A Two-Stage Detection Algorithm for the V-BLAST System

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Abstract – MIMO system (multiple antennas at the transmitter and receiver) is capable of very high theoretical capacities. Foschini et al proposed V-BLAST (Vertical-Bell Lab Layered Space-Time) code with a detection algorithm based on linear combination nulling and successive symbol cancellation. However this conventional detection algorithm requires time to execute these both operations. The time delay will be enhanced if the number of transmit antennas increase. In order to avoid this obstacle, parallel symbol cancellation (PSC) was proposed. But the performance is degraded. In this paper, we propose a two-stage detection algorithm derived from the combination of SSC and PSC to improve the BER performance. The proposed scheme is applied to Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) criterion. We also perform simulation to verify the analysis

I. INTRODUCTION

In recent research, it has been shown that the deployment of multiple antennas on both transmitter and receiver side provides a larger capacity compared to single antennas systems [1], [2], [3]. A multiple-input multiple-output (MIMO) system that employs this tendency is the V-BLAST (Vertical Bell Labs Layered Space-Time) architecture proposed in [3]. The structure is designed as a vertically layered coding, where independent code streams (called layers) are assigned to a certain transmit antenna. At the receiver, one way to execute the detection of this system is to use linear combination nulling. Nulling is carried out by linearly weighting the received signals in order to meet some relevant performance standard, such as zero-forcing (ZF) or minimum mean square error (MMSE). Zero-forcing was proposed in [1]. To attain better performance, nulling always comes together with successive symbol cancellation. Unfortunately, time delay appears in this detection algorithm. Furthermore, if we increase the number of transmit antennas this problem will be more severe. In order to combat this disadvantage, parallel symbol cancellation (PSC) without optimal order was proposed in [4]. However this proposal showed degradation in BER performance. Aiming at this point, we introduce the two-stage detection algorithm by combining SSC and PSC so that the performance will be improved.

This paper is organized as follows. In section II, the system overview is introduced. In section III, ZF V-BLAST detection is briefly reviewed. The two-stage detection algorithm is investigated in section IV. The results are compared in section V and concluding remark in section VI.

II. SYSTEM OVERVIEW

The V-BLAST system is considered with n_T transmit and $n_R \geq n_T$ receive antennas. The data is demultiplexed in n_T data sub-streams of equal length (called layers). These sub-streams are mapped into M-PSK or M-QAM symbols $t_1, t_2, ..., t_{n_T}$ and simultaneously transmitted over n_T antennas. We investigate the application under assumption uncoded symbols.

In order to outline the V-BLAST system, one time slot of the time-discrete complex base band model is examined. Let $t = \left[t_1 t_2 ... t_{n_T} \right]^T$ define the $n_T \times 1$ vector of transmit symbols, then the corresponding $n_R \times 1$ vector of receive symbols $r = \left[r_1 r_2 ... r_{n_R} \right]^T$ is given by

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$$r = Ht + n \quad (1)$$

In[2] (1), $r = \left[r_1 r_2 ... r_{n_R} \right]^T$ stands for the white Gaussian noise of variance σ_n^2 observed at the n_R receive antennas while the average transmit power of each antenna is normalized to one i.e. $E\left\{ tt^H \right\} = I_{n_T}$ and $E\left\{ nn^H \right\} = \sigma_n^2 I_{n_R}$.

The $n_R \times n_T$ channel matrix H

$$\mathbf{H} = \begin{pmatrix} h_{1,1} & \cdots & h_{1,n_T} \\ \vdots & \ddots & \vdots \\ h_{n_R,1} & \cdots & h_{n_R,n_T} \end{pmatrix} \quad (2)$$

includes i.i.d complex fading gains $h_{j,i}$ expressing the tap gains between transmit antenna i and receive antenna j with unit variance. We presume a flat fading environment, in which the channel matrix H is constant over a frame and changes independently from frame to frame (block fading channel). The distinct gains are assumed to be uncorrelated and are perfectly known in the receiver side.

III. ZERO-FORCING V-BLAST DETECTION

In this section, ZF criterion in V-BLAST architecture is reviewed. Two major operations are used: nulling and cancellation. With nulling, each sub-stream is regarded as the desired signal and the remaining are considered as interferences. At each detecting step, all undesired sub-streams are nulled by linearly weighting the receive vector r. In the literature, ZF and MMSE criteria are widely deployed. The decision statistic y_i of the $i-th$ sub-stream is calculated by multiplying the $i-th$ row of the decorrelating matrix D with the receive vector given by:

$$y_i = \left(D \right)_i r \quad (3)$$

where $\left(D \right)_i$ denotes row $i-th$ of decorrelating matrix D corresponding to the criterion in use. To attain better performance nulling always comes together with cancellation. At every detecting step, based on the decision the generated version is cancelled from the received signal before moving on to the next stage. The receive vector r is multiplied with a filter matrix D. Zero-forcing points out that the mutual interference between all layers will be completely suppressed. This can be achieved by the Moore-Penrose pseudo-inverse (denoted by $(.)^+$) of the channel matrix

$$D_{ZF} = H^+ = \left(H^H H \right)^{-1} H^H \quad r_i \quad (4)$$

The receive vector is linearly weighted with the nulling vector $\left(D \right)_i$ and the result is expressed by

$$y_i = \left(D \right)_i r = \left(D \right)_i \left(Ht + n \right) \quad (5)$$

$$y_i = t_i + \tilde{n}_i \quad (6)$$

y_i is considered as the decision statistic for the $i-th$ sub-stream where $\tilde{n}_i = \left(D \right)_i n$ is the noise enhancement. By using the quantization operation $Q\left[. \right]$ appropriately, the $i-th$ sub-stream can be estimated likely

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2 In this paper, $(.)^T$ and $(.)^H$ represents the matrix transposition and hermitian transposition, in that order. Furthermore I_a denotes the $a \times a$ identity matrix.

$$\hat{t}_i = Q[y_i] \quad (7)$$

A successive interference cancellation technique based on the ZF criterion was proposed in [2]. In this scheme, the signals are not detected in parallel, but one after another. The interference caused by the detected signal $\hat{t}_i$ is now extracted from the receive signal vector r_i

$$r_{i+1} = r_i - h_i \hat{t}_i \quad (8)$$

where h_i is $i-th$ column of the channel matrix. In successive symbol cancellation, the order detection becomes very important to the entire performance of the system. Let the order set $S = \{k_1, k_2, ..., k_{n_T}\}$ be a permutation of the integers 1, 2, …, n_T to specify the detection sequence. Thus the values $y_{k_1}, y_{k_2}, ..., y_{k_{nT}}$ are filtered one by one, the transmit signals $\hat{t}_{k1}, \hat{t}_{k2}, ..., \hat{t}_{k_{nT}}$ are estimated and the interference is cancelled out step by step according to equations (6) and (8). In order to obtain the minimum error probability, the optimal order is used. The sub-stream which has the largest post detection signal-to-noise ratio is detected first:

$$(SNR_{ZF})_{k_i} = \frac{E\{|t_{k_i}|^2\}}{E\{|n_{k_i}|^2\} \|(D)_{k_i}\|^2} \sim \frac{1}{\|(D)_{k_i}\|^2}\,. \quad (9)$$

<.> denotes the expectation over the constellation set. | . |, and || . || denote the complex amplitude and the vector norm respectively. Consequently, we choose the row $k_i - th$ of decorrelating matrix D with minimum norm and hence detect the corresponding sub-stream t_{k_i}

IV. THE TWO-STAGE DETECTION ALGORITHM

Our proposed algorithm is divided into two distinct stages.
Stage1: using successive symbol cancellation together with optimal order to obtain a good initial decision.
Stage2: using parallel symbol cancellation to attain the estimated value of transmit vector.
The proposed algorithm for Zero-Forcing criterion is described as follows:

Stage1:

Initialization

$i \leftarrow 1$ (a)

$D_1 = H^+$ (b)

$k_1 = \arg\min_j \|(D_1)_j\|^2$ (c)

Recursion

$y_{k_i,0} = (D_i)_{k_i} . r_i$ (d)

$\hat{t}_{k_i,0} = Q(y_{k_i,0})$ (e)

$r_{i+1} = r_i - \hat{t}_{k_i,0} (H)_{k_i}$ (f)

$(H)_{k_i} = 0$ (g)

$D_{i+1} = H^+_{k_i}$ (h)

$k_{i+1} = \arg\min_{j \notin \{k_1,...k_i\}} \|(D_{i+1})_j\|^2$ (i)

$i \leftarrow i+1$ (j)

Stage2:

Initialization

$k = 1$ (k)

$\hat{t}_{n,0} = \hat{t}_{k_i,0}$ n = 1,2,3,... n_T (l)

Recursion

$r_{n,k} = r - \sum_{i=1, i\neq n}^{n_T} \hat{t}_{i,k-1} (H)_i$ (n = 1,2,... n_T) (m)

$y_{n,k} = (D)_n . r_{n,k}$ (n)

$\hat{t}_{n,k} = Q(y_{n,k})$ (o)

$k = k + 1$ (p)

$(D)_n = [(H)_n]^+$

$(H)_n$ is the n-th column of H, $(D)_n$ is the n-th row of D, $y_{n,k}$ is the decision statistic, $\hat{t}_{n,k}$ is the estimated component of t_n, Q(.) denotes the slicing operation, (c,i) determine the elements of the optimal order; (d-f) compute the ZF-nulling vector decision statistic, and the estimated component of t; (g) executes successive symbol cancellation; (h) performs the new pseudo inverse matrix for the next step, (k-q) : parallel symbol cancellation and detection, obtain the estimated value of $t = (t_1, \ldots\ t_{n_T})^T$

V. SIMULATION RESULTS

In the simulation, we investigate the bit error rates (BER) for the V-BLAST system with (8, 8) and (12, 12) transmit and receive antennas deploying uncoded BPSK modulation through a flat Rayleigh fading channel. The simulation compares the proposed algorithm with optimal order SSC and PSC. The results of the (8, 8) system for Zero-Forcing criterion are shown in **Fig. 1.** It is obvious that PSC has a better BER performance compared to that of random order SSC. However, comparing the simulation result of PSC with that of the optimal order SSC, degradation can be observed. Finally, two-stage detection algorithm shows the best BER performance. The results of the (12, 12) system for MMSE criterion are given in **Fig. 2.** As evident from the figure, the two-stage detection algorithm exposes the best BER performance compared to those of PSC and optimal order SSC.

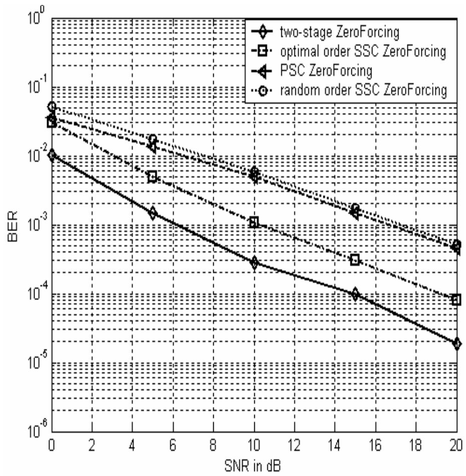

Fig. 1 Simulation Zero-Forcing with n_T = 8 and n_R = 8, uncoded BPSK symbols.

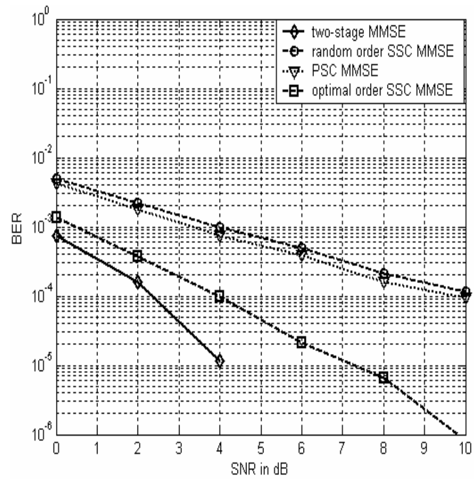

Fig. 2 Simulation MMSE with n_T = 12 and n_R = 12, uncoded BPSK symbols.

VI. CONCLUSION AND DISCUSSION

We have introduced a two-stage detection algorithm for the V-BLAST system. Instead of the parallel symbol cancellation without optimal order, we proposed the new detection algorithm with two distinct stages by combining the SSC with PSC. Our proposed algorithm shows the better BER performance for both Zero-Forcing and Minimum Mean Square Error criterion.

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