Performance Evaluation of Space Time Block Coded Spatial Modulation, Vertical-BLAST and Diagonal-BLAST Space Time Block Code

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***Abstract*: — Multiple Input Multiple Output MIMO, Space-Time Coding (STC) improves the BER by adding diversity in the presence of a channel fading. The V-BLAST and D-BLAST techniques are designed to improve the data rate. The performance of these techniques is highly dependent on the MIMO channel environment. Space-time block coded spatial modulation (STBC-SM*)* combines spatial modulation (SM) and space-time block coding (STBC) to take advantage of the benefits of both. In the STBC-SM scheme, the transmitted information symbols are expanded not only to the space and time domains but also to the spatial (antenna) domain which corresponds to the on/off status of the transmit antennas available at the space domain, and therefore high spectral efficiency along with diversity advantage of STBC. The performance of the STBC-SM, V-BLAST and D-BLAST are compared at high and low SNR environment. It is observed that STBC-SM performs better than V-BLAST and D-BLAST but with more decoding complexity.**

Keywords: MIMO, STBC, V-BLAST, D-BLAST, STBC-SM

I. Introduction:

The use of multiple antennas at both transmitter and receiver is an effective way to improve capacity and reliability over those achievable with single antenna wireless systems. Capacity increases linearly with signal-to-noise ratio (SNR) at low SNR, but increases logarithmically with SNR at high SNR. In a MIMO system, a given total transmit power can be divided among multiple spatial paths (or modes), driving the capacity closer to the linear regime for each mode, thus increasing the aggregate spectral efficiency.

As observed in Figure 1, [1], MIMO systems enable high spectral efficiency at much lower required energy per information bit. Here M stands for no. of input-output elements i.e. antenna. Spectral efficiency is observed to be improved with increase in no. of input, output elements of MIMO system.

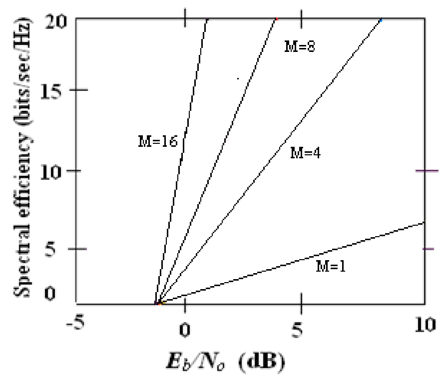

Figure 1 Spectral Efficiency Versus Normalized Energy per information bit (Eb/No)

The increasing demand for high data rates and, consequently, high spectral efficiencies has led to the development of spatial multiplexing systems such as V-BLAST (Vertical-Bell Lab Layered Space-Time). Since the development of the Bell Laboratories layered space-time (BLAST) approach to LST processing for MIMO systems, a large number of publications have addressed the performance evaluation or the complexity of non-adaptive STC MIMO techniques under specific channel conditions such as independent channel fading versus spatially correlated fading, high SNR versus SNR limiting.

The ability of any specific non-adaptive STC MIMO technique to get benefit of the array gain, the diversity order, or the spatial multiplexing gain will vary depending on the environment conditions.

The BLAST techniques; V-BLAST and D-BLAST are designed to improve the data rate. The performance of these techniques is highly dependent on the MIMO channel environment. The high SNR environment with spatially uncorrelated fading is well conditioned for achieving spatial multiplexing gain through V-BLAST. While, the low SNR or the fading is spatially correlated, the MIMO channel is much less able to support spatial multiplexing and performance is improved through the additional diversity order provided by D-BLAST.

A high-rate, low complexity MIMO transmission scheme, called STBC-SM, is an alternative to techniques such as V-BLAST and D-BLAST. The number of required RF chains is only two in this scheme, and the synchronization of all transmit antennas is not required.

II. THE BLAST SYSTEM ARCHITECTURE

Bell Labs Layered Space-Time Architecture (BLAST) is a transceiver architecture for offering spatial_multiplexing over multiple-antenna wireless_communication systems. Such systems have multiple antennas at both the transmitter and the receiver to exploit the many different paths between the two.. BLAST was developed by Gerard__Foschini at Lucent Technologies' Bell_Laboratories (now Alcatel-Lucent Bell Labs). By careful allocation of the data to be transmitted to the transmitting antennas, multiple data__streams can be transmitted simultaneously within a single frequency_band .The data_capacity of the system then grows directly in line with the number of antennas. The architecture of two BLAST techniques is shown below [5].

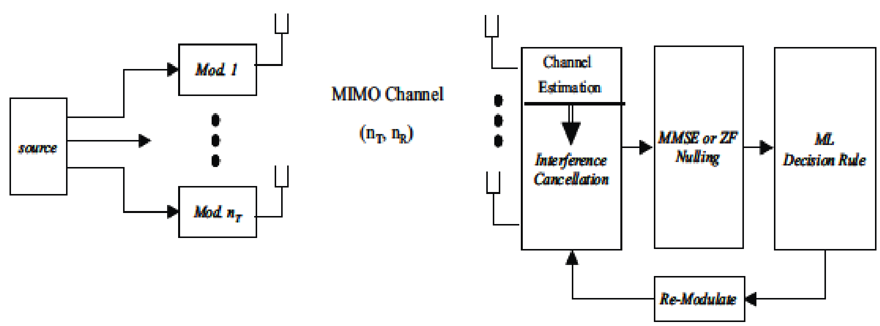

Figure 2: V BLAST Architecture

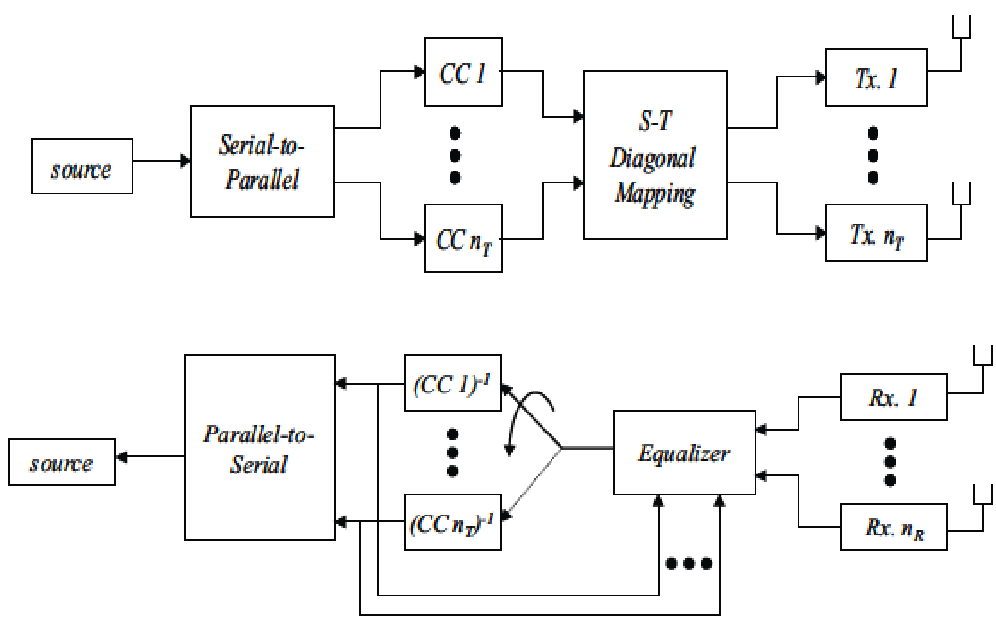

Figure 3: D BLAST Architecture

The non-adaptive LST codewords mapping of both V-BLAST and D-BLAST [3] for such system is illustrated in figure 4.

$$\begin{pmatrix} x_1^1 & x_1^2 & x_1^3 & x_1^4 \\ x_2^1 & x_2^2 & x_2^3 & x_2^4 \\ x_3^1 & x_3^2 & x_3^3 & x_3^4 \\ x_4^1 & x_4^2 & x_4^3 & x_4^4 \end{pmatrix} \qquad \begin{pmatrix} x_1^1 & x_1^2 & x_1^3 & x_1^4 \\ 0 & x_2^1 & x_2^2 & x_2^3 \\ 0 & 0 & x_3^1 & x_3^2 \\ 0 & 0 & 0 & x_4^1 \end{pmatrix}$$

V-BLAST **D-BLAST**

Figure 4V-BLAST and D_BLAST codeword mappings

V-BLAST and D-BLAST mapping ($nT = nR = 4$) Where nT is the number of transmit antennas and nR the number of receive antennas, x_t^i denotes the modulator output symbols, where i represents the layer number and t is the time interval. Few practical wireless environments exist to accommodate these non-adaptive LST designs at all times. V-BLAST is able to improve MIMO spectral efficiency in the Rayleigh fading channel as it can fully get use of the rich scattering and high signal quality for spatial multiplexing purposes, but may potentially result in unacceptable error performance as channel fading becomes spatially correlated or as errors in channel state information (CSI) increase due to low receiver SNR. Similarly, D-BLAST, which provides full diversity encoding, is able to maximize diversity order for the benefit of improved link reliability, but it results in a conservative throughput than could otherwise be achieved with additional spatial multiplexing gain.

In V BLAST systems, a high level of inter-channel interference (ICI) occurs at the receiver since all antennas transmit their own data streams at the same time. This further increases the complexity of an optimal decoder exponentially, while low-complexity suboptimum linear decoders, such as the minimum mean square error (MMSE) decoder, degrade the error performance of the system significantly.

III. Space Time Block Coded Spatial Modulation: STBC-SM

The basic idea of SM is an extension of two dimensional signal constellations (such as M-ary phase shift keying (M-PSK) and M-ary quadrature amplitude modulation (M-QAM), where M is the constellation size) to a third dimension, which is the spatial (antenna) dimension. Therefore, the information is conveyed not only by the amplitude/phase modulation (APM) techniques, but also by the antenna indices. The error performance of the SM scheme [2] is improved approximately in the amount of 4 dB by the use of the optimal detector under conventional channel assumptions and that SM provides better error performance than V-BLAST.

In this technique information is conveyed with an STBC matrix that is transmitted from combinations of the transmit antennas of the corresponding MIMO system. The Alamouti code is chosen as the target STBC to exploit. As a source of information, we consider not only the two complex information symbols embedded in Alamouti's STBC, but also the indices (positions) of the two transmit antennas employed for the transmission of the Alamouti STBC.

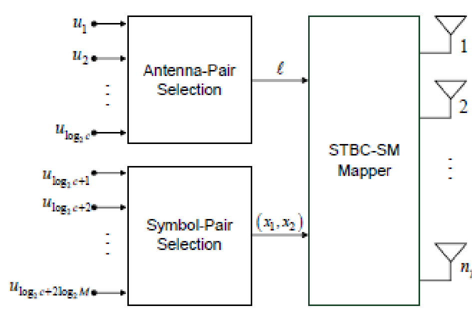

Figure 5: Block diagram of the STBC-SM transmitter

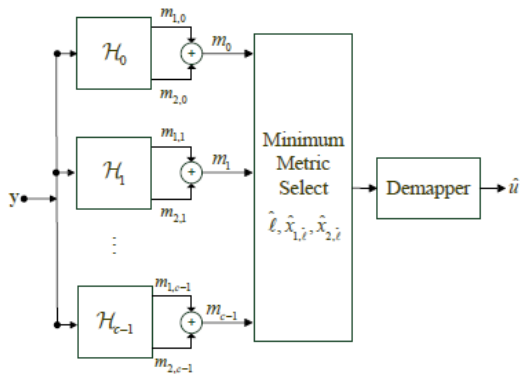

Figure 6: Block Diagram of the STBC-SM Receiver

A general technique is presented in figure 5 and figure 6 for constructing the STBC-SM scheme for any number of transmitting antennas. A low complexity Maximum Likelihood ML decoder is derived for the STBC-SM system, to decide on the transmitted symbols as well as on the indices of the two transmit antennas that are used in the STBC transmission. It is observed [2] that STBC-SM scheme has significant performance advantages over the SM with an optimal decoder, due to its diversity advantage.

In the STBC-SM scheme, both STBC symbols and the indices of the transmit antennas from which these symbols are transmitted, carry information. We choose Alamouti's STBC, which transmits one symbol pcu (Per Channel Use) , as the core STBC due to its advantages in terms of spectral efficiency and simplified ML detection. In Alamouti's STBC, two complex information symbols ($x1$ and $x2$) drawn from an M-PSK or M-QAM constellation are transmitted from two transmit antennas in two symbol intervals in an orthogonal manner by the codeword

$$\mathbf{X} = (\mathrm{X}_1 \quad \mathrm{X}_2) = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix} \qquad \text{— (1)}$$

where columns and rows correspond to the transmit antennas and the symbol intervals, respectively. For the STBC-SM scheme the matrix extended in to the antenna domain. The concept of STBC-SM is explained via the following simple example.

Example (STBC-SM with four transmit antennas, BPSK modulation):

Consider a MIMO system with four transmit antennas which transmit the Alamouti STBC using one of the following four codewords:

$$\mathcal{X}_1 = \{\mathrm{X}_{11}, \mathrm{X}_{12}\} = \left\{ \begin{pmatrix} x_1 & x_2 & 0 & 0 \\ -x_2^* & x_1^* & 0 & 0 \end{pmatrix} \begin{pmatrix} 0 & 0 & x_1 & x_2 \\ 0 & 0 & -x_2^* & x_1^* \end{pmatrix} \right\}$$

$$\mathcal{X}_2 = \{\mathrm{X}_{21}, \mathrm{X}_{22}\} = \left\{ \begin{pmatrix} 0 & x_1 & x_2 & 0 \\ 0 & -x_2^* & x_1^* & 0 \end{pmatrix} \begin{pmatrix} x_2 & 0 & 0 & -x_1 \\ x_1^* & 0 & 0 & -x_2^* \end{pmatrix} \right\} e^{j\theta} \qquad \text{— (2)}$$

where χi, i = 1, 2 are called the STBC-SM codebooks each containing two STBC-SM codewords $\mathbf{X}ij$, j = 1, 2 which do not interfere to each other.

Suppose there are four information bits ($u1$, $u2$, 3, $u4$) to be transmitted in two consecutive symbol intervals by the STBCSM technique. The mapping rule for 2 bits/s/Hz transmission is given by Table I for the codebooks of (2) and for binary phase-shift keying (BPSK) modulation, where a realization of any codeword is called a transmission matrix. In Table I, the first two information bits ($u1$, $u2$) are used to determine the antenna-pair position ℓ while the last two ($u3$, $u4$) determine the BPSK symbol pair. If we generalize this system to M-ary signaling, we have four different codewords each having M^2 different realizations. Consequently, the spectral efficiency of the STBC-SM scheme for four transmit antennas becomes $m = (1/2) \log_2 4M^2 = 1 + \log_2 M$ bits/s/Hz, where the factor 1/2 normalizes for the two channel uses spanned by the matrices in (2).

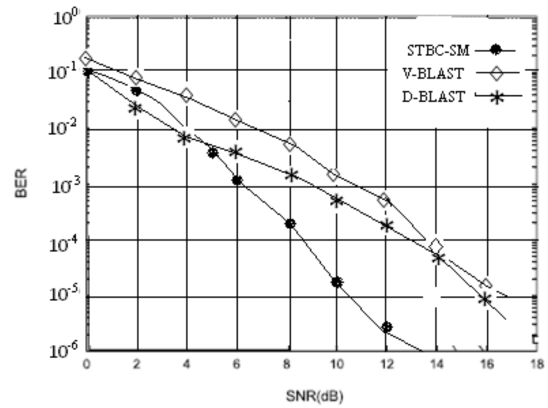

Figure 7 BER performance of STBC-SM, V_BLAST and D_BLAST

TABLE I

STBS-SM MAPPING RULE FOR 2 BITS/S/Hz TRANSMISSION USING BPSK,FOUR TRANSMIT ANTENNAS

		Input Bits	Transmission Matrices			Input Bits	Transmission Matrices
X1	$\ell = 0$	0000	$\begin{bmatrix} 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{bmatrix}$	X2	$\ell = 2$	1000	$\begin{bmatrix} 0 & 1 & 1 & 0 \\ 0 & -1 & 1 & 0 \end{bmatrix} e^{j\theta}$
		0001	$\begin{bmatrix} 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{bmatrix}$			1001	$\begin{bmatrix} 0 & 1 & -1 & 0 \\ 0 & 1 & 1 & 0 \end{bmatrix} e^{j\theta}$
		0010	$\begin{bmatrix} -1 & 1 & 0 & 0 \\ -1 & -1 & 0 & 0 \end{bmatrix}$			1010	$\begin{bmatrix} 0 & -1 & 1 & 0 \\ 0 & -1 & -1 & 0 \end{bmatrix} e^{j\theta}$
		0011	$\begin{bmatrix} -1 & -1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix}$			1011	$\begin{bmatrix} 0 & -1 & -1 & 0 \\ 0 & 1 & -1 & 0 \end{bmatrix} e^{j\theta}$
	$\ell = 1$	0100	$\begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & -1 & 1 \end{bmatrix}$		$\ell = 3$	1100	$\begin{bmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & -1 \end{bmatrix} e^{j\theta}$
		0101	$\begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \end{bmatrix}$			1101	$\begin{bmatrix} -1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 \end{bmatrix} e^{j\theta}$
		0110	$\begin{bmatrix} 0 & 0 & -1 & 1 \\ 0 & 0 & -1 & -1 \end{bmatrix}$			1110	$\begin{bmatrix} 1 & 0 & 0 & -1 \\ -1 & 0 & 0 & -1 \end{bmatrix} e^{j\theta}$
		0111	$\begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & -1 & -1 \end{bmatrix}$			1111	$\begin{bmatrix} -1 & 0 & 0 & -1 \\ -1 & 0 & 0 & 1 \end{bmatrix} e^{j\theta}$

IV. Performance Evaluation of STBC-SM, V-BLAST and D-BLAST STBC

Bit Error Rate performance of STBC-SM, V-BLAST and D-BLAST is shown in figure 7. It is observed that Bit Error Rate (BER) is poor in case of V-BLAST as compared to D-BLAST for low as well as high SNR environment.

At high SNR, STBC-SM gives excellent results as far as BER is concerned.

At 5dB SNR, BER for STBC-SM is observed to be $0.55*10^{-3}$, while V-BLAST gives $55*10^{-3}$ and D-BLAST gives $5.5*10^{-3}$. At 10dB SNR STBC-SM is giving BER of $0.8*10^{-5}$ while V-BLAST and D-BLAST give BER of 10^{-2} and 10^{-3}. These are the approximate figures obtained by observing the graphs. STBC-SM shows excellent performance yielding negligible BER for SNR greater than 10dB. In very low SNR environment D-BLAST shows less BER as compared to STBC-SM and V-BLAST. But this is observed only up to 4 dB of SNR. D-BLAST shows gradual reduction in BER while V-BLAST still gives countable value of BER.

V. Conclusion:

V-BLAST eliminates the space time wastage, as it can fully get use of the rich scattering and high signal quality for spatial multiplexing purposes. V-BLAST is able to improve MIMO spectral efficiency in the Raleigh fading channel but loses the transmit diversity and potentially result in unacceptable error performance as channel fading becomes spatially correlated or as errors in channel state information (CSI) increase due to low receiver SNR. D-BLAST provides full diversity encoding giving improved reliability. But it is unable to reach the capacity limit and also gives conservative throughput. STBC-SM offers significant improvements in BER performance compared to V-BLAST and D-BLAST systems (approximately 3-5 dB depending on the spectral efficiency) with an acceptable linear increase in decoding complexity. From a practical implementation point of view, the RF (radio frequency) front-end of the system should be able to switch between different transmit antennas similar to the classical SM scheme. On the other hand, unlike V-BLAST in which all antennas are employed to transmit simultaneously, the number of required RF chains is only two in this scheme, and the synchronization of all transmit antennas would not be required. We conclude that STBC-SM is better as compared with V-BLAST and a D-BLAST scheme as far as error performance is concerned compromising on decoding complexity.

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