Layered Space-Time Block Codes with Iterative Decoding

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Abstract

Layered space-time coding (LST) architectures are able to achieve high capacities due to the fact that they transmit independent information on separate antennas. Sub-optimal decoding schemes such as zero-forcing (ZF) and minimum mean squared error (MMSE) are commonly used due to their lower complexity but make the system more susceptible to the effects of error propagation (EP) through the detected layers. In this paper we propose a LST architecture which employs space-time block codes on one of its layers to radically reduce the effect of EP at the expense of throughput. Simulation results show that error rate performances, close to the EP free performance are achieved making the trade-off in throughput equitable. The increase in diversity also allows for higher modulation levels to be used thereby achieving a target capacity with improved error rate performance.

1. Introduction

The use of multiple transmit and receive antennas has been shown to improve the capacity (bits/sec/Hz) of wireless channels significantly [1]. Research work carried out in the area of multiple-input multiple-output (MIMO) systems has produced schemes which apply the concept of space-time coding and are able to provide improved performance and increased capacity compared to single transmit and receive antenna schemes.

BLAST and space-time block codes [2] represent two extremes of space-time coding. The former separates the symbols in spatial dimension to achieve high rates (or throughput), while the latter uses temporal dimension to construct orthogonal spreading codes with full diversity but with large rate penalty. Efficient exploitation of spatial and temporal dimensions calls for a balance of diversity and rate as proposed in [3] and [4], where rate is traded-off for diversity. We propose such an approach for transmit diversity utilisation that combines layered space-time coding with space-time block coding in the spatial and temporal domains. The scheme is called 'Layered Space-Time Block Coding' (L-STBC) and is applicable for more than two transmit antenna configurations and uses a two step iteration at the receiver for decoding.

The remainder of this paper is set out as follows: in section 2 we present the performance of a BLAST scheme with perfect decisions ('Genie-BLAST') at each layer and compare it to that of the imperfect case. Section 3 introduces the system model of our proposed scheme and section 4 compares simulation results to the case of Genie-BLAST. We conclude the paper with some general remarks.

2. Genie-BLAST

The general BLAST receiver architectures are based on a layer by layer peeling method, where the decision made on one layer is used to remove its interference from all subsequent layers. An imperfect decision at a certain layer leaves an element of interference from that layer in all subsequent layers to be decoded. This increases the signal to interference plus noise ratio (SINR) of the subsequent layers. This effect is known as error propagation (EP). Genie-BLAST is a special ideal case scenario in which all the decisions at each layer are correct (no EP).

The simulations for Figs. 1 and 2 [5] use a configuration with 4 transmit and 4 receive antennas and uncoded QPSK modulation. In Fig.1, the error curve for the first decoded layer decays inversely proportional to the SNR, therefore showing a diversity level of one. The subsequent curves for antennas 2 through 4 decay much steeper. This is due to the perfect removal of interference from previously detected symbols, thereby increasing the diversity level up to 4. This happens in the case when there is only one signal left to be detected by the four receive antennas. Fig. 2 shows the original BLAST case in which the effect of EP degrades the performance quite significantly. Here we can see that hardly any improvement in performance is achieved when proceeding through the detection layers.

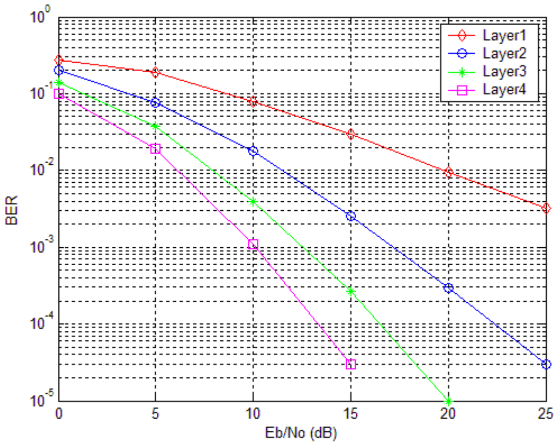

Fig. 1 Genie-BLAST (no EP)

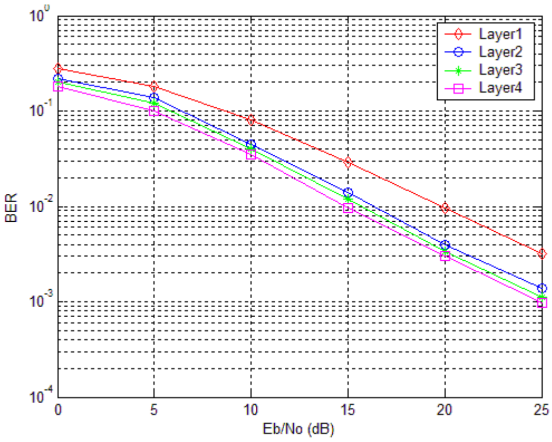

Fig. 2 Original BLAST with EP

3. L-STBC System Model

We consider a wireless communications system with $M_T>2$ transmit antennas and $M_R \geq M_T$ receive antennas. Perfect channel state information (CSI) is assumed at the receiver and all antennas transmit with the same power. The channel is modeled by a $M_R \times M_T$ matrix $\mathbf{H}$ with elements h_{ij}, denoting the channel fading coefficient between transmit antenna j and receive antenna i. The coefficients h_{ij} are assumed constant over two symbol periods and are modeled as independent samples of complex Gaussian random variables with mean zero and variance 0.5 per dimension.

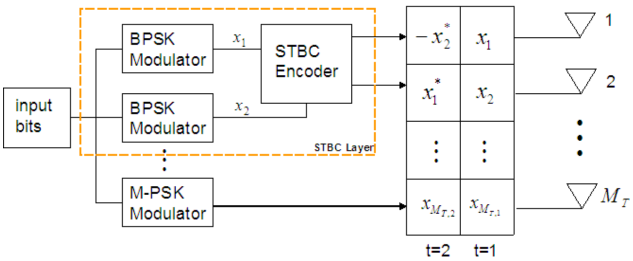

Fig. 3 Transmitter Architecture for Iterative Layered Space-Time Block Coding

Transmission frames have a length of two symbol periods and decoding is performed on a frame by frame basis. At each frame period, $2l+2k(M_T-2)$ bits arrive at the transmitter, where l and k are the number of bits per symbol chosen for the STBC layer and the independent layers respectively. The first $2l$ bits are sent to the 2^l-PSK modulators prior to STBC encoding as shown in Fig. 3 (l=1). The remaining bits are split and forwarded on to the M_T-2 2^k-PSK modulators over two time periods. The $M_T \times 2$ transmitted column vector is given as

$$X = \begin{bmatrix} x_1, x_2, \ldots, x_{M_T,1} \\ -x_2^*, x_1^*, \ldots, x_{M_T,2} \end{bmatrix}^T \qquad (1)$$

where $[\bullet]^T$ denotes the transpose operation and $x_{M_T,t}$ is the output of the M_T^{th} modulator at time t.

Detection at the receiver is done over two symbol periods. The received M_R×1 column vector at time t is given as

$$r_t = \mathbf{H}X_t + N_t \tag{2}$$

where X_t is the t^{th} column of X and N_t is the M_R×1 noise column vector at time t. The components of N_t are independent samples of a zero-mean complex Gaussian random variable with variance $N_o/2$ per dimension. For the sake of convenience we define the constant K as the number of independent transmit antennas ($K= M_T-2$).

In the first iteration we attempt to remove the interference in the STBC layer caused by the signals from the K independent antennas. We obtain a K×1 column vector y_t, which contains the soft estimates of the signals from the K independent layers at time t given as

$$y_t = \mathbf{w}r_t \tag{3}$$

where $\mathbf{w}$ which is a $K\times M_R$ matrix given as

$$\mathbf{w} = \left(\mathbf{h}^H\mathbf{h} + \frac{N_o}{2} I_{M_T}\right)^{-1}\mathbf{h}^H \tag{4}$$

and $\mathbf{h}$ is a matrix containing the last K columns of matrix $\mathbf{H}$. We now form a new vector $\mathbf{z}_t$, which represents a soft estimate of the summed interference from the K independent layers at time t, and is given as

$$\mathbf{z}_t = \mathbf{h}y_t\,. \tag{5}$$

This interference is subtracted from the received vectors r_t to form the vectors $r_t^{'}$ as follows

$$r_t^{'} = r_t - \mathbf{z}_t \tag{6}$$

The vectors $r_t^{'}$ at times $t=1$ *and* 2 are forwarded to the STBC decoder given in [2] for the G_2 matrix with M_R receive antennas, to produce the outputs $\hat{x}_1$ and $\hat{x}_2$, which are the estimates of the signals transmitted on antennas l and 2 respectively. In the second iteration, the interference from the STBC layer is recreated and subtracted from the received vector r_t as follows

$$r_t^{''} = r_t - \overline{\mathbf{h}}v, \quad v = \begin{cases} \begin{bmatrix}\hat{x}_1 & \hat{x}_2\end{bmatrix}^T & \forall t = 1 \\ \begin{bmatrix}-\hat{x}_2^* & \hat{x}_1^*\end{bmatrix}^T & \forall t = 2 \end{cases} \tag{7}$$

where $\overline{\mathbf{h}}$ is a matrix made up of the first two columns of $\mathbf{H}$ and $r_t^{''}$ is the new received vector without the interference from the STBC layer. We then repeat steps (3-4), replacing r_t with $r_t^{''}$ to produce a K×1 column vector $y_t^{''}$ as the new decision statistics. These are then decoded using the 2^k-PSK demodulators to give us the recovered symbols $\hat{x}_{3,t} \ldots \hat{x}_{M_T,t}$ transmitted on the K in independent layers at time t. The bits received are obtained by a simple constellation de-mapping operation on the recovered symbols.

4. Simulation Results

Fig. 4 compares the 4^{th} layer performance of our proposed L-STBC to the 3^{rd} and 4^{th} layer of Genie-BLAST for a 4 transmit and 4 receive antenna configuration. The L-STBC configuration used is QPSK on the STBC layer and 8-PSK on the independent layers, providing a total spectral efficiency of 7b/s/Hz. The Genie-BLAST configuration used is QPSK on all four layers providing a total spectral efficiency of 8b/s/Hz. At a target BER of 1×10^{-3}, L-STBC is shown to provide a 1dB improvement in performance compared to 3^{rd} layer Genie-BLAST and is within 1dB of 4^{th} layer Genie-BLAST. This is a 10dB improvement over the original BLAST 4^{th} layer performance shown in Fig. 2. The diversity level of the 4^{th} layer D4, for L-STBC lies in the region $M_R – M_T+3<D4< M_R – M_T+4$.

Figure 5 compares the BER performances of three (4,4) antenna configuration schemes. VB1 (7 b/s/Hz) uses BPSK on the first layer and QPSK on the remaining three, based on the rate-diversity trade-off proposition in [4]. VB2 (8 b/s/Hz) uses QPSK on all four layers and employs optimal post-detection SNR ordering at the receiver as proposed in [6]. L-STBC (8 b/s/Hz) uses QPSK on the first layer and 8-PSK on the independent layers and is shown to yield gains of 8 dB and 3.5 dB at a target BER of 1×10^{-2} over VB1 and VB2 respectively.

Comparing the 4th layer performance of V-BLAST in figure 2 with that of L-STBC in figure 4, we have shown that a 1b/s/Hz trade-off in rate can provide a 10dB improvement at a target BER of 1×10^{-3}.

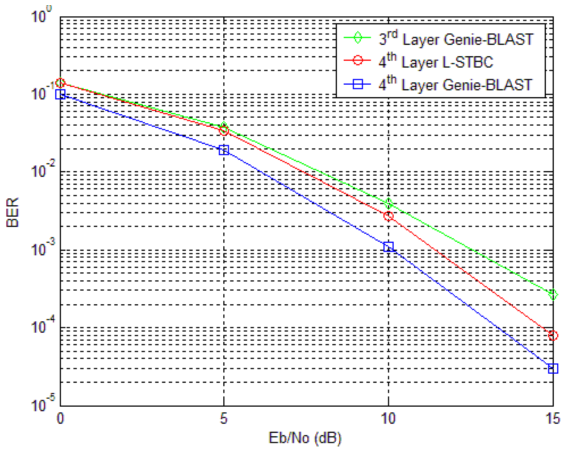

Fig. 4 Performance comparison of L-STBC vs. Genie-BLAST

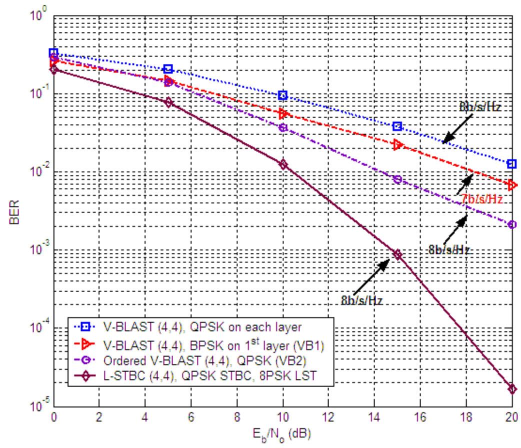

Fig. 5 Overall performance comparison of L-STBC with other Layered Architectures

5. Conclusion

The effect of EP through the detected layers is a serious impediment to good overall performance of BLAST systems and makes it hard for original BLAST to get near the possible capacity of the MIMO channel. On an overall performance comparison, L-STBC is shown to significantly outperform other variations of V-BLAST without any rate penalty (Fig. 5). The iterative process used in the L-STBC scheme is limited to two iterations and hence does not demand any major complexity in return for the improved performance. We are currently investigating the applicability of the L-STBC methodology to space-time spread spectrum CDMA systems for improved multi-user detection.

6. References

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