} r_{k,i}s_i + \eta_k \quad (4)$$

From the equation (4), we can see that the k^{th} element is free interference from the layer 1,2,···,k-1. Therefore, it is easy to conclude that the M^{th} element is totally free of interference and can be be decoded directly. With the assumption that the M^{th} element is correctly decoded, the interference of the M^{th} element is perfectly cancelled from (4) then the $(M-1)^{th}$ element can be easily recovered. By doing the same fashion as above, we are able to detect the remaining transmitted symbols.

Let us define the Euclidean distance of the k^{th} element on the given layer as:

$$d_k = \left| \tilde{s}_k - \sum_{i=k}^{M} r_{k,i}s_i \right|^2 \quad (5)$$

We can see that, at the lowest layer, which is first decoded so called the worst subchannel, the diversity gain is $G = N - M + 1$. Thus, with the case of system with the number of transmit antennas is equal to the number of receive antennas, the diversity gain of the worst subchannel is only 1. This low diversity gain causes the degradationin BER performance of system.

In order to improve the BER performance, first the proposed decoder applies the same idea of [6] and [7] to find out the list of promising possible solutions for the lowest layer. Each possible solution in the list is consideredas a node. Nodes are arranged in such order that their corresponding Euclidean distance defined in (5)are increased. After that, the decoder chooses each node as a possible ML solution for the layer, substitutes into (4) to find the list for the second layer. Let us denote the length of the list in the layer k^{th} is K_k $(K_k \le S)$. Now the decoder gets new K_1K_2 nodes. With $K_2 > 1$, the decoder increases the number of possible solution vectors, resulting higher performance than [6], [7] do. If the decoder chooses $K_i = K_j = S$ (ij) and the number of layer applied list decoder equal to M-1, the decoder becomes optimal ML decoder, whose complexity is exponentially increased with number of transmit antennas and order of modulation scheme. The proposed decoder compromises the trade off between system performance and the complexity by finding out list of solutions in only few first layers, which are sensitivewith the error propagation, and by choosing flexible length of the list for each layer. The decoder is illustrated in Figure 2 for (4,4) system using QPSK with $K_i = 2$ (i=1,2,3).

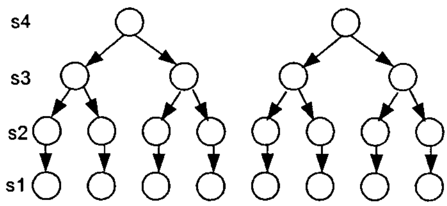

Figure 2: Examined node for (4x4) system using QPSK with nList=2and number of applied layers is 3

IV. Computer simulation results

The system, which is considered in our simulations for verifying the proposed decoder, is set up as follows. The number of transmit antennas is equal to the number of receive antennas and is set to 4. The modulation scheme applying for the system is QPSK. The data frame length is set to 100 symbol periods.

Figure 3 shows the BER performance of the proposed approach and the ML scheme when the length of the list is changed. In this simulation, we choose the number of layers for applying list decoder is 2. It can be seen that the increase of the list length results in lower BER performance. For example, at EbN0=10dB, the decoder with the list length of 1, 2 and 4 result in BER=0.0434, 0.0141 and 0.0024 respectively. This can be explained as follows. When the list length increases the possible choices for the worst sub-channels increases, thus the diversity order of the few first layers increases. As a result, the error propagation is significantly reduced. It also can be seen from the Figure 3 that BER performance of the proposed scheme with only 2 applied layers and list length of 4 (which is equal to number of signal points in QPSK constellation) is comparable with that of ML detection.

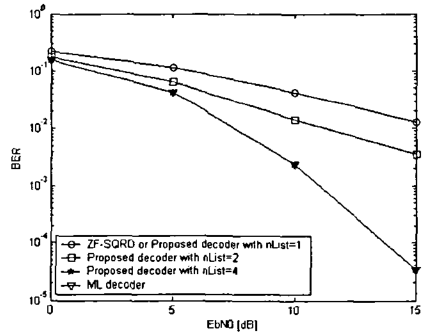

Figure 3: BER performance of the proposed decoder for (4x4) system using QPSK when the number of applied layers is 2 and the chosen length of list for decoding few first layers varies

Figure 4 compares the BER performance of the proposed decoder and the decoder [6] when the list length is set to 4. The parameters for simulation are the same as those used for Figure 3. As can see that, when the number of applied layers is increased only one more from [6], the proposed decoder can be able to obtain significantly higher BER performance than [6] can.

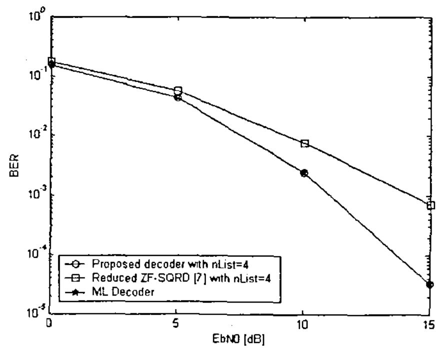

Figure 4: Comparison BER performance of the proposed decoder and [6] for (4,4) system using QPSK when list length is 4 , and number of applied layers is 2

The average computational load per symbol period comparison of the ZF-SQRD, the schemes in [6], [7], the proposed decoder and the ML decoder is shown in the Table 1. The condition for the simulation is the same as which used to conduct Figure 4. In addition, the EbN0 is kept constant at 10dB, the number of iterations is set to 5×10^3. In the Table 1, we only count all the complex additions and multiplications for implementation of the searching process. From the Table 1, we can see that the proposed decoding scheme can offer the complexity order that is comparable to that of [6], [7] while it outperforms [6], [7] in term of BER performance. On the other hand, the computational load of the proposed decoding scheme is much more smaller than that of ML decoder while it can provide comparable BER performance.

Table 1: Comparison of average complexity per symbol period.

Decoder	Number of complex additions	Number of complex multiplications
ZF-SQRD	12	13
Propose decoder with list length of 4 and 2 applied layers	200	205
Reduced ZF-SQRD [6]	124	124
ML	2048	1024

V. Conclusion

In this work, we have proposed a new extended-list SQRD-based decoder for VBLAST systems. By extending the possible solution points for few first sub-channels, the decoder becomes less sensitive to error propagation. Consequently, the proposed decoder can provide significant improvement in BER performance with a slight increase in computational load as comparison with its counterparts. With capability of flexibly choosing number of layers for applying list decoder and length of list, the proposed decoder can be able to obtain comparable BER performance of ML decoder while it still has feasible complexity. As a result, the proposed decoder seems to be very promising for

VBLAST applications.

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