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Improvement of the Spatial Multiplexing MIMO Systems (VBLAST) by Using Constellation Rearrangement

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Abstract: The use of a unique bit-to-symbol mapping for each diversity branch (often referred to as constellation rearrangement) is known to provide good performance for higher level linear modulation techniques when used in conjunction with orthogonal transmit diversity (OTD) and automatic repeat request (ARQ). This paper investigates the performance of constellation rearrangement (CoRe) scheme when used in conjunction with Spatial Multiplexing system without Channel State information (CSI) (Vertical Bell labs layered space-time (VBLAST)). The idea is to use optimized constellation so that minimum squared Euclidean distance (SED) between different branches is maximized. We get two fold gain from this scheme; spatial diversity by using multiple antennas at transmitter and receiver and performance gain by using CoRe.

Key words: Channel State information (CSI) · Constellation Rearrangement (CoRe) · Squared Euclidean distance (SED) · Multiple input Multiple output (MIMO) · Vertical Bell labs layered space-time (VBLAST)

INTRODUCTION

In the past few years, theoretical investigations have revealed that the multipath wireless channel is capable of enormous capacities, provided that the multipath scattering is sufficiently rich and is properly exploited through the use of an appropriate processing architecture [1-4]. Bell Labs layered space-time architecture (BLAST) was proposed by Foschini in [3] that is used to achieve the higher capacities with the help of MIMO techniques. initially D-BLAST with diagonal coding structure was used but due to involvement of some technical complexities it was modified to a new version called (VBLAST) was then proposed and prototyped in the laboratory stated in [6]. The block diagram of the VBLAST system is as shown below in Figure 1. From the block diagram it is clear that single stream of information signal is demultiplexed into multiple different substreams, where every substream is of information signal is then mapped to symbols by an appropriate modulator and sent to corresponding transmitting antenna element. The encoding process in this case involves the mapping of every bit to a symbol constellation for every substream, where as seen from block diagram all the substreams are mapped independently. The point to note is that the transmitting power dedicated to all the transmitters is divided equally. Similarly at the receiving end demodulators are operating independently while remaining in the same frequency band. The signal from every transmitter is transmitted and received by every receiver. Here in this case it is assumed that channel matrix H does not vary over transmission of single block of data and remains constant.

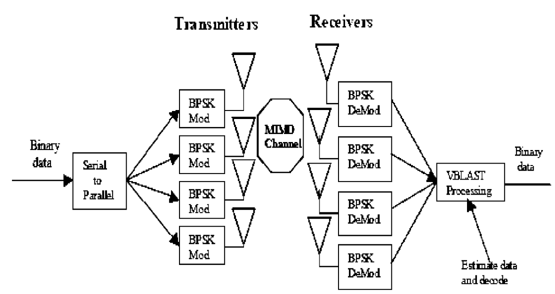

Fig. 1: V-BLAST Architecture

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In [7, 8], a constellation rearrangement scheme for multi-level modulation has been proposed to improve the reliability of the different transmitted bits where the Log-Likelihood Ratio (LLR) has been employed at the receiver for signal detection. In [7, 8], a constellation rearrangement scheme for multi-level modulation has been proposed to improve the reliability of the different transmitted bits where the Log-Likelihood Ratio (LLR) has been employed at the receiver for signal detection. In This paper investigates the performance of constellation rearrangement (CoRe) scheme when used in conjunction with Spatial Multiplexing system without Channel State information (CSI) (Vertical Bell labs layered space-time (VBLAST)).

.CONSTELLATION REARRANGEMENT AND V-BLAST TRANSMISSION

Constellation Rearrangement: CoRe for OTD was introduced in [6]. The basic concept behind CoRe is explained by following example. Consider a 4-PAM (Pulse amplitude modulation) scheme for OTD case.

In case of conventional OTD scheme, same symbol is transmitted on all branches. Figure.2 shows conventional OTD branches with gray coding. The constellation points remain one dimensional while we are using two dimensional signal space. This scheme can give us diversity gain when each channel undergoes different fading path. If we increase the number of branches, the signal space will become a hyper-cube but dimension of constellation points will remain the same. This scheme can be improved by employing constellation rearrangement. By rearranging the constellation point as illustrated in Figure.4, we can increase the minimum SED between the neighbors and utilize both signal space dimensions. In case of 4-PAM with two branches, a relative gain of 4dB is achieved. In order to obtain full diversity we have to transmit unique constellation on each branch. For high level linear modulation schemes, CoRe is done through computer search where we iterate over all possible symbol and over all branches to choose the constellation set which maximizes the minimum squared Euclidean distance between constellation points.

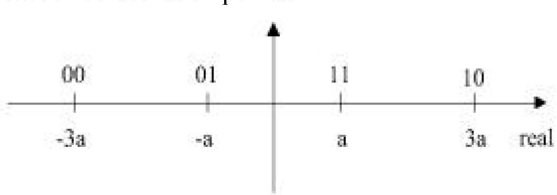
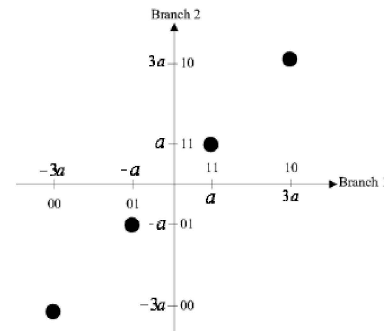


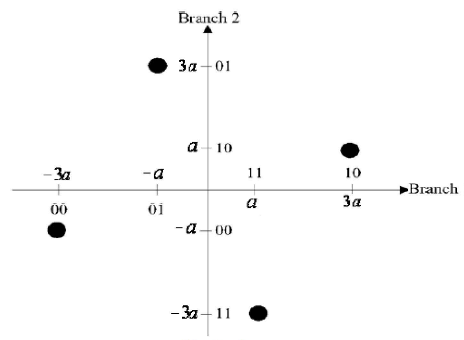
Fig. 2: Signal constellation for 4PAM



$$Branch1:[00\ 01\ 10\ 11]\xrightarrow{Mapping1}[-3a\ \ -a\ \ +3a\ \ +a]$$

$$Branch2:[01\ 10\ 11\ 00]\xrightarrow{Mapping2}[-a\ \ +3a\ \ +a\ \ -3a]$$

Fig. 3: Signal constellation for conventional TD with 4PAM



$$Branch\ 1:[00\ \ 01\ \ 10\ \ 11]\xrightarrow{Mapping\ 1}[-3a\ \ -a\ \ +3a\ \ +a]$$

$$Branch\ 2:[01\ \ 10\ \ 11\ \ 00]\xrightarrow{Mapping\ 2}[+3a\ \ +a\ \ -3a\ \ -a]$$

Fig. 4: Signal constellation for OTD with CoRe for 4PAM

$$d_{\min} = \max\left\{ \min\left\{ \left| s_m - s_{\hat{m}} \right|^2 \right\} \right\} \tag{1}$$

where S_N is the transmitted symbol and N[th] denotes the detected symbol. In conventional VBLAST systems transmitted data vector is given as:

$$S = [s_1 \quad s_1 \ldots\ldots s_N] \tag{2}$$

where S_N denotes the N[th] symbol transmitted on the N[th] branch. Figure.3 gives the signal constellation set for conventional VBLAST. Since same bits to symbol mapping is done on all branches, hence we get one dimensional constellation set at receiver. It is interesting to note that after using constellation rearrangement, the signal spread is increased as shown in Figure.4 In 'Improved Vblast system' same symbol say 3α,α is transmitted on both branches but the energy corresponding to each symbol is different, with one

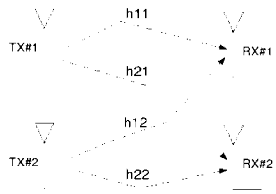


Fig. 5: 2 transmit 2 receive MIMO channel

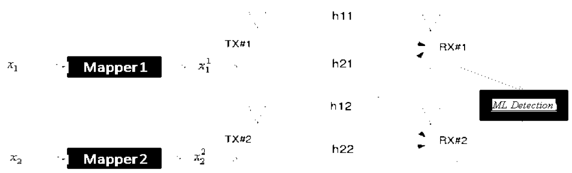


Fig. 6: VBLAST system with CoRe

branch having more energy than the other. Hence CoRe has an effect of equalization of transmitted energy per symbol. This effect is more pronounced in higher order linearly modulated signals like M-QAM. It is important to note here that CoRe optimizes the constellation set in terms of symbol rate performance instead of bit rate performance.

B.V-blast Transmission for 2×2 Mimo Channel:

In a 2×2 Mimo Channel, Probable Usage of the Available 2 Transmit Antennas Can Be as Follows: Consider that we have a transmission sequence, for example $x_1, x_2, \ldots x_n$. In normal transmission, we will be sending x_1 in the first time slot, x_2 in the second time slot, x_3 and so on. However, as we now have 2 transmit antennas, we may group the symbols into groups of two. In the first time slot, send $x_1$and x_2 from the first and second antenna. In second time slot, send x_3 and x_4 from the first and second antenna, send x_5 and x_6 in the third time slot and so on. Notice that as we are grouping two symbols and sending them in one time slot, we need only $\frac{n}{2}$ time slots to complete the transmission so data rate is doubled.

System Model: The V-BLAST transmission for 2×2 MIMO system with CoRe can be represented in matrix notation as follows:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1^1 \\ x_2^2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (3)$$

Where, y_1, y_2 are the received symbol on the first and second antenna respectively, $h_{j,i}$ is the channel from i^{th} transmit antenna to j^{th} receive antenna, x_1^1, x_2^2 are the transmitted symbols that use first and second constellation mapper respectively and n_1,n_2 is the noise on 1^{st}, 2^{st}receive antennas. We assume that the receiver knows $y_2, y_1, h_{2,2}, h_{1,2}, h_{1,1}$. The unknown s are x_1,x_2.

Receiver Structures: The Maximum Likelihood receiver tries to find $\hat{x}$ which minimizes, $J = |y - H\hat{x}|^2$

$$J = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} \hat{x}_1^1 \\ \hat{x}_2^2 \end{bmatrix} \right|^2 \quad (4)$$

if the modulation was BPSK, the possible values of $\hat{x}_1^1$ is +1 or -1 Similarly $\hat{x}_2^2$ also take values +1 or -1. So, to find the Maximum Likelihood solution, we need to find the minimum from the all four combinations of $\hat{x}_1^1$ and $\hat{x}_2^2$.

$$J_{+1,+1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} +1 \\ +1 \end{bmatrix} \right|^2 \quad (5)$$

$$J_{+1,-1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} +1 \\ -1 \end{bmatrix} \right|^2 \quad (6)$$

$$J_{-1,+1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -1 \\ +1 \end{bmatrix} \right|^2 \quad (7)$$

$$J_{-1,-1} = \left| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -1 \\ -1 \end{bmatrix} \right|^2 \quad (8)$$

The estimate of the transmit symbol is chosen based on the minimum value from the above four values i.e,

if the minimum is $J_{+1,+1} \Rightarrow [1,1]$
if the minimum is $J_{+1,-1} \Rightarrow [1,0]$,
if the minimum is $J_{-1,+1} \Rightarrow [0,1]$and
if the minimum is $J_{-1,-1} \Rightarrow [0,0]$.
In general we can say

$$C = \min_{x} \left(\left\| Y - H\hat{X} \right\|^2 \right) \quad (9)$$

RESULTS AND CONCLUSION

We demonstrated the performance of improved Spatial Multiplexing MIMO systems (VBLAST) using different linearly modulated signals namely 16-QAM and QPSK for different antenna configurations. We compared the system performance with conventional VBLAST system. Simulation results for 16QAM with multiple

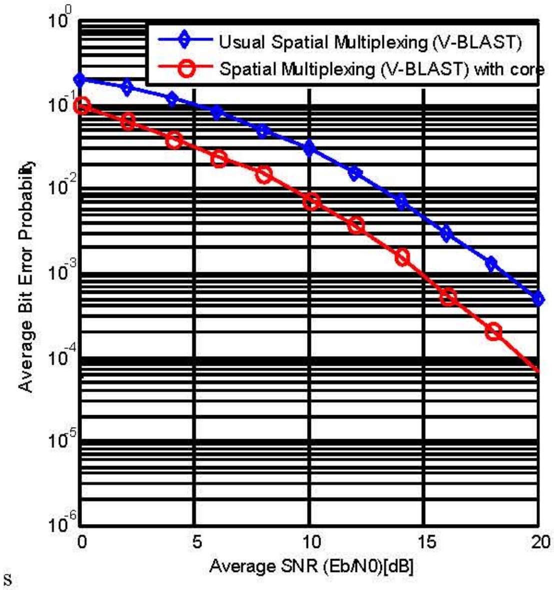


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Fig. 7: Average Bit Error Probability for QPSK for 2x2 MIMO Antenna Systems

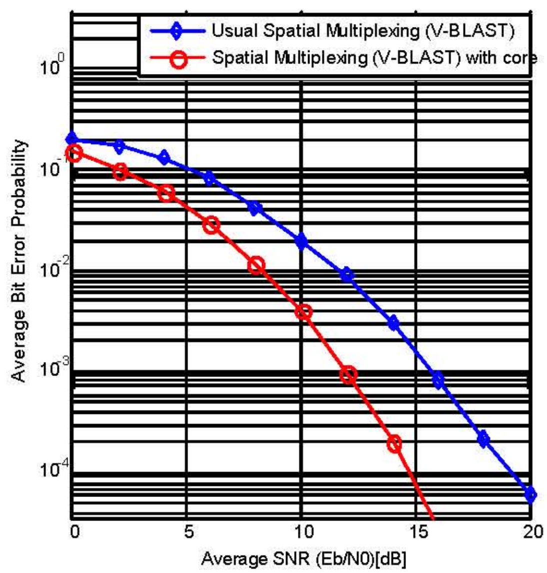

Fig. 8: Average Bit Error Probability for QPSK for 3x3 MIMO Antenna Systems

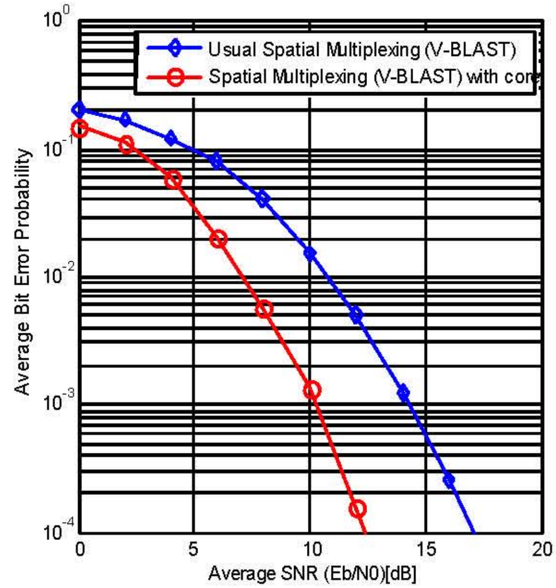

Fig. 9: Average Bit Error Probability for QPSK for 4x4 MIMO Antenna Systems

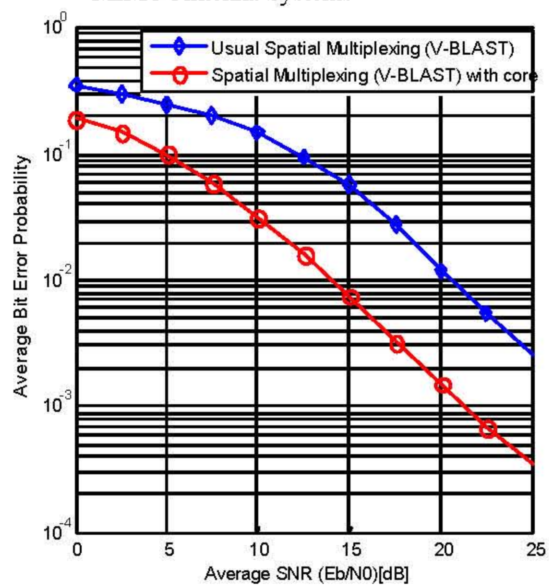

Fig. 10: Average Bit Error Probability for 16QAM for 2x2 MIMO Antenna Systems

antennas at transmitter and receiver respectively are shown in Figure.10. The results show that we get a gain of 6.9dB at BER of 3×10^{-3} for 2×2 MIMO. For high level modulation schemes, CoRe performance is improved because of the presence of more energy per symbol which minimizes error probability. Figure.7, Figure.8, Figure.9 shows the BER for QPSK with 2×2 and 3×3 and 4×4 antenna configurations. in case of 2×2, we get a gain of approximately 3.75 dB at BER of 9×10^{-4} and for 3×3 we get a gain of 4.6dB at a BER of 9×10^{-4} and for 4×4 we get a gain of 5dB at a BER of 9×10^{-4}. This is due to the fact that when the number of transmit branches is increased the signal space dimension is spread more [6].

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