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Turbo-Space Time Block Coded and Turbo-Vertical Bell Laboratories Layered Space Time coded Wireless Communication: Which One is better to Use and under What Circumstances?

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Abstract*: In this research, performance of Turbo-Space Time Block Coded and Turbo-Vertical Bell Laboratories Layered Space Time coded Multiple Input Multiple Output Wireless Communication System is compared and investigated to find which one is better under which circumstances. The Turbo Encoder accepts binary bits as input and generates turbo encoded bits as output which is sent to 64 QAM modulator. These 64 QAM Modulated symbols are further mapped using Space Time Block Code and Vertical Bell Laboratories Layered Space Time code for Turbo-Space Time Block Coded system and Turbo-Vertical Bell Laboratories Layered Space Time coded system respectively and then divided into several streams based on number of transmit antennas before transmission. It is found that there is 3 to 22 dB coding gain at 10-5 for using Turbo-STBC instead of using Turbo-VBLAST for 2 or 3 or 4 transmit antennas and 2 or 3 or 4 or 5 or 6 receive antennas. On the other hand, at low SNR STBC shows 1-2 b/s/Hz improvement in capacity compare to VBLAST but capacity declines significantly at high SNR for using STBC. It is also observed that VBLAST improves the capacity around 5 to 15 b/s/Hz at high SNR.

***Index Terms*: STBC, VBLAST, MIMO, turbo codes, wireless communication**

I. INTRODUCTION

According to Cisco Visual Networking Index, the uses of wireless communication on mobile devices are increasing over 50% every year. In fact in 2017, 8.38 billion electronic devices were connected with internet which was more than the human beings (7.5) on earth (source Gartner 2017). It is expected that half of 17 billion connected electronic devices will be wireless device by 2021 in which 80% of the data transfer will be multimedia wireless. This demand of higher data rate for wireless communications makes this field an exciting and challenging.

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Multiple Input and Multiple Output (MIMO) is one of the most used techniques for transferring more data at same time on a scattering-rich wireless communication which is suggested for future generation wireless communication system, especially when receiver knows the channel or propagation environment. Spatial diversity and spatial multiplexing are two basic MIMO techniques used in wireless communication. One of the common spatial diversity techniques is Space Time Block Coding (STBC) and one of the common spatial multiplexing techniques is Bell Labs Layered Space-Time (BLAST) [1-3]. STBC technique is used to transmit several copies of signal through multiple antennas to reduce BER by using the different versions of received signal. The idea behind sending multiple copies of signal is to get few better signals among all received signals which was travel across potentially rough environment and effected by thermal noise of the receiver. Actually, detector and decoder at the receiver merge all versions of the received signal using most appropriate way to take out best signal. Most of the researchers focused study on antenna array at receiver [4]. Vahid Tarokh proposed another approach named Space Time Block Codes (STBC) for using multiple antennas at transmitter and receiver which provides significant improvement on error rate. The first approach was designed from trellis codes but Siavash Alamouti developed the simpler Space Time Block Codes for two transmit and receive antennas, and later Vahid Tarokh enhanced this technique for more transmit and receive antennas. Receiving multiple copies of data is called spatial diversity which was studied by most of researcher until Foschini proposed Bell Laboratories Layered Space-Time (BLAST) technique. BLAST was developed at Lucent Technologies' Bell Laboratories in which data streams are sent through multiple antennas simultaneously. By considering certain assumptions, BLAST technique provides very high data rate where capacity increases linearly with number of transmit antennas. Indeed, Turbo Code (TC) is chosen in this research because of high uses in most of the wireless communication systems to improve the performance of BER. The BER performance of STBC and VLAST can be improved remarkably by combing TC with STBC or VBLAST. A combination of TC and STBC is referred to as the Turbo-STBC (Turbo- Space Time Block Coded) and combination of TC and VBLAST is mentioned as the Turbo-VBLAST

(Turbo-Vertical Bell Laboratories Layered Space Time) in this paper. We published several papers on Turbo-STBC and Turbo-VBLAST [5-7] from our previous research. To the best of the author's knowledge, comparison between Turbo-STBC and Turbo-VBLAST with same antenna configuration is unprecedented in the literature [8-14]. The objective of this work is to design a MIMO wireless communication system with Turbo-STBC and Turbo-VBLAST; and compare them with same antenna configuration. Because, if we know the performance of Turbo-STBC and Turbo-VBLAST with same antenna configuration, it is possible to use Turbo-STBC or Turbo-VBLAST adaptively based on the channel condition or user required data rate which could greatly improve the performance of BER or capacity in many future wireless communication application.

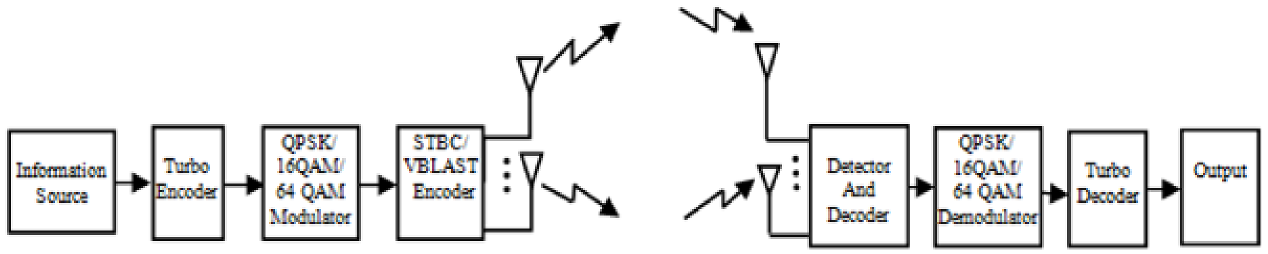

Figure 1. System block diagram

II. SYSTEM MODEL

The proposed system consists of N transmit and M receive antennas as shown in fig.1 where turbo encoder is used to encode binary information. Two recursive systematic convolutional (RSC) encoders are used to build a basic turbo encoder which joined in parallel. A pseudorandom (turbo) interleaver is inserted between two RSC encoder as shown in figure2. The first encoder of two RSC encoders operates on the original copy of input bits, whereas Turbo interleaver is used to permute the input bits before sending to second encoder. The code rate is considered as , r=1/R where the length of input symbol is 1 and the size of output symbol is R. Size and structure of interleaver influence on the performance of bit error rate (BER). However, optimization of interleave size and structure of turbo code is not part of this research. Block diagram of a turbo encoder with rate 1/3 is presented using figure 2 where b_k^s is the systematic bits, and b_k^{p1} , and b_k^{p2} are the parity check bits. A 64 QAM modulator is used to modulate the turbo encoded bits which are further mapped by STBC or VBLAST encoder. The STBC or VBLAST encoded symbol are finally transmit through multiple transmission antennas.

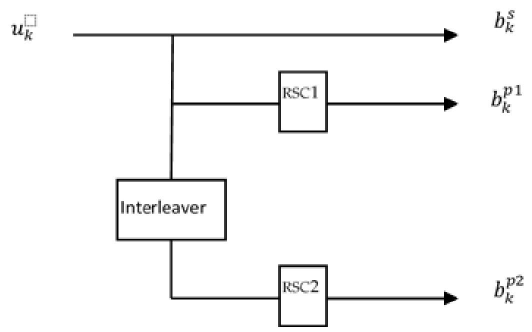

Figure 2. Block diagram of a turbo encoder of rate 1/3

Details of encoding and decoding techniques will be explained in following sections.

III. ENCODING OF STBC AND VBLAST

A. *Encoding using STBC*

The STBC encoding technique depends on number of transmit antennas. We consider two, three and four transmit antennas to compare turbo coded STBC and VBLAST system. The mapping of two, three and four transmit antennas using STBC is as shown in Table 1,2 and 3 respectively. N transmit antennas are considered in this paper to transmit the mapped streams s_t^i , i =1, 2, ... n simultaneously at each time slot t.

Table 1. Mapping using STBC for transmitting symbols by two transmission antennas

Time slot	Antenna-I	Antenna-II
I	x_1	x_2
II	$-x_2^*$	x_1^*

Table 2. Mapping using STBC for transmitting symbols by three transmission antennas with Code Rate ½.

I	x_1	x_2	x_3
II	$-x_2$	x_1	$-x_4$
III	$-x_3$	x_4	x_1
IV	$-x_4$	$-x_3$	x_2
V	x_1^*	x_2^*	x_3^*
VI	$-x_2^*$	x_1^*	$-x_4^*$

Table 3. Mapping using STBC for transmitting symbols by four transmission antennas with code rate ½.

Time slot	Antenna			
	Antenna-I	Antenna-II	Antenna-III	Antenna-IV
I	x_1	x_2	x_3	x_4
II	$-x_2$	x_1	$-x_4$	x_3
III	$-x_3$	x_4	x_1	$-x_2$
IV	$-x_4$	$-x_3$	x_2	x_1
V	x_1^*	x_2^*	x_3^*	x_4^*
VI	$-x_2^*$	x_1^*	$-x_4^*$	x_3^*
VII	$-x_3^*$	x_4^*	x_1^*	$-x_2^*$
VIII	$-x_4^*$	$-x_3^*$	x_2^*	x_1^*

B. *Encoding using VBLAST*

The modulated symbols are divided using a serial-to-parallel converter to create separate streams. Number of stream depends on number of antennas. For simplicity n number of streams, si where i=1, 2, ... n and N number of transmit antennas are considered in this paper. These n streams are transmitted with N transmit antennas simultaneously at time *t*. So signal si can be represented as s_t^i for time t. Table 4, 5 and 6 represent the stream of modulated symbols at different time for two, three and four transmit antennas:

Table 4.. Mapping using VBLAST for transmitting symbols by two transmission antennas

	Antenna-I	Antenna-II
I	x_1	x_2
II	x_3	x_4

TABLE 5.. Mapping using VBLAST for transmitting symbols by three transmission antennas

	Antenna-I	Antenna-II	Antenna-III
I	x_1	x_2	x_3
II	x_4	x_5	x_6
III	x_7	x_8	x_9

TABLE 6.. Mapping using VBLAST for transmitting symbols by four transmission antennas

	Antenna-I	Antenna-II	Antenna-III	Antenna-I
I	x_1	x_2	x_3	x_4
II	x_5	x_6	x_7	x_8
II	x_9	x_{10}	x_{11}	x_{12}
IV	x_{13}	x_{14}	x_{15}	x_{16}

IV. CHANNEL

In this research, flat fading channel is considered for signal when goes from transmitter to receiver. If signal transmit from transmit antenna *i* to receive antenna *j*, the path gain is represented as $h_{i,j}$ which is modeled as samples of independent and identically distributed (i.i.d), zero–mean, complex Gaussian, unit variance entries (the variance of each entry is $\sigma_c^2 = 1$) .

V. RECEIVED SIGNAL

A. *For STBC encoded symbols*

The receiver accepts the signal at different time slot which were affected by rayleigh fading that can be represented by (1):

$$r_t^j = \sum_{i=1}^{N} \alpha_{i,j} s_t^i + n_t^j \qquad (1)$$

where r_t^j is the received signal having $M \times 1$ dimension complex vector

$\alpha_{i,j}$ is the channel matrix having $M \times N$ dimension.

s_t^i is the transmitted sub-streams which has $N \times 1$ dimension complex vector

n_t^j is is the additive receiver noise having $M \times 1$ dimension complex which is assumed as zero-mean, uncorrelatd random variables with variance σ_n^2 .

B. *For VBLAST encoded symbols*

The received signal at destination can be represented as:

$$\mathbf{r} = \sum_{i=1}^{N} \alpha_i s_i + \eta \qquad (2)$$

where, $\mathbf{r}$ is the vector of received signal at destination, α_i is the i^{th} row of path gain matrix, and s_i is the i^{th} symbol transmitted from source.

VI. DECODING OF STBC AND VBLAST ENCODED SYMBOLS

A. *Decoding using STBC*

Decisions metrics (3) and (4) have been used for detecting symbols which were transmitted from two transmit antennas [1-2]:

Decisions metric (3) is used to detect symbol s1:

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{1,j}^* + \left(r_2^j\right)^*\alpha_{2,j}\right)\right]-s_1\right|^2 + \left(-1+\sum_{j=1}^{m}\sum_{i=1}^{2}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \tag{3}$$

Decisions metric (4) is used to detect symbol s2:

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{2,j}^* - \left(r_2^j\right)^*\alpha_{1,j}\right)\right]-s_2\right|^2 + \left(-1+\sum_{j=1}^{m}\sum_{i=1}^{2}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \tag{4}$$

We use (5), (6), (7) and (8) decision metrics for detecting STBC symbols s_1 , s_2 , s_3 , s_4 respectively which transmitted from three transmit antennas :

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} r_1^j\alpha_{1,j}^* + r_2^j\alpha_{2,j}^* + r_3^j\alpha_{3,j}^* + \\ \left(r_5^j\right)^*\alpha_{1,j} + \left(r_6^j\right)^*\alpha_{2,j} + \left(r_7^j\right)^*\alpha_{3,j}\end{matrix}\right)\right]-s_1\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \tag{5}$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} r_1^j\alpha_{2,j}^* + r_2^j\alpha_{1,j}^* + r_4^j\alpha_{3,j}^* + \\ \left(r_5^j\right)^*\alpha_{2,j} - \left(r_6^j\right)^*\alpha_{1,j} + \left(r_8^j\right)^*\alpha_{3,j}\end{matrix}\right)\right]-s_2\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_2\right|^2 \tag{6}$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} r_1^j\alpha_{3,j}^* - r_3^j\alpha_{1,j}^* - r_4^j\alpha_{2,j}^* + \\ \left(r_5^j\right)^*\alpha_{3,j} - \left(r_7^j\right)^*\alpha_{1,j} - \left(r_8^j\right)^*\alpha_{2,j}\end{matrix}\right)\right]-s_3\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_3\right|^2 \tag{7}$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} -r_2^j\alpha_{3,j}^* + r_3^j\alpha_{2,j}^* - r_4^j\alpha_{1,j}^* - \\ \left(r_6^j\right)^*\alpha_{3,j} + \left(r_7^j\right)^*\alpha_{2,j} - \left(r_8^j\right)^*\alpha_{1,j}\end{matrix}\right)\right]-s_4\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_4\right|^2 \tag{8}$$

We use (9), (10), (11) and (12) decision metrics for detecting symbols s_1 , s_2 , s_3 , s_4 respectively which transmitted from four transmit antennas:

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} r_1^j\alpha_{1,j}^* + r_2^j\alpha_{2,j}^* + r_3^j\alpha_{3,j}^* + r_4^j\alpha_{4,j}^* \\ +\left(r_5^j\right)^*\alpha_{1,j} + \left(r_6^j\right)^*\alpha_{2,j} + \left(r_7^j\right)^*\alpha_{3,j} \\ +r_8^j\alpha_{4,j}^*\end{matrix}\right)\right]-s_1\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{4}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \tag{9}$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} r_1^j\alpha_{2,j}^* - r_2^j\alpha_{1,j}^* - r_3^j\alpha_{1,j}^* + r_4^j\alpha_{3,j}^* \\ +\left(r_5^j\right)^*\alpha_{2,j} - \left(r_6^j\right)^*\alpha_{1,j} - \left(r_7^j\right)^*\alpha_{4,j} \\ +\left(r_8^j\right)^*\alpha_{3,j}\end{matrix}\right)\right]-s_2\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_2\right|^2 \tag{10}$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} r_1^j\alpha_{3,j}^* + r_2^j\alpha_{4,j}^* - r_3^j\alpha_{1,j}^* - r_4^j\alpha_{2,j}^* \\ +\left(r_5^j\right)^*\alpha_{3,j} + r_6^j\alpha_{4,j}^* - \left(r_7^j\right)^*\alpha_{1,j} \\ -\left(r_8^j\right)^*\alpha_{2,j}\end{matrix}\right)\right]-s_3\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_3\right|^2 \tag{11}$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{matrix} -r_1^j\alpha_{4,j}^* - r_2^j\alpha_{3,j}^* + r_3^j\alpha_{2,j}^* - r_4^j\alpha_{1,j}^* \\ -\left(r_5^j\right)^*\alpha_{4,j} - \left(r_6^j\right)^*\alpha_{3,j} + \left(r_7^j\right)^*\alpha_{2,j} \\ -\left(r_8^j\right)^*\alpha_{1,j}\end{matrix}\right)\right]-s_4\right|^2 \quad (8)$$

$$+\left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_4\right|^2 \tag{12}$$

B. Decoding using VBLAST

ZF, MMSE and ML are well known techniques for VBLAST to detect the transmitted symbol. ZF is used for detecting the symbols of proposed Turbo-VBLAST system. Every stream in turn will be taken as desired stream in ZF technique where remaining stream will be taken as interferers.

Those interferers can be removed by linearly weighting the received streams which can be explained with following steps [24]:

I: Ordering – It is required for placing the received symbols in order for detection. Received symbol with highest SNR will be considered first for detection and then choose the symbol in the order of decreasing SNR. In this paper, $\hat{s}$ is used to represent the detected symbol.

II: Interference cancellation – This step removes the interference from detected symbol which obtained from the ordering. It is required to subtract detect symbols $\hat{s}$ from the received vector $\mathbf{r}$ to remove interface. For example, suppose the symbol s_l is being detected at stage l where $s_1, s_2, \ldots, s_{l-1}$ have been already detected with a perfect decoder. So, it is possible to deduct the $\sum_{i=1}^{l-1} s_i \alpha_i$ from the received vector $\mathbf{r}$ to get undetected received symbols $\mathbf{r}_l$, i.e.

$$\mathbf{r}_l = \mathbf{r} - \sum_{i=1}^{l-1} s_i \alpha_i \qquad (13)$$

In fact, by using induction in addition to the convention $r_l = r$, one can show that

$$\mathbf{r}_{l+1} = \mathbf{r}_l - s_l \alpha_l, \quad n = 1,2,\ldots,L-2. \qquad (14)$$

Therefore, at the l^{th} stage of the algorithm after detecting the l^{th} symbol as $\hat{s}_l$, its effect is canceled from the equation by

$$\mathbf{r}_{l+1} = \mathbf{r}_l - \hat{s}_l \alpha_l \qquad (15)$$

III: Nulling Interference– It is required to null the effects of undetected symbols for detecting the required the l^{th} symbol s_l from receive signal $\mathbf{r}_l$. So the interference created by $s_{l+1}, s_{l+2}, \ldots, s_L$ will be nulled at this step. The fading effected required symbol $s_l \alpha_l$ will be taken out from $\mathbf{r}_l$ by multiplying $\mathbf{r}_l$ by an $m \times 1$ vector W_l that is orthogonal to interference vectors $\alpha_{l+1}, \alpha_{l+2}, \ldots, \alpha_L$ but not orthogonal to α_l. In other words, W_l should be such that

$$\alpha_i W_l = 0, \qquad i = l+1, l+2, \ldots, L, \qquad (16)$$
$$\alpha_l W_l = 1.$$

In fact, W_l is called the zero-forcing nulling vector with minimum norm. Such a vector is uniquely calculated from the channel matrix α. To calculate W_l from α, for $m \geq n$, first we should replace the rows $1,2,\ldots,l-1$ of α by zero. Let us denote the resulting matrix by Z. Then, W_l is the l^{th} column of Z^+, the Moore-Penrose generalized inverse, pseudo-inverse, of Z.

Using the error free detection formula for $\mathbf{r}_l$ in (13) and W_l in (16), we have

$$\mathbf{r}_l . W_l = s_l + \eta . W_l \qquad (17)$$

s_l can be decoded easily because the noise is Gaussian in (17)

IV: Slicing – Finding the symbol from QAM constellation point. i.e. slice the symbol s_l from nearest QAM constellation point. After slice, s_l can be represented as $\hat{s}_l$. The decoded symbol $\hat{s}_l$ is the closest constellation point to $\mathbf{r}_l . W_l$.

V: Iteration – Repeat all steps again from beginning for detecting the next symbol.

64QAM demodulator is used to demodulate the detected symbols and to turbo decoder decode the demodulated bits for getting the final output.

VII. CAPACITY ANALYSIS OF PROPOSED TURBO-STBC AND TURBO-VBLAST SYSTEM:

A. Capacity of Turbo-STBC System

The capacity of Turbo-STBC system can be written as:

$$C_{STBC} = r_c \log_2 \det\left(\mathbf{I}_{n_R} + \frac{P_T}{r_c\, n_T\, \sigma_n^2} \mathbf{H}_{STBC} \mathbf{H}_{STBC}^H\right) \qquad (18)$$

where, $\mathbf{r}_c$ is code rate that depends on construction of STBC [2], and $\text{code rate } (\mathbf{r}_c) = \frac{\text{Number of Symbols}}{\text{Time slot}}$, H_{STBC} is the channel matrix when STBC is used to encode information and H_{STBC} for two transmit antennas and two, four and six receive antennas are $\begin{bmatrix} h_{11} & h_{21} \\ h_{12} & (16) \\ h_{21}^* & --_{1}1 \\ h_{22}^* & -h_{12}^* \end{bmatrix}$, $\begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \\ h_{13} & h_{23} \\ h_{14} & h_{24} \\ h_{21}^* & -h_{11}^* \\ h_{22}^* & -h_{12}^* \\ h_{23}^* & -h_{13}^* \\ h_{24}^* & -h_{14}^* \end{bmatrix}$ and $\begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \\ h_{13} & h_{23} \\ h_{14} & h_{24} \\ h_{15} & h_{25} \\ h_{16} & h_{26} \\ h_{21}^* & -h_{11}^* \\ h_{22}^* & -h_{12}^* \\ h_{23}^* & -h_{13}^* \\ h_{24}^* & -h_{14}^* \\ h_{25}^* & -h_{15}^* \\ h_{26}^* & -h_{16}^* \end{bmatrix}$ respectively.

B. Capacity of Turbo-VBLAST System:

The capacity of VBLAST can be written as:

$$C_{VBLAST} = log_2\, det\left(\mathbf{I}_{n_R} + \frac{P_T}{n_T\sigma_n^2}\mathbf{H}_{VBLAST}\mathbf{H}_{VBLAST}^H\right) \quad (19)$$

where, H_{VBLAST} is the channel matrix when VBLAST is used to encode information and H_{VBLAST} for two transmit antennas and two, four and six receive antennas are $\begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \end{bmatrix}$, $\begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \\ h_{13} & h_{23} \\ h_{14} & h_{24} \end{bmatrix}$ and $\begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \\ h_{13} & h_{23} \\ h_{14} & h_{24} \\ h_{15} & h_{25} \\ h_{16} & h_{26} \end{bmatrix}$ respectively.

VIII. SIMULATION RESULTS

BER Performance and Capacity of proposed Turbo-STBC and Turbo-VBLAST are presented in this section. Different combination of transmit and receive antennas are considered to perform computer simulation. The results are computed with following configuration of turbo code:

Encoder generator g = [1 0 1 1; 1 1 0 1; 1 1 1 1]
Frame size= 378,
Number of iterations =2; and
Rate= 1/3

Fig. 3 shows the comparison of MIMO System encoded with Turbo-STBC and Turbo-VBLAST for 2 Tx with 2 ,4 and 6 Rx where Turbo-STBC encoded system provides coding gain 10, 4.5 and 3 dB compared to Turbo-VBLAST encoded system for 2, 4 and 6 Rx respectively with 2 Tx.

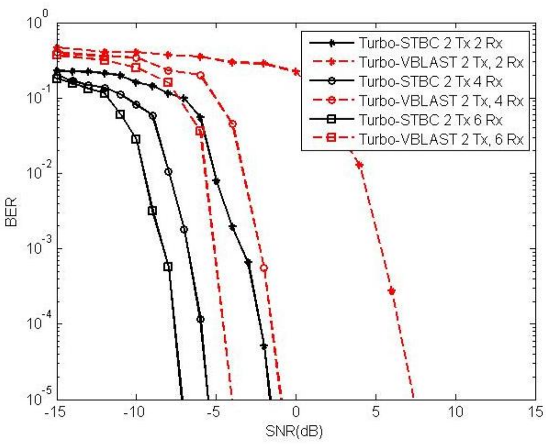

Fig. 3. Performance comparison of BER for Turbo-STBC and Turo-VBLAST with 2Tx & 2Rx, 2Tx & 4Rx and 2Tx & 6Rx

Comparison of MIMO System encoded with Turbo-STBC and Turbo-VBLAST is presented Fig. 4 for 3 Tx with 3, 4 and 6 Rx where Turbo-STBC encoded system provides coding gain 17, 12 and 10 dB compared to Turbo-VBLAST encoded system for 3, 4 and 6 Rx respectively with 3 Tx.

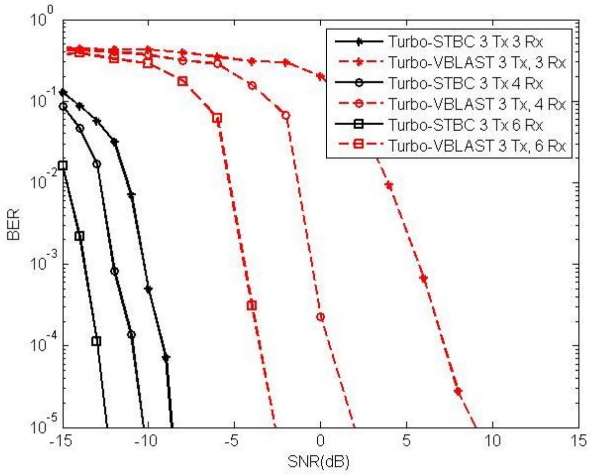

Fig. 4. Performance comparison of BER for Turbo-STBC and Turo-VLAST with 3Tx & 3Rx, 3Tx & 4Rx and 3Tx & 6Rx

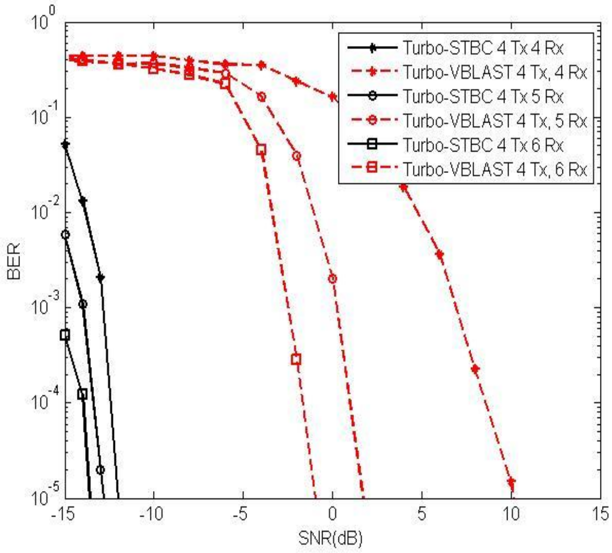

Fig. 5. Performance comparison of BER for Turbo-STBC and Turo-VLAST with 4Tx & 4Rx, 4Tx & 5Rx and 4Tx & 6Rx

Comparison of MIMO System encoded with Turbo-STBC and Turbo-VBLAST is presented in Fig. 5 for 4 Tx and 4, 5 and 6 Rx where Turbo-STBC encoded system provides 22, 14 and 12 dB coding gain compared to Turbo-VBLAST encoded system for 4, 5 and 6 Rx with 4 Tx. Capacity of STBC and VBLAST is compared in fig.6. It is observed that Turbo-STBC system provides 1.5 to 2 b/s/Hz improvement of capacity with 2 Tx and 2, 4 and 6 Rx compared to VBLAST with same configuration at 10 dB .

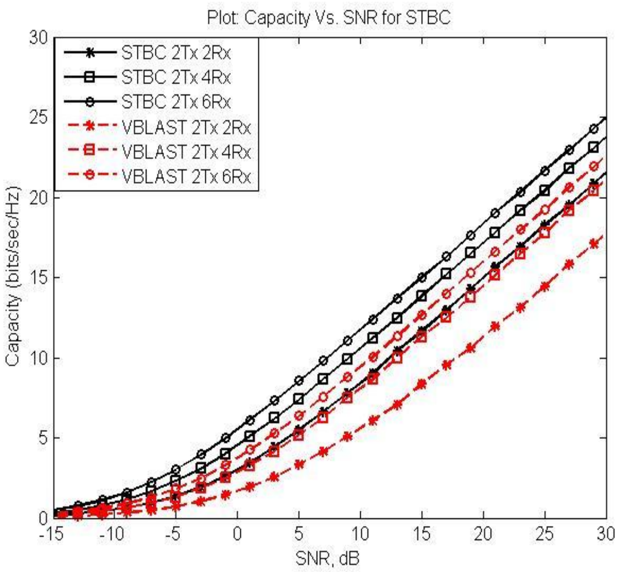

Fig. 6. Comparison of capacity for Turbo-STBC and Turbo-VBLAST with 2 Tx and 2, 4, and 6 Rx

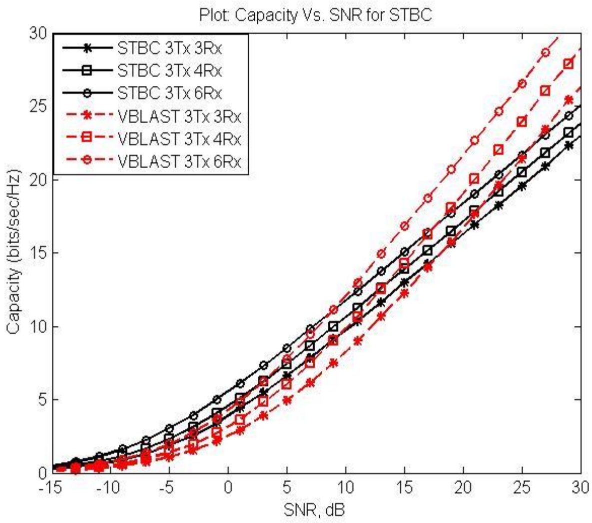

Fig. 7 shows comparison of capacity for the proposed Turbo-STBC and Turbo- VBLAST encoded MIMO system for 3 Tx with 3, 4 and 6 Rx. The capacity of Turbo-VBLAST is slightly lower than Turbo-STBC at lower SNR(-15 to 16 dB) but higher than STBC at high SNR (16 dB onward). There is around 1 to 1.5 b/s/Hz gain of capacity for using Turbo-STBC with 3 Tx and 3, 4 and 6 Rx compared to Turbo-VBLAST with same configuration at 10 dB. But there is around 5 to 8 b/s/Hz decline of capacity with Turbo-STBC for 3 Tx and 3, 4 and 6 Rx compared to Turbo-VBLAST with same configuration at 30 dB.

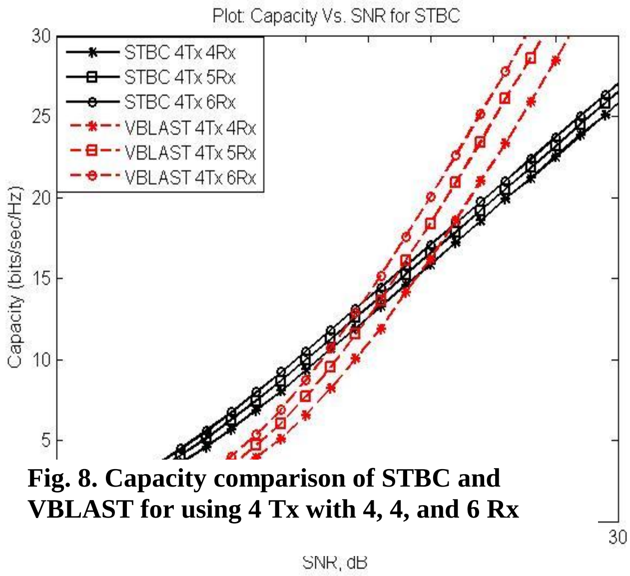

Fig. 8. Capacity comparison of STBC and VBLAST for using 4 Tx with 4, 4, and 6 Rx

Turbo-STBC and Turbo-VBLAST encoded MIMO system for 4 Tx with 4, 5 and 6 Rx. It is found that capacity of Turbo-VBLAST is slightly lower than Turbo-STBC at lower SNR(-15 to 12 dB) but higher than Turbo-STBC at high SNR (12 dB onward). There is around 1 to 2 b/s/Hz gain of capacity with Turbo-STBC for 4 Tx and 4, 5 and 6 Rx compared to Turbo-VBLAST with same configuration at 10 dB. But there is around 10 to 15 b/s/Hz decline of capacity for using Turbo-STBC with 4 Tx and 4, 5 and 6 Rx compared to Turbo-VBLAST with same configuration at 25 dB.

II. CONCLUSION

Performance of Turbo encoded STBC and VBLAST system for MIMO channel is compared using BER and capacity. It is found that Turbo-STBC makes a significant difference over Turbo-VBLAST encoded system with respect to BER performance. It is possible to get 3 to 22 dB coding gain at 10-5 for using Turbo-STBC instead of using Turbo-VBLAST for 2 or 3 or 4 transmit antennas and 2 or 3 or 4 or 5 or 6 receive antennas. On the other hand, at low SNR STBC shows 1-2 b/s/Hz improvement in capacity compare to VBLAST but capacity declines significantly at high SNR for using STBC. It declines around 5 to 15 b/s/Hz at high SNR for using STBC.

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