A Combination Of SSC And PSC
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. As an important space-time code, V-BLAST (Vertical-Bell Lab Layered Space-Time) code has been researched recently. The important operation of V-BLAST system is cancellation. However the conventional detection algorithm requires time to execute linear combination nulling and successive symbol cancellation. 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 combination of SSC and PSC to improve the system performance.**

Keywords **— V-BLAST, MIMO, Zero-Forcing, successive symbol cancellation, parallel symbol cancellation.**

1. 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 conventional adaptive antenna array (AAA) techniques [3], i.e. 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 cancellation (successive symbol cancellation). In addition, we can apply optimal order to achieve better performance. 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 a degradation in system performance. Aiming at this point, we introduce a combination of SSC and PSC so that the performance will be improved.

This paper is organized as follows. In section 2, the system overview is introduced. In section 3, the Zero-Forcing V-BLAST detection is reviewed. The combining model of SSC and PSC is investigated in section 4. The results are compared in section 5 and concluding remark is introduces in section 6.

2. System Overview

In this paper, we examine a V-BLAST system as illustrated in Figure. 1. The 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 $t_1,...,t_{n_T}$ and simultaneously transmitted over n_T antennas. Furthermore, we can use a forward error correction code to encode the data sub-streams before mapping. However, it is not addressed in this paper. We investigate the application under assumption uncoded symbols.

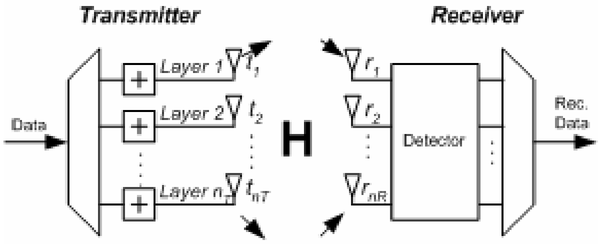

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Figure1. Model of A MIMO System With n_T Transmit And n_R Receive Antennas

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

$$r = Ht + n \tag{1}$$

In (1), $n = \left[n_1 \ldots n_{n_R}\right]^T$ 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

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

includes i.i.d complex fading gains h_{ji} 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.

3. 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 interferers.

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:

$$y_i = \left(D\right)_i r \tag{3}$$

where $\left(D\right)_i$ represents the i-th row of 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

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

The receive vector is linearly weighted with the nulling vector D_i and the result is expressed by

$$y_i = D_i r = D_i\left(Ht + n\right) \tag{5}$$

where D_i denotes row i-th of decorrelating matrix D

$$y_i = t_i + \tilde{n}_i \tag{6}$$

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

$$\hat{t}_i = Q\left[y_i\right] \tag{7}$$

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

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

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 $S = \left\{k_1, k_2, \ldots, k_{n_T}\right\}$ be a permutation of the integers $1, 2, \ldots, n_T$ to specify the detection sequence. Thus the values $y_{k_1}, y_{k_2}, \ldots, y_{k_{nT}}$ are filtered one by one, the transmit signals $\hat{t}_{k_1}, \hat{t}_{k_2}, \ldots, \hat{t}_{n_T}$ are

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

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:

$$\left(SNR_{ZF}\right)_{k_i} \frac{E\{|t_{ki}|^2\}}{E\{|n_{ki}|^2\}\|D_{ki}\|^2} \sim \frac{1}{\|D_{ki}\|^2} \qquad (9)$$

<.> 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 D_{k_i} of decorrelating matrix D with minimum norm and hence detect the corresponding sub-stream t_{k_i}

4. A combination of SSC and PSC

Firstly, the parallel symbol cancellation is reviewed. The PSC was introduced as a multistage parallel symbol cancellation model without optimal order. This detection algorithm is found in [4] and can be summarized as follows:

Initialization

$$k = 1 \qquad (11a)$$

$$D = H^{+} \qquad (11b)$$

$$y_0 = D.r \qquad (11c)$$

$$\hat{t}_{n,0} = Q\left(y_{n,0}\right) \ \left(n = 1,2,\ldots,n_T\right) \qquad (11d)$$

Recursion

$$r_{n,k} = r - \sum_{i=1,i\neq n}^{n_T} \hat{t}_{i,k-1}\left(H\right)_i \ \left(n = 1,2,\ldots,n_T\right) \qquad (11e)$$

$$y_{n,k} = \left(D\right)_n .r_{n,k} \qquad (11f)$$

$$\hat{t}_{n,k} = Q\left(y_{n,k}\right) \qquad (11g)$$

$$k = k+1 \qquad (11h)$$

$$\left(D\right)_n = \left[\left(H\right)_n\right]^{+} \qquad (11i)$$

It is clear that the initial decision is very important. Based on this point of view we apply the optimal order to the initial step so that we achieve a better performance.

Our proposed algorithm is divided into two distinguish stages and is described as follows:

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 is described as follows:

Stage1:

Initialization

$$i \leftarrow 1 \qquad (a)$$

$$D_1 = H^{+} \qquad (b)$$

$$k_1 = \arg\min_{j} \left\|\left(D_1\right)_j\right\|^2 \qquad (c)$$

Recursion

$$y_{k_i,0} = \left(D_i\right)_{k_i} .r_i \qquad (d)$$

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

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

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

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

$$k_{i+1} = \operatorname*{argmin}_{j\notin\{k_1,\ldots k_i\}} \left\|\left(D_{i+1}\right)_j\right\|^2 \qquad (i)$$

$$i \leftarrow i+1 \qquad (j)$$

Stage2:

Initialization

$$k = 1 \qquad (k)$$

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

Recursion

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

$$y_{n,k} = \left(D\right)_n .r_{n,k} \qquad (n)$$

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

$$k = k+1 \qquad (p)$$

$$\left(D\right)_n = \left[\left(H\right)_n\right]^{+} \qquad (q)$$

where

$\left(H\right)_n$ is the n-th column of H

$\left(D\right)_n$ 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) determines the elements of the optimal order; (d-f) computes 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) is parallel symbol cancellation and detection, obtain the estimated value of $t = \left(t_1,\ldots,t_{n_T}\right)^T$

5. Simulation Results

In the simulation, we investigate the bit error rates (BER) for a Zero-Forcing V-BLAST system with $n_T = 4$ transmit and $n_R = 4$ receive antennas deploying uncoded BPSK modulation through a flat Rayleigh fading channel. Figure 2 shows that PSC has a better BER compared to random order SSC. However, comparing the simulation results of PSC with optimal order SSC, a slight degradation can be observed. Finally, our proposed algorithm shows the best BER

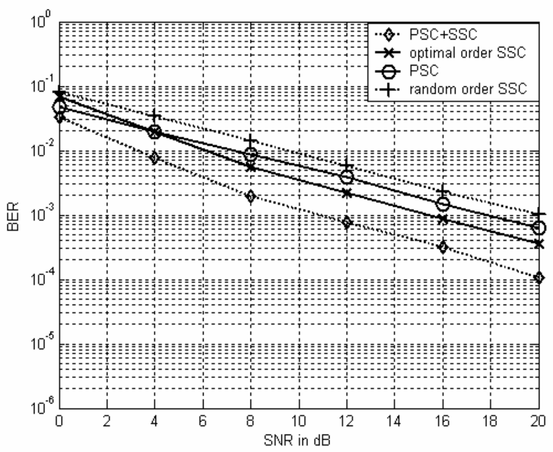

Figure 2. Simulation Zero-Forcing With (4×4) Antennas, Uncoded BPSK Symbols.

6. Conclusion and Discussion.

We have introduced a combination of SSC and PSC. Instead of the parallel symbol cancellation without optimal order, we proposed the new detection algorithm for PSC with optimal order. Obviously the BER is improved because we achieve a better initial decision.

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