Error Propagation Analysis of Different Detectors for V-BLAST MIMO Channels

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Abstract. In a highly-scattering wireless environment, Vertical Bell Laboratories Layered Space-Time (V-BLAST) is a promising MIMO spatial multiplexing scheme, which can achieve high channel capacity without any increase in bandwidth and transmission power. In this paper a Parallel Interference cancellation (PIC) detection and ordered successive interference cancellation (OSIC) schemes are proposed to reduce the high computational complexity and large system delay caused by the pseudo inverse of channel matrix and the ordering process. The V-BLAST algorithms with ordered and un-ordered ZF / MMSE detectors are compared for the error propagation. The V-BLAST algorithm is combined with various Transmitter / Receiver antenna selection combination to achieve high channel capacity while sharing the spectral resources over a MIMO channel. The received signal after interference cancellation passes through linear equalization or parallel interference cancellation with low complexity. Simulation results shows, the proposed algorithms can decrease the computational complexity without performance loss.

Keywords: V-BLAST, OSIC, PIC, ZF, MMSE.

1 Introduction and Related Work

As a upcoming new 4G technology, MIMO (Multiple Input and Multiple Output) channels with Flat fading conditions are having multiple transmit and receive antennas offers relatively huge spectral efficiencies compared to SISO (Single Input and Single Output) channels [1][2][3]. As per the literature available, Capacity increases linearly with the number of transmit antennas as long as the number of receive antennas are greater than or equal to the number of transmit antennas. To achieve this capacity, Diagonal BLAST was proposed by Foschini [3]. This scheme utilizes multi-element antenna arrays at both ends of wireless link. However, the

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computational complexities of D-BLAST implementation led to V-BLAST which is a modified version of BLAST [4]. Two nulling criteria, namely Zero-Forcing (ZF) [5] and Minimum Mean Squared Error (MMSE) [8], are utilized as detection algorithms.Originally, the BLAST detection scheme was based on a successive interference cancellation [4] [5] [6]. A parallel interference cancellation scheme was also proposed later [7]. BLAST detectors including both SIC and PIC suffer from the error propagation problem, so that they lead to the poor energy efficiency which can be improved if the previously detected layers (symbols) were perfectly cancelled because the following layers depend highly on the result of the previous detected signals. The error propagation problem of BLAST detectors can be reduced with channel coding and interleaving [9] [10].

2 The Proposed V-BLAST Scheme with MIMO

The proposed V-BLAST scheme with MIMO channel is shown in Fig. 1. The received vector with size $n_R \ X1$ is modeled by

$$r = Ha + n. \tag{1}$$

H represents the channel matrix with dimension $n_R \times n_T$, whose element $h_{i,\,j}$ represents the complex fading coefficient for the path from transmit j to receive antenna i. These fading coefficients are modeled by an independent zero mean complex Gaussian random variable with variance 0.5 per dimension. a denotes the vector of transmitted symbols with dimension $n_T X\ 1$, n represents a complex vector of independent samples of AWGN over each received antenna with zero mean and variance σn^2.

The nulling matrix G is described in Equations 2 and 3 for the ZF and MMSE criteria with the form of pseudo-inverse of the channel matrix H:

$$G = (H^+ \ H)^{-1} \ H^+ \tag{2}$$

$$G = (H^+ H \ + \ \sigma_n^2 / \sigma_d^2 \ )^{-1} \ H^+ \tag{3}$$

Where σ_n^2 / σ_d^2 denote the inverse of signal-to-noise ratio at each receive antenna.

H^+ represents the conjugate transpose matrix of channel matrix *H.*

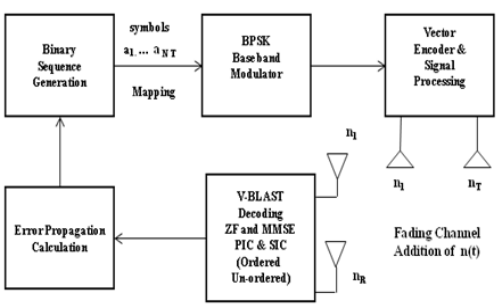

Fig. 1. Proposed System diagram of V-BLAST scheme in MIMO configuration

Figure.1 shows the proposed V-BLAST system model. Here the transmitted symbols are decoded first, and then the receiver needs to estimate the channel matrix. In this simulation, the fading channel characteristics are assumed to be known perfectly at the receiver. The transmitter consists of a binary random generator, a BPSK modulator and a vector encoder. The binary random generator generates the transmitted bits. These bits are modulated in the BPSK modulator. It is assumed that each symbol has an ideal rectangular pulse shape and may be sampled with a single point per symbol. The vector encoder maps the symbols to each antenna. In the channel block, the transmitted symbols undergo Rayleigh fading and additive noise. Rayleigh fading channel coefficients are generated with two independent Gaussian random variables with unit variance. The channel is assumed to be quasistationary, that is, the channel coefficients do not vary during the given time period. The receiver is made up of decoding processing and an error rate (BER) calculation block. Only SIC needs proper ordering process for interference cancellation (at each layers) using maximum iterations. But PIC does not need to consider the ordering issue since it cancels out all other paths of interference in the same stage (iteration). As shown in the figure.1, transmitted bits are demultiplexed into n_T parallel sub streams. Each sub stream is modulated using BPSK, interleaved and then assigned to a transmit antenna. As such, the number of layers is n_T and the spatial rate is b_{nT}. Since each layer is associated with a fixed transmit antenna, this architecture can accommodate applications with possibly different data rates and/or different users. The spatial diversity achieved by this scheme varies between one and n_R, depending on the detection scheme employed at the receiver. For instance, when interference cancellation and suppression is used, the first layer detected will have a spatial diversity of $n_R - n_T + 1$ because the other layers are suppressed. The last layer detected, on the other hand, will have a spatial diversity of n_R since the $n_T - 1$ previously detected layer is subtracted from the last layer, i.e., there is no suppression but rather cancellation.

The Receiver block consists of ordered and non-ordered ZF/MMSE detectors, which requires knowledge of the SNR at the receiver. Finally the BER is calculated by comparing the originally transmitted symbols with received symbols that are estimated at the receiver.

3 Comparison of OSIC and PIC

As per the previous surveys in the areas of symbol Interference cancellation schemes, there are mainly two types of detection schemes. They are OSIC and PIC schemes. The OSIC detection algorithm operates by successively canceling out one layer per iteration. The ordering of detected layers gives effect to the performance of the SIC detector. The nulling matrix is first initialized with Equations (2) and (3) for ZF and MMSE criteria respectively, assuming perfect channel estimation. For the ordering scheme, we determine the biggest post-detection signal-to-noise ratio. This corresponds to choosing the minimum norm row of the nulling matrix G in each iteration. First the layered signal is decoded with row vector of G suppressing the signals from all other antennas shown in Equation 4. The received signal after ith layer interference cancellation is formulated by

$$r_{i+1} = r_i - \text{est}(a_i)(H)_i \quad (4)$$

Where ai is the decoded symbols in the ith step. (H)i is the ith column of channel matrix. G is newly updated by nulling out the previous pseudo-inverse of the channel matrix. This procedure is repeated until symbols from all transmit antennas are decoded in a similar manner. The non-ordered scheme does not need to determine the largest post-detection SNR but chooses the row vector of nulling matrix randomly. The PIC-based V-BLAST detector does not obtain the gain with applying the ordering of the layers. In the first stage, all layers with Equation. (5) Are detected simultaneously.

$$\text{est}(a) = G\, r \tag{5}$$

Where G is the pseudo-inverse matrix of the channel matrix with size $n_T\, X\, n_R$, r is the received symbol vector and est (a) is a vector form of all detected layers. Equation (6) describes the cancellation process, which subtracts the interference of the other $(n_T\, X\, 1)$ layers. The received signal after first step interference cancellation is formulated by

$$r_k = r - \sum_{j=k} \text{est}(a_j)\ (H)_j. \tag{6}$$

Where rk is the received symbol vector applied with the interference cancellation of all but the k^{th} layer, (H) j is the j^{th} column vector of channel matrix and est(a_j) is the computed j^{th} layer symbol that is the j^{th} element of the estimated symbol vector. In the second stage, the new nulling matrix is recalculated with the channel matrix nulling out the all but the kth layer. Therefore, the nulling matrix becomes a row vector with size $(1\times n_R)$ as Equation. (7).

$$G_k = C\, H^{+}_k \tag{7}$$

By multiplying rk from Equation. (6) withGk from Equation. (7), the PIC-based V-BLAST detector recovers the all components of the transmitted symbol vector a.

4 Results and Discussions

Based on the effect of error propagation, OSIC and PIC detector schemes with MIMO V-BLAST are illustrated in this section using mat lab simulation results. Here, we compare the performance for ordered and non-ordered ZF/MMSE detection algorithms. The performance of individual layers of 4Tx X 4Rx MIMO systems is compared for error propagation. Figure 3 shows the simulated results of ZF / MMSE nulling algorithms with ordered and un-ordered algorithms. Here, the error propagation has improved for ZF-OSIC and MMSE-OSIC with ordered technique. The MMSE-SIC ordered technique works still better at maximum value of SNR (i.e. around 14 dB) compared to ZF-SIC. Similarly, figure 4 depicts the simulated results for PIC/OSIC detector techniques with 4Tx X 4Rx MIMO systems for ZF / MMSE methods. The improved performance of MMSE technique is adequate. Figure 5 displays 2Tx X 2Rx V-BLAST MIMO scheme simulation for with ordered ZF/MMSE-SIC in Rayleigh faded Channel. The simulation results with maximum SNR limits and its corresponding BER values are clearly seen from the performance comparison table. These results clearly show 8-10 dB improvement in SNR with respect to error propagation for MMSE detectors. In the ZF criterion, when a layer is detected, the interference coming from undetected layers is suppressed, whereas in the MMSE criterion, a compromise between interference suppression and noise reduction is achieved.

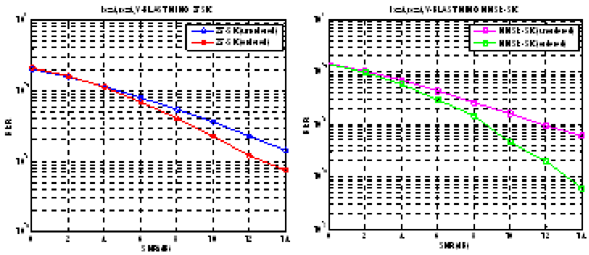

Fig. 2. Comparison of ZF & MMSE with SIC in unordered and ordered detectors

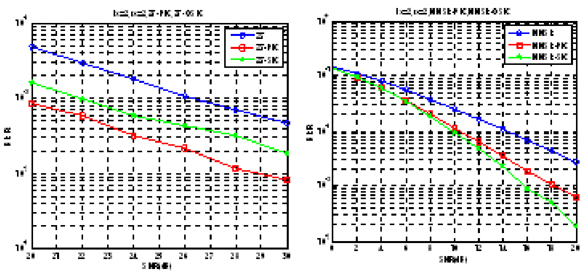

Fig. 3. Comparison of ZF, ZF - SIC and ZF-PIC MMSE, MMSE – SIC, MMSE-PIC

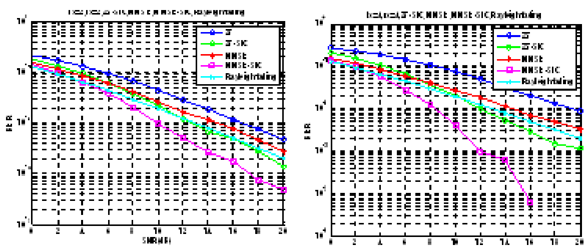

Fig. 4. Simulation results with ordered ZF-SIC and MMSE-SIC in Rayleigh faded Channel

Table 1. Performance with BER from all possible Interference Cancellation Detectors

SL.No	Type of the Detector	Maximum SNR limit	BER (Approximation)
1	ZF-SIC (Un-ordered)	14 dB	Nearly Equal to 10^{-1}
2	ZF-SIC (Ordered)	14 dB	Below 10^{-2}
3	MMSE (Un-ordered)	14 dB	Well Below 10^{-2}
4	MMSE (ordered)	14 dB	Below 10^{-3}
5	ZF-PIC	30 dB	Nearly Equal to 10^{-4}
6	MMSE-PIC	20 dB	Nearly Equal to 10^{-4}

5 Conclusions

As per the table, simulated results show the Ordered MMSE SIC performs better than un-ordered detectors. PIC method has also having limitation over OSIC nulling techniques. While both detection approaches are asymptotically equivalent, the ZF approach is less practical than the MMSE approach because the complete interference suppression achieved by ZF comes at the expense of enhancing the noise power, which leads to performance degradation. Another difference between the two schemes is that the constraint $n_R \geq n_T$, that is required for the ZF detector can be relaxed for the MMSE detector.

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