

Reduced Complexity Detection for V-BLAST Systems from Iteration Canceling

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Keywords – BLAST, MIMO, Successive interference cancellation

Abstract—V—BLAST is an effective detection method for MIMO communication system, but has large computational complexity due to its successive iteration. In this paper, we proposed modified V-BLAST to lessen its computational complexity reducing the number of successive iteration. As a result of this simplification, the computational complexity of the detection is lowered significantly. Simulation results show that the proposed V-BLAST reduces calculation complexity by about the 30% while achieving a very close BER performance as the original one.

I. INTRODUCTION

The multiple-input multiple-output (MIMO) system can increase the spectral efficiency greatly through multiple element antenna arrays at both the transmit and receive ends so as to meet high bit rate demand in wireless communications and attracts more and more attentions of communication community. Many approaches have been proposed to combat the frequency-selective fading in MIMO channel, such as MIMO-DFE, MIMO Turbo equalization, MIMO single-carrier frequency-domain-equalization and MIMO OFDM etc. In the MIMO OFDM approaches proposed, V-BLAST is frequently

employed in the signal detection of the system's subcarrier channel [1][2]. V-BLAST is a detection method based on successive interference cancellation and needs the computation of the pseudoinverses of the channel matrix and its deflated matrices [3]. For a MIMO OFDM system with a larger subcarrier number and a greater transmit antenna number, the V-BLAST detection will have a very large computational complexity. The Fig. 1 shows the architecture and successive cancellation process of the V-BLAST. The detector of Fig.1 can be Zero-forcing or minimum mean square error (MMSE) detector. The y is the received vector signal.

When symbol cancellation is used, the order in which the components detected becomes important to the overall performance of the system. We focus on this property of V-BLAST to reduce the number of successive cancellation process. Normally, the ordering is based on the channel matrix which has the signal to interference and noise ratio (SINR) information. Optimal detection Ordering is introduced in [3] and the each error performance for optimal ordering and arbitrary ordering are described in [4] and [5].

This paper is organized as follows. Section 2 briefly describes the V-BLAST detection in MIMO communication. Section 3 proposes the modified V-BLAST method. Section 4 gives the simulation results of the number of reduced iteration and BER performance comparison between the modified and the ordinary V-BLAST method. Finally, section 5 concludes the paper.

II. MIMO SYSTEM MODEL

Let us assume a MIMO system with N_t transmit and N_r receiver antennas. The data stream is de-multiplexed into N_t independent sub-stream, and then each stream is encoded into transmit symbols using a rectangular QAM modulation at the transmitter. The received signal vector \mathbf{r} which has the N_r dimension can be expressed mathematically as

$$\mathbf{r} = \mathbf{H}\mathbf{a} + \mathbf{n} \quad (1)$$

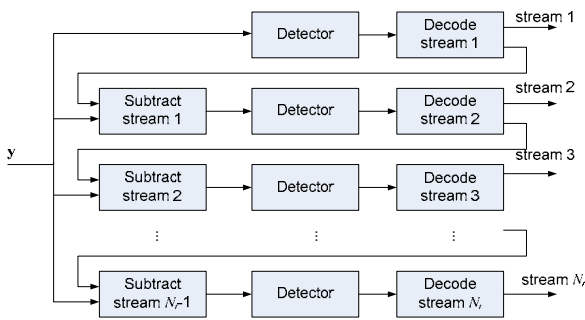


Fig. 1 The architecture of the successive interference cancellation (SIC) detecting algorithm for V-BLAST.

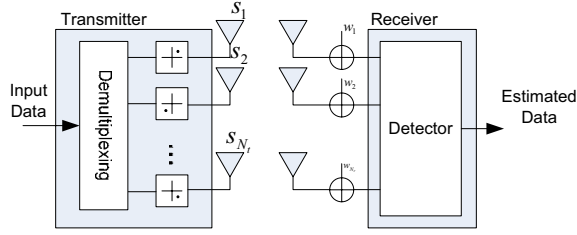


Fig. 2 MIMO System Model

where $\mathbf{H} = [h_{ij}] \in \mathbb{C}^{N_r \times N_t}$ is a quasi-static Rayleigh flat fading channel matrix, i.e. h_{ij} are independent and identically distributed (*i.i.d*) complex Gaussian with unit variance, $\mathbf{a} = (s_1, s_2, \dots, s_{N_t})^T$, $s_i \in \mathcal{A}$ is the transmitted signal vector, and the additive noise vector $\mathbf{n} = (w_1, w_2, \dots, w_{N_r})^T$ is iid complex Gaussian with zero mean and variance σ_w^2 . The signal constellation is \mathcal{A} . The column of \mathbf{H} are linearly independent, so that $N_r \geq N_t$. Note that it is customary to assume that all the entries of \mathbf{H} is independent provided that a rich scattering environment exists between the antennas.

We assume that the channel \mathbf{H} is perfectly known at the receiver. This assumption is also justified by the fact that the channel remains constant over a channel coherence time that is much longer than the transmit signal period [6].

III. THE V-BLAST ALGORITHM

As mentioned in Chapter II, the system model is $\mathbf{r} = \mathbf{H}\mathbf{a} + \mathbf{n}$ where \mathbf{r} is the received vector, \mathbf{a} is a vector of the transmit symbols and \mathbf{n} is a zero-mean white Gaussian noise vector with covariance matrix $\sigma^2 \mathbf{I}$. Some notations are used for describing the process of V-BLAST decoding: $Q(\cdot)$ is the symbol detection function, $(\mathbf{A})_i$ is the i^{th} column of the matrix \mathbf{A} , and $\|\mathbf{v}\|$ is the Euclidean norm of the vector \mathbf{v} . \mathbf{H}^+ is the Moore-Penrose pseudo-inverse of \mathbf{H} and $H_{k_i}^+$ is obtained

from \mathbf{H} by zeroing the $k_1^{\text{th}}, \dots, k_i^{\text{th}}$ column of \mathbf{H} . the transpose for \mathbf{w} is denoted by \mathbf{w}^T . The whole process is described in the following set of equations (2) and (3). In the initialization phase, we get the $\mathbf{r}, \mathbf{G}, \mathbf{k}$ corresponding the iteration number. The subscript number, or 1 stands for the first iteration.

Initialization:

$$\begin{aligned} r_1 &= \mathbf{r} \\ \mathbf{G}_1 &= (\mathbf{H}^+)^T \\ k_1 &= \arg \min_j \|(G_1)_j\| \quad : \text{ordering} \end{aligned} \quad (2)$$

Recursion :

$$\begin{aligned} w_{k_i} &= (\mathbf{G}_i)_{k_i} \\ y_{k_i} &= \mathbf{w}_{k_i}^T \mathbf{r}_i & : \text{nulling} \\ \hat{a}_{k_i} &= Q(y_{k_i}) & : \text{slicing} \\ r_{i+1} &= \mathbf{r}_i - \hat{a}_{k_i} (\mathbf{H})_{k_i} & : \text{canceling} \\ \mathbf{G}_{i+1} &= (\mathbf{H}_{k_i}^+)^T \\ k_{i+1} &= \arg \min_{j \in (k_1, \dots, k_i)} \|(G_{i+1})_j\| & : \text{ordering} \end{aligned} \quad (3)$$

In the recursive phase, nulling slicing, canceling and ordering process are performed sequentially. We can estimate the symbols at the slicing process, and make a new received signal \mathbf{r}_{i+1} by subtracting the estimated symbols. At the canceling process.

Since the SNR (signal to noise) ratio for the i^{th} sub-stream signal $SNR_i = |a_i|^2 / \sigma^2 \|\mathbf{w}_i\|^2$, $k_1 = \arg \min_j \|(G_1)_j\|$

corresponds to the strongest sub-stream signal. Similarly, k_i corresponds to the strongest sub-stream signal among the remaining $(M-i+1)$ sub-stream signals.

In the V-BLAST algorithm described above, it is consisted of M iterations and for each iteration, the strongest sub-stream signal among the remaining sub-stream signals is found and the corresponding weight vector is obtained. This means that the processes for finding the decoding order and finding the weight vectors are mixed together [4].

IV. THE PROPOSED MODIFIED V-BLAST

Generally, in successive interference cancellation detection scheme, later iterations have lesser cancellation effect because most of interference and noise components have been cancelled during the early stage of iteration through the 'ordering' step. Applying this property to V-BLAST detection, it can be interpreted as the bigger the difference of

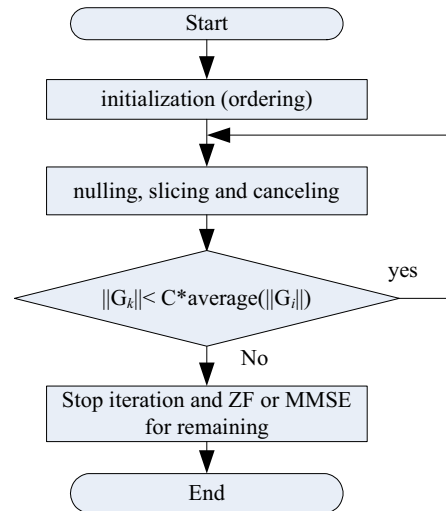


Fig. 3 Propose algorithm for modified V-BLAST

the norm of $\|(G_{i+1})_j\|$ in early iterations, the lesser the efficiency of symbol cancellation in late iterations.

Considering this property, we propose a modified V-BLAST algorithm based on stopping the iteration if its effect of cancellation is sufficiently small, this simplifying the calculation complexity. According to the ordering process of equation (3), in every iteration stage, ordinary V-BLAST algorithm selects the smallest norm of the remaining norm value, and performs the cancellation process. However, our proposed modified V-BLAST compares the selected smallest norm value with the average of the remaining norm values. If the selected norm value is smaller than the average norm value multiplied by a constant parameter C , it proceeds with the cancellation process. It means that the selected one is much smaller than others and it is well worth being canceled.

If the selected one is bigger, it stops the iteration process, and performs ZF or MMSE detection for the remaining received signals. The constant parameter C is a weighting factor, from zero to one. If C is zero, the proposed algorithm becomes the pure zero-forcing or MMSE detector's algorithm, and if C is one, it becomes the original V-BLAST detector.

The algorithm for modified V-BLAST can be represented by the flow chart of Fig. 3. $\|G_k\|$ is the selected norm value for k -th column of \mathbf{G} , and $\|G_i\|$ is the norm value for the remaining columns of \mathbf{G} .

V. SIMULATIONS

The computer simulation of BER performance and complexity comparison between the modified and original V-BLAST detections are performed for a MIMO system with four transmit and four receive antennas. MIMO Rayleigh fading channel and 16-QAM signals are used in this simulation. The channel state information is assumed known to the receiver. Fig. 4 compares the BER performances for different C parameter values. It can be seen from the figure

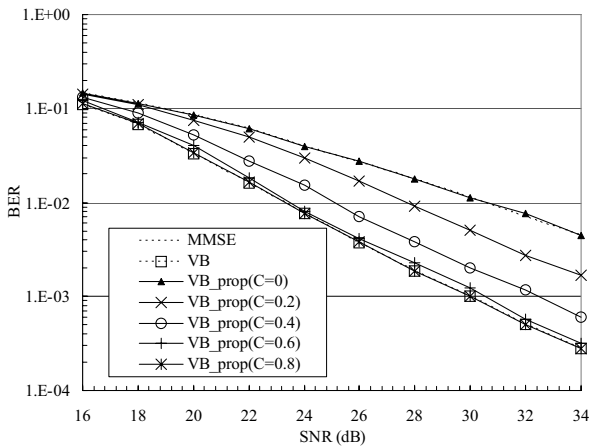


Fig. 4 BER Performance for 16 QAM 6x6 MIMO communications.

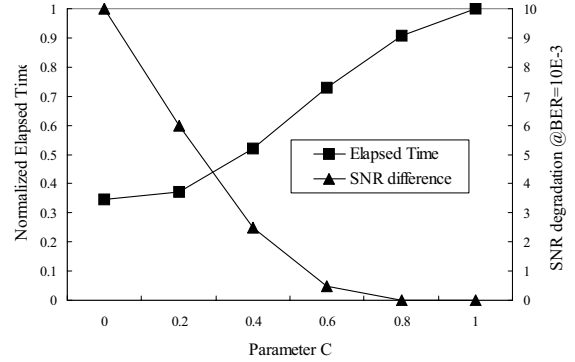


Fig. 5 Normalized computational time and SNR degradation.

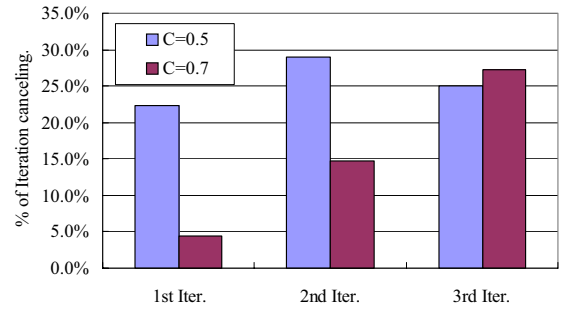


Fig. 6 Distribution of iteration canceling for each iteration.

that the performance graph fast approaches the original V-BLAST as parameter C increases to the maximum value of one. In the case of parameter $C = 0.6$, the performance difference between the V-BLAST and Proposed Simplified V-BLAST is less than 1 dB over the entire SNR range.

Fig. 5 shows the elapsed time of the proposed method normalized by the elapsed time of the original V-BLAST, and SNR degradation for $\text{BER}=10^{-3}$ against the parameter C . This elapsed time stands for the computational complexity and it is in proportion to the power consumption for the MIMO decoding process. For example, 0.4 dB degradation occurs with 73% computational time when parameter C is 0.6. In the case of 0.8 of C . There is no difference in the performance with 90% complexity of original V-BLAST.

Finally, Fig. 6 represents the distribution of canceling iteration against the stage of iteration for two cases of $C=0.5$ and 0.7 . We can see that the larger parameter C , the more canceling iteration.

The simulation results show that the modified V-BLAST method lowers the detection complexity significantly while achieving a very close BER performance as the original one.

VI. CONCLUSION

In this paper, we present a simplified V-BLAST scheme with low computational complexity. Compared with the ordinary V-BLAST detection, the proposed simplified method significantly lowers the complexity of the signal detection in MIMO system at a very little cost of BER performance, and

thus is a good candidate for the practical detection of MIMO signals.

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