Low Complexity Maximum-likelihood Decoder for VBLAST-STBC scheme using non-square O-STBC code rate $\frac{3}{4}$

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ABSTRACT

This work presents a low complexity maximum-likelihood decoder for signal detection in VBLAST-STBC system, which employs non-square O-STBC code rate 3/4. By stacking received symbols from different received symbolduration and applying QR decomposition resulting the special format of upper triangular matrix R, the proposed decoder is able to provide not only ML-like BER performance but also very low computational load. The low computational load and ML-like BER performance properties of the proposed decoder are verified by computer simulations.

Keywords

Space Time Code, Multiple-Input Multiple-Output (MIMO) system, VBLAST, Wireless Communication System.

I. Introduction

The Vertical Bell Laboratories Layered Space Time (VBLAST) code [4] has been known as a high spectral efficiency space time code. Similar to STBCs or QSTBCs, the optimal decoder for the VBLAST as well as other high-rate STCs is obviously ML decoder. However, unlike the STBCs whose ML decoding scheme is very simple based on only linear processing of the received signal, the complexity of ML decoder for the VBLAST and other high-rate STCs grows exponentially with the number of transmit antennas, making it impractical when large number of transmit antennas and/or high-order modulation schemes are employed.

In literature, bunches of sup-optimal decoding schemes have been proposed [1], [2], [6] for VBLAST. However, in VBLAST using either ZF, MMSE or QRD interference suppression, the diversity order of the first decoded layer, so-called the lowest layer, is $G = n_R - n_T + 1$. Thus, if VBLAST systems employ equal transmit and receive antennas, this diversity is reduced to 1, leading to a very poor system performance. Although, MMSE-BLAST and MMSE-SQRD [6] show remarkable system performance improvement in comparison with other sub-optimal decoders, the slope of the bit-error-rate (BER) curves indicate that they are able to improve diversity of the system only in low signal-to-noise power ratio (SNR) region. To increase the diversity order of the first decoded symbol, and thus of the system, a combination of ML and QRD decoding algorithm was proposed [3]. Because of using ML, the system could hardly achieve high diversity order under the constraint of reasonable complexity. One alternative is the use of combination of VBLAST and STBC [3], that diversity order is considerably increased compared to VBLAST system, yet at the cost of spectral lost. In this work, by employing the operation principle of VLCMLDec1 and VLCMLDec2 decoders [7], we propose a new decoder for MIMO system employing VBLAST-STBC scheme. It is shown that the proposed decoder can significantly reduce the computational load while still obtain the ML performance-like.

The remaining part of the paper is organized as follows. In section II, we describe the system model using in our consideration. The detail of the proposed decoding scheme is presented in section III. The simulation results and discussion are given in section IV. Finally, the conclusion is given in section V.

II. SYSTEM MODEL

Let us consider the MIMO system as depicted in Figure 1

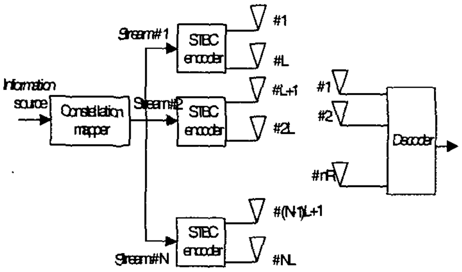

Figure 1: VBLAST-STBC System model

In our system, the number of receiver antennas satisfies the condition $n_R \geq N$ and can be less than the number of transmit antennas. The transmit signals is then written by stacking all signal matrices resulting from space-time encoding of all layers as:

$$G(s)=\begin{pmatrix} G_1(s) \\ G_2(s) \\ \vdots \\ G_N(s) \end{pmatrix} \qquad (1)$$

At the receiver, we have the received signal given as:

$$y = HG(s)+n \qquad (2)$$

With the assumption that the channel matrix is perfectly known at the receiver, the transmitted signals can be ML decoded as follows:

$$\hat{s} = \arg\min_{s\in S}\left\| y - HG(s) \right\|^2 \qquad (3)$$

where S is set of signal constellation corresponding to the given modulation scheme.

From the equation (2), let us defined the transmitted signal vector as:

$$s=\begin{pmatrix} s_1 \\ s_2 \\ \vdots \\ s_i \\ \vdots \\ s_{NL} \end{pmatrix} \qquad (4)$$

With the definition of s, the receive signal can be rewritten as:

$$z = \tilde{H}s+\tilde{n} \qquad (5)$$

where $\tilde{H}$ and $\tilde{n}$ are the equivalent channel matrix and noise vector, respectively. With the equivalent channel matrix, we can directly apply the QRD-based detection [5]-[6] or ZF-VBLAST decoder [4]. However, it is worth emphasizing that those approach are sub-optimal ones, that obtain low computational load at the expense of remarkable degradation in bit-error-rate (BER) performance compared to the optimal ML decoder.

We start with the QR decomposition of the equivalent channel matrix $\tilde{H}$ as $\tilde{H}=QR$, where the $n_R T \times n_T$ matrix Q has orthogonal columns with unit norm and the $n_T \times n_T$ matrix R is an upper triangular matrix. By pre-multiplying the equation (5) with Q^H, where $(\ )^H$ denotes the Hermitian transform, we obtain the following equation:

$$\tilde{z} = Q^H z = Rs+\eta \qquad (6)$$

In (6), since Q is an unitary matrix, the noise term $\eta = Q^H\tilde{n}$ has the same statistical properties as n. Consequently, the ML solution of vecter s in (4), $\tilde{s}$, can be obtained by utilizing either the decision rule in (3) or the following rule:

$$\tilde{s} = \arg\min_{s\in S}\left\| \tilde{z} - Rs \right\|^2 \qquad (7)$$

Due to the upper triangular structure of matrix R, we can express the kth element of $\tilde{z}$ as follows:

$$\tilde{z}_k = r_{k,k}s_k + \sum_{i=k+1}^{n_T} r_{k,i}s_i + \eta_k \qquad (8)$$

where $r_{i,j}$ is the element in the ith row and jth column of matrix R.

III. PROPOSED DECODER

For brevity, we exemplify the working of the proposed decoder with the (6,2) system using STBC code rate 3/4 for three transmit antennas given in equation (3.49) of [2]. Thus, the equation (6) can be rewritten as follows:

$$\tilde{z} = Rs + \eta \qquad (9)$$

In (9), the upper triangular matrix R has the following format:

$$R = \begin{pmatrix} r_{1,1} & 0 & 0 & r_{1,4} & r_{1,5} & r_{1,6} \\ 0 & r_{2,2} & 0 & r_{2,4} & r_{2,5} & r_{2,6} \\ 0 & 0 & r_{3,3} & r_{3,4} & r_{3,5} & r_{3,6} \\ 0 & 0 & 0 & r_{4,4} & r_{4,5} & r_{4,6} \\ 0 & 0 & 0 & 0 & r_{5,5} & r_{5,6} \\ 0 & 0 & 0 & 0 & 0 & r_{6,6} \end{pmatrix} \qquad (10)$$

Let us define the Euclidean distance of the kth element as:

$$d_k = \left| \tilde{z}_k - \sum_{i=k}^{n_T} r_{k,i} s_i \right|^2 \qquad (11)$$

From (7) and (11) we have:

$$\tilde{s} = \arg\min_{s \in S} \sum_{k=1}^{n_T} d_k \qquad (12)$$

The decoder can be stated as follows. In this statement, s is the vector containing all the signal points of the transmission constellation, whose size is S. DECSORT() is a function that uses s, the equation (11) to compute d_k and to sort the values of d_k as well as the corresponding signal points in $\tilde{s}$ in an ascending order of d_k. The output of DECSORT() are vectors d_k and x_k, which contain the sorted values of d_k and s respectively.

1. (Initialization) Set $k := n_T$, $D_{min} := 0$, $D_t := 0$, $D_k := 0$, $D_{n_T+1} := 0$.
2. Set $l_k := 1$, $m := k+1$, compute $\xi_k := \tilde{z}_k - \sum_{j=m}^{n_T} r_{k,j} x_j(l_j)$.
3. Find [d_k, x_k]:=DECSORT(ξ_k, s).
4. If $k = n_T$ then $D_k = d_k(l_k)$ else $D_k := d_k(l_k) + D_m$.
5. Set $x_k(l_k)$ as a solution for s_k, if $k > 4$ then $k := k-1$ and goto Step 2; else compute $\xi_k := \tilde{z}_k - \sum_{j=4}^{n_T} r_{k,j} x_j(l_j)$ and find [d_k, x_k]:=DECSORT(ξ_k, s) $(k = 1,2,3)$ and $D_t := d_1(1) + d_2(1) + d_3(1) + D_4(l_4)$.
6. (Searching) Set $D_{min} := D_t$, $k := 4$, $l_k := l_k + 1$ and goto Step 8.
7. If $k > 3$ find [d_k, x_k]:=DECSORT(ξ_k, S), $l_k := 1$ else find [d_k, x_k]:=DECSORT(ξ_k, s), $l_k := 1$ for $k = 3,2,1$.
8. If $k > 3$ then $D_k := d_k(l_k) + D_{k+1}$ else $D_t = d_3(1) + d_2(1) + d_1(1) + D_4$
9. If $D_t \ge D_{min}$ or $l_k > S$ then: if $k = n_T$ then terminate and report the result; else set $k := k+1$, $l_k := l_k + 1$ and goto Step 8.
10. If $k > 3$ then let $m := k$, $k := k-1$, compute $\xi_k := \tilde{z}_k - \sum_{j=m}^{n_T} r_{k,j} x_j(l_j)$ and goto Step 7; else set $D_{min} := D_t$, update $x_j(l_j)$ $(j = 1, \ldots, n_T)$, let $k := k+1$, $l_k := l_k + 1$ and goto Step 8.

IV. COMPUTER SIMULATION RESULT

To verify performance and complexity of the proposed decoder, we apply it to a VBLAST-STBC scheme in a (6,2) system. In addition, the modulation scheme is BPSK. The frame length is set to equal to 100 STBC symbol periods, i.e. 400 symbol periods.

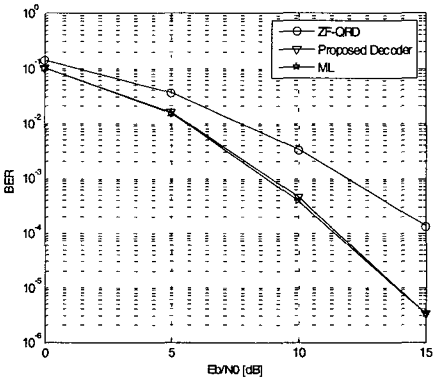

Figure2 : BER performance of the proposed decoder, ML decoder and ZF-QRD for VBLAST-STBC scheme in a (6,2) system using STBC code rate 3/4 and QPSK

Figure 2 shows the BER performances versus average bit-energy-to-noise ratio (EbN0) per receive antenna of the proposed decoder, the ZF-QRD decoder and the optimal ML decoder. It can be seen from the Figure 2 that the proposed decoding scheme obtains almost the same BER performance as the optimal ML decoder does whereas it significantly outperforms the ZF-QRD decoder in term of BER performance.

The average computational loads per symbol period of our proposed decoder, ZF-QRD decoder and optimal ML decoder in term of complexity addition and multiplication operations are given in the Table I. In this comparison, we only concern the complexity in searching stages. The parameters for the simulation are the same as those used for Figure 2. In addition, the EbN0 is kept constant at 10dB, the number of iterations is set to 5×10^3.

Table 1: Comparison of average complexity per symbol period of the proposed decoder and its counterparts

Decoder	Number of additions	Number of multiplications
ZF-QRD	20	26
Proposed Decoder	59	51
ML	3520	3584

It can be seen from the Table I that the complexity of the proposed decoder is comparable to that of ZF-QRD decoder while it is remarkably smaller than that of the optimal ML decoder.

V. CONCLUSION

In this work, the new low-complexity ML-like performance decoder for MIMO system employing VBLAST-STBC has been proposed. The proposed decoder is shown to be capable of not only providing the systems with ML performance-like but also obtaining extremely low complexity. Although it suffers from spectral efficiencies loss by nature of VBLAST-STBC, the significant low complexity and the capacity of using in case number of receive antennas less than number of transmit antennas make it to be a very promising decoder for practical applications.

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