International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

PERFORMANCE AND CAPACITY COMPARISON BETWEEN HYBRID BLAST-STBC, VBLAST AND STBC SYSTEMS

Mohammed Salemdeeb[1], Ammar Abu-Hudrouss[2]

[1]*ICT Faculty Member, Al-Quds Open University, Gaza, Palestine*
[2]*Assisstant Professor, Department of Electrical Engineering, Islamic University of Gaza, Palestine*

***Abstract* — The hottest issue of next generation communication systems is data throughput improvement for any wireless channel conditions. MIMO systems are the key techniques for the next generation communication systems. BLAST systems achieve high data rates with acceptable BER performance over a good channels state while STBC systems can achieve better BER performance even for bad-state channels but with lower data rates than BLAST.**

Hybrid BLAST-STBC systems is the effective solution to achieve a good tradeoff between STBC and BLAST systems since it improves the BER performance and keep them robust over a special MIMO channel state compared with the conventional BLAST system.

This paper will study and compare the hybrid BLAST-STBC systems BER performance and capacity at ML receiver with both BLAST and STBC systems. MATLAB software has been used as the main platform for system simulation.

***Keywords* — MIMO, BLAST, VBLAST, STBC, Hybrid BLAST-STBC, spatial Multiplexing, Hybrid MIMO Transmission Schemes.**

I. INTRODUCTION

Compared with single antenna wireless systems, Multiple Input Multiple Output (MIMO) systems have much higher capacity and reliability [1], [2]. There are several MIMO techniques which have been introduced recently such as the Space Time Block Code (STBC) which achieves diversity gain [3] and the spatial multiplexing which achieves capacity gain [2].

The STBCs has a very low decoding complexity and it can be easily implemented to achieve high spatial diversity gain. In case of orthogonal STBC the complexity of the Maximum likelihood detector becomes linear [4]. The STBC has maximum data rate of 1 symbol per transmission time slot in case of 2-transmit antenna Almouti Scheme [1]. There is no orthogonal space time code that can achieve this full rate with linear complexity [6], [7].

The spatial multiplexing such as Vertical Bell lab Layered Space Time (V-BLAST) scheme can provide high data rate [2].

Joint ML decoding for the data streams is done at the receiver. The detection complexity increases exponentially with the number of transmit antenna. Sub-optimal reception techniques have been introduced to have lower complexity with the price of degradation of bit error rate performance [8], [9].

This paper compares the BER performance and the capacity of different topologies of Hybrid STBC-BLAST, orthogonal STBC, V-BLAST, Qausi–Orthogonal QO-STBC.

II. SYSTEM MODEL

Next generations of wireless communication systems made a demand for high data rate with high quality systems, in other words spectrum has become a scarce and expensive resource while the bandwidth is very limited and restricted. Transmit power is limited in addition to time/frequency domain processing are at limits, but space is not [10].

A. MIMO System

Let H be the channel matrix of $N \times M$ dimensions, where M is the number of the transmit antennas and N is the number of the receive antennas. In the ideal case, each path is assumed to be statistically independent from the others. Herein, consider a transmitted vector $x=[x_1, x_2, x_3......x_M]^T$, the vector is then transmitted via a MIMO channel characterized by the channel matrix H whose element $h_{i,j} \approx CN(0,1)$ is the random Gaussian complex channel coefficient between the j^{th} transmit and i^{th} receive antennas with zero mean and unity variance. The received vector $r=[r_1, r_2, r_3......r_N]^T$ can then be given as following:

$$\boldsymbol{r} = \boldsymbol{Hx} + \boldsymbol{n} \qquad (1)$$

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

Eq. (1) can be expressed in full matrix format as:

$$\begin{pmatrix} r_1(k) \\ r_2(k) \\ \vdots \\ r_N(k) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & \dots & h_{1M} \\ h_{21} & h_{22} & \dots & h_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N1} & \dots & \dots & h_{NM} \end{pmatrix} \begin{pmatrix} x_1(k) \\ x_2(k) \\ \vdots \\ x_M(k) \end{pmatrix} + \begin{pmatrix} n_1(k) \\ n_2(k) \\ \vdots \\ n_N(k) \end{pmatrix} \quad (2)$$

Capacity of MIMO Systems

It was shown by Shannon that the attainable capacity for a flat fading Single Input Single Output (SISO) communication system is

$$C_{SISO} = log_2(1+\gamma |h^2|) \text{ bps/Hz}, \quad (3)$$

where γ is the average SNR and h denotes the fading gain.

In 1998, Foschini has demonstrated that the capacity of the flat fading channel of the MIMO communication systems is given by [6]:

$$C_{MIMO} = log_2(det\,| \boldsymbol{I}_N + \frac{\gamma}{M} \boldsymbol{H}^H \boldsymbol{H}|) \text{ bps/Hz}, \quad (4)$$

With the assumption that numbers of transmit and receive antennas are equal. This theoretical capacity expression for MIMO systems points out that the capacity may be increased linearly with the number of used antennas [7]. Thus capacity for MIMO systems is increased in comparison to SISO systems, where the capacity increases logarithmically with SNR.

B. *Space Time Block Coding System*

This method takes advantage of the additional spatial diversity that MIMO offers. With STC [7]-[51], unlike BLAST system which transmitting independent data streams, the same signal is transmitted in a predetermined manner instantaneously from different transmit antennas to obtain transmit diversity, in order to combat the fading of the channel. Generally, Space Time Coding (STC) leads to signal-reliability improvement, so that even when one or more of the paths is in a deep-fade, it is still possible to obtain an error-free signal. Using spatial diversity, however, reduces the number of independent paths, which leads to a decreased maximum possible rate at the transmitter.

i. *Alamouti STBC*

A simple Space Time Code suggested by Mr. Alamouti in October 1998 [1]. He offered a simple method for achieving spatial diversity with two transmit antennas. However, Alamouti suggested that the symbols will be divided into two groups.

In the first time slot, x_1 and x_2 are sent from the 1st and 2nd antennas. In second time slot - x_2* and x_1* are sent from the 1st and 2nd antennas. There is no change in the data rate (1 symbol per time slot).

The transmitted 2 × 2 STBC codeword is $\boldsymbol{x}$, and the symbols x_i can be any quadrature modulated symbols.

$$\boldsymbol{x} = \begin{pmatrix} x_0 & -x_1^* \\ x_1 & x_0^* \end{pmatrix} \quad (5)$$

The flat faded channel matrix for two transmit and one receive antennas is

$$\mathrm{H} = \begin{bmatrix} h_{00} & h_{01} \\ h_{10} & h_{11} \end{bmatrix} \quad (6)$$

The received signal from eq. (1) at the first time slot the received signal is:

$$\begin{pmatrix} r_0^0 \\ r_1^0 \end{pmatrix} = \begin{pmatrix} h_{00}x_0 + h_{01}x_1 \\ h_{10}x_0 + h_{11}x_1 \end{pmatrix} + \begin{pmatrix} n_0^0 \\ n_1^0 \end{pmatrix} \quad (7)$$

And, at the second time slot the received signal is:

$$\begin{pmatrix} r_0^1 \\ r_1^1 \end{pmatrix} = \begin{pmatrix} -h_{00}x_1^* + h_{01}x_0^* \\ -h_{10}x_1^* + h_{11}x_0^* \end{pmatrix} + \begin{pmatrix} n_0^1 \\ n_1^1 \end{pmatrix} \quad (8)$$

Rearrange eq. (7) and (8) in matrix notation, the received signals for two time slots are:

$$\begin{pmatrix} r_0^0 \\ r_1^0 \\ r_0^{1*} \\ r_1^{1*} \end{pmatrix} = \begin{pmatrix} h_{00} & h_{01} \\ h_{10} & h_{11} \\ h_{01}^* & -h_{00}^* \\ h_{11}^* & -h_{10}^* \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \end{pmatrix} + \begin{pmatrix} n_0^0 \\ n_1^0 \\ n_0^{1*} \\ n_1^{1*} \end{pmatrix}, \quad (9)$$

Where r_0^0 and r_1^0 are the received signals on the 1st time slot from the 1st and 2nd receive antenna respectively, r_0^1 and r_0^1 is the received signals on the 2nd time slot from the 1st and 2nd receive antennas, respectively, h_0 is the channel gain from 1st transmit antenna to receive antenna, h1 is the channel gain from 2nd transmit antenna to receive antenna, x_0 and x_1 are the transmitted symbols and n_0^0, n_0^1, n_1^0 and n_1^1 are the AWGN modeled as independent identical distribution (i.i.d) complex Gaussian random variables with zero mean and power spectral density $N_0/2$ per dimension on 1st ,2nd time slots and on 1st and 2nd receive antennas, respectively.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

So the virtual channel matrix for 2 × 2 MIMO system in two time slots with Alamouti scheme is (Assuming a flat Rayleigh fading channel):

$$\boldsymbol{H}_A = \begin{pmatrix} h_{00} & h_{10} & h_{01}^* & h_{11}^* \\ h_{01} & h_{11} & -h_{00}^* & -h_{10}^* \end{pmatrix}^T \quad (10)$$

The columns of the matrix represent antennas and the rows represent the time slots. Therefore, p time slots are needed to transmit k symbols, resulting in a code rate

$$Rs = k/p \text{ Symbols/Time slot}, \quad (11)$$

$Rs = 1$ for Alamouti scheme. It is of special interest to find code matrices achieving the maximum transmission rate permitted by the STC theory, $Rs = 1$ Symbols/Time slot (full rate) [44].

The demodulator can treats the channel matrix of 2 × 2 as a virtual 4 × 2 matrix for two time slots, and then it can do the decoding process by multiplying the received signal by the hermitian of the Alamouti 2 × 2 channel matrix (Assuming a full channel estimation).

$$\tilde{\boldsymbol{r}} = \boldsymbol{H}_A^H \begin{pmatrix} r_0^0 & r_1^0 & r_0^{1*} & r_1^{1*} \end{pmatrix}^T$$

$$\tilde{\boldsymbol{r}} = \begin{pmatrix} h_{00}^* & h_{10}^* & h_{01} & h_{11} \\ h_{01}^* & h_{11}^* & -h_{00} & -h_{10} \end{pmatrix} \begin{pmatrix} r_0^0 & r_1^0 & r_0^{1*} & r_1^{1*} \end{pmatrix}^T \quad (12)$$

$$\begin{bmatrix} \tilde{r}_0 \\ \tilde{r}_1 \end{bmatrix} = \begin{pmatrix} h_{00}^* & h_{10}^* & h_{01} & h_{11} \\ h_{01}^* & h_{11}^* & -h_{00} & -h_{10} \end{pmatrix} \begin{pmatrix} h_{00} & h_{01} \\ h_{10} & h_{11} \\ h_{01}^* & -h_{00}^* \\ h_{11}^* & -h_{10}^* \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \end{pmatrix}$$

$$+ \begin{pmatrix} h_{00}^* & h_{10}^* & h_{01} & h_{11} \\ h_{01}^* & h_{11}^* & -h_{00} & -h_{10} \end{pmatrix} \begin{pmatrix} n_0^0 & n_1^0 & n_0^{1*} & n_1^{1*} \end{pmatrix}^T \quad (13)$$

$$\begin{pmatrix} \tilde{r}_0 \\ \tilde{r}_1 \end{pmatrix} = \begin{pmatrix} h^2 & 0 \\ 0 & h^2 \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \end{pmatrix} + \begin{pmatrix} n_0' \\ n_1' \end{pmatrix}, \quad (14)$$

$$h^2 = |h_{00}|^2 + |h_{01}|^2 + |h_{10}|^2 + |h_{11}|^2$$

The noise term is still white.

$$\begin{pmatrix} \tilde{x}_0 \\ \tilde{x}_1 \end{pmatrix} = \arg \min_{x \in A^S} \begin{pmatrix} (|h_{00}|^2 + |h_{01}|^2 + |h_{10}|^2 + |h_{11}|^2) x_0 \\ (|h_{00}|^2 + |h_{01}|^2 + |h_{10}|^2 + |h_{11}|^2) x_1 \end{pmatrix} + \begin{pmatrix} n_0' \\ n_1' \end{pmatrix} \quad (15)$$

General STBC Based on Orthogonal Designs

The Alamouti scheme presented above works only with two transmit antennas. This scheme was later generalized in [4], [12] to any number of transmit antennas. Like Alamouti code in (5), the general STBC is defined by a code matrix with orthogonal columns.

In general, STBC is defined by a $(P \times M)$ matrix G. The entries of the matrix G are linear combinations of the variables $x_1, x_2, \ldots, x_k$ (representing real or complex symbols). The columns of the matrix represent the transmit antennas and the rows represent time slots [11]. General STBC based on real orthogonal designs achieving full diversity and full rate can be found for any number of transmit antennas M [4],[12], and [13].

For $M = 3$ real symbols $R_s = 1$ S/Ts and the complex symbols $R_s = 1/2$ S/Ts

$$\boldsymbol{G}_3 = \begin{pmatrix} x_1 & -x_2 & -x_3 \\ x_2 & x_1 & x_4 \\ x_3 & -x_4 & x_1 \end{pmatrix} \quad (16)$$

For real and for complex, the code matrix is given as,

$$\boldsymbol{G}_3 = \begin{pmatrix} x_1 & -x_2 & -x_3 & x_1^* & -x_2^* & -x_3^* \\ x_2 & x_1 & x_4 & x_2^* & x_1^* & x_4^* \\ x_3 & -x_4 & x_1 & x_3^* & -x_4^* & x_1^* \end{pmatrix}^T \quad (17)$$

For M = 4, the real symbols with Rs = 4/4 = 1 S/Ts (full rate)

$$\boldsymbol{G}_4 = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & x_2 \\ -x_4 & -x_3 & x_2 & x_1 \end{pmatrix} \quad (18)$$

And for complex symbols with Rs = 1/2 S/Ts

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

$$G_4 = \begin{pmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & x_3 & x_2 & x_1 & x_4^* & x_3^* & x_2^* & x_1^* \end{pmatrix}^T \quad (19)$$

This paper studies 4 × 4 MIMO system but in [4] it has been proven that complex orthogonal design of size 4 × 4 does not exist.

Quasi-Orthogonal STBC

Recently in 2001, H. Jafarkhani in [14] develops a new full rate (Rs = 1 S/Ts) complex Quasi-Orthogonal STBC (QOSTBC) for four-transmit antennas as shown below:

$$G_4 = \begin{pmatrix} G_{12} & G_{34} \\ -G_{34}^* & G_{12}^* \end{pmatrix} = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & -x_3 & -x_2 & x_1 \end{pmatrix} \quad (20)$$

where

$$G_{12} = G_2 = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix}$$

is the Alamouti encoding scheme like eq. (5) and the subscript '12' is included to denote that the matrix contains symbols x_1 and x_2, also the subscript '34' to denote the matrix which contains symbols x_3 and x_4.

From eq.(18) with 4 × 4 MIMO system and similar to Alamouti analysis eq.(5-15) with four time slots assuming a flat fading channel and by letting $x = G_4^T$.

$$H_{4x4} = \begin{pmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \\ h_{41} & h_{42} & h_{43} & h_{44} \end{pmatrix} = \begin{pmatrix} \boldsymbol{h}_1 & \boldsymbol{h}_2 & \boldsymbol{h}_3 & \boldsymbol{h}_4 \end{pmatrix} \quad (21)$$

$$\begin{pmatrix} \boldsymbol{r}_1 \\ \boldsymbol{r}_2^* \\ \boldsymbol{r}_3^* \\ \boldsymbol{r}_4 \end{pmatrix} = \begin{pmatrix} \boldsymbol{h}_1 & \boldsymbol{h}_2 & \boldsymbol{h}_3 & \boldsymbol{h}_4 \\ \boldsymbol{h}_2^* & -\boldsymbol{h}_1^* & \boldsymbol{h}_4^* & -\boldsymbol{h}_3^* \\ \boldsymbol{h}_3^* & \boldsymbol{h}_4^* & -\boldsymbol{h}_1^* & -\boldsymbol{h}_2^* \\ \boldsymbol{h}_4 & \boldsymbol{h}_3 & -\boldsymbol{h}_2 & -\boldsymbol{h}_1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} + \begin{pmatrix} \boldsymbol{n}_1 \\ \boldsymbol{n}_2^* \\ \boldsymbol{n}_3^* \\ \boldsymbol{n}_4 \end{pmatrix} \quad (22)$$

The virtual channel matrix of 4 transmit time slots is of size 16 × 4

$$\boldsymbol{H}_{4,QOSTBC} = \begin{pmatrix} \boldsymbol{H}_{4x4} \\ \boldsymbol{H}_{4x4}^* \\ \boldsymbol{H}_{4x4}^* \\ \boldsymbol{H}_{4x4} \end{pmatrix}_{16x4} = \begin{pmatrix} \boldsymbol{h}_1 & \boldsymbol{h}_2 & \boldsymbol{h}_3 & \boldsymbol{h}_4 \\ \boldsymbol{h}_2^* & -\boldsymbol{h}_1^* & \boldsymbol{h}_4^* & -\boldsymbol{h}_3^* \\ \boldsymbol{h}_3^* & \boldsymbol{h}_4^* & -\boldsymbol{h}_1^* & -\boldsymbol{h}_2^* \\ \boldsymbol{h}_4 & \boldsymbol{h}_3 & -\boldsymbol{h}_2 & -\boldsymbol{h}_1 \end{pmatrix}_{16x4} \quad (23)$$

Similar Alamouti decoding scheme at the receiver side,

$$\tilde{\boldsymbol{r}} = \boldsymbol{H}_{4,QOSTBC}^H \boldsymbol{r} = \boldsymbol{H}_{4,QOSTBC}^H \boldsymbol{H}_{4,QOSTBC} \boldsymbol{x} + \boldsymbol{H}_{4,QOSTBC}^H \boldsymbol{n} \quad (24)$$

$$\tilde{\boldsymbol{r}} = \Delta \boldsymbol{x} + \tilde{\boldsymbol{n}} \quad (25)$$

The noise term is still white since the noise terms are (i.i.d.). For an orthogonal block code, Δ is 4 × 4 diagonal matrix but for a quasi-orthogonal block code Δ have some non-zero terms other than diagonal elements that reduce the diversity gain of the code and it will have the form [14]

$$\Delta = \left(\boldsymbol{H}_{4,QOSTBC}^H\right)_{4x16} \left(\boldsymbol{H}_{4,QOSTBC}\right)_{16x4} = \begin{pmatrix} \gamma & 0 & 0 & \alpha \\ 0 & \gamma & -\alpha & 0 \\ 0 & -\alpha & \gamma & 0 \\ \alpha & 0 & 0 & \gamma \end{pmatrix}_{4x4} \quad (26)$$

Where $\gamma = \sum_{k=1}^{4} \left|\boldsymbol{h}_k^H \boldsymbol{h}_k\right|$ and $\alpha = Re\left\{\boldsymbol{h}_1^H \boldsymbol{h}_4 - \boldsymbol{h}_2^H \boldsymbol{h}_3\right\}$

$$\begin{pmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \tilde{x}_3 \\ \tilde{x}_4 \end{pmatrix} = \arg\min_{x \in A^S} \begin{pmatrix} (|\boldsymbol{h}_1^H \boldsymbol{h}_1| + |\boldsymbol{h}_2^H \boldsymbol{h}_2| + |\boldsymbol{h}_3^H \boldsymbol{h}_3| + |\boldsymbol{h}_4^H \boldsymbol{h}_4|)x_1 \\ (|\boldsymbol{h}_1^H \boldsymbol{h}_1| + |\boldsymbol{h}_2^H \boldsymbol{h}_2| + |\boldsymbol{h}_3^H \boldsymbol{h}_3| + |\boldsymbol{h}_4^H \boldsymbol{h}_4|)x_2 \\ (|\boldsymbol{h}_1^H \boldsymbol{h}_1| + |\boldsymbol{h}_2^H \boldsymbol{h}_2| + |\boldsymbol{h}_3^H \boldsymbol{h}_3| + |\boldsymbol{h}_4^H \boldsymbol{h}_4|)x_3 \\ (|\boldsymbol{h}_1^H \boldsymbol{h}_1| + |\boldsymbol{h}_2^H \boldsymbol{h}_2| + |\boldsymbol{h}_3^H \boldsymbol{h}_3| + |\boldsymbol{h}_4^H \boldsymbol{h}_4|)x_4 \end{pmatrix} + \begin{pmatrix} \boldsymbol{n}_1' \\ \boldsymbol{n}_2' \\ \boldsymbol{n}_3' \\ \boldsymbol{n}_4' \end{pmatrix}$$

(27)

The effective bandwidth of the STBC system must be divided by *P* to compensate $\tilde{r}$ in eq.(25) since it must be measured over *P*-(time slots) consecutive symbol periods. The resulting capacity equation is [15]:

$$C_{4,QOSTBC} = \frac{1}{4} \log_2 (\det | \boldsymbol{I}_N + \frac{\gamma}{M} \boldsymbol{H}_{4,QOSTBC}^H \boldsymbol{H}_{4,QOSTBC} |) \quad (28)$$

$$C_{4,OSTBC} = \frac{1}{8} \log_2 (\det | \boldsymbol{I}_N + \frac{\gamma}{M} \boldsymbol{H}_{4,OSTBC}^H \boldsymbol{H}_{4,OSTBC} |) \quad (29)$$

C. Hybrid BLAST STBC System

Recently, there are several proposals to combine space-time block coding (STBC) and spatial multiplexing (SM) to obtain transmit diversity and spatial multiplexing gain simultaneously in a system called Hybrid BLAST-STBC (or Hybrid STBC-BLAST) MIMO system [16].

This idea emerged in a Multi-User (MU) systems, if each user has a STBC encoder then by letting all users considered as one user having multilayer STBC scheme (every layer has a STBC encoder) then this user enjoys a high spectral efficiency and transmit diversity benefits.

As MU-STBC system and the hybrid BLAST-STBC system are equivalent, symbol detection schemes for MU-STBC systems could be applied to the case of the hybrid BLAST-STBC system [16].

There are two types of hybrid systems, the first type in some references called Hybrid STBC-BLAST system, it is a BLAST system with STBC encoders in the lower layers, the second type is called Hybrid BLAST-STBC system or it is referred to as Multi-Layered STBC (MLSTBC) system.

Hybrid STBC-VBLAST System

The first study on this system was in 2005 [17] when Mao and Motani complete their technical report at National University of Singapore (NUS) in 2004. In their study, they introduced a new STBC-VBLAST scheme, by letting J to be the number of STBC layers and each layer has n transmit antennas, the new system integrates J orthogonal $n \times p$ STBC into the lower layers of VBLAST systems with a total M transmit and N receive antennas.

The remaining higher layers transmit independent data streams (VBLAST). This structure is called in [18] the Hybrid MIMO Transmission Schemes (HMTS) and it also aims to achieve diversity and multiplexing gains at the same time [19]. Fig. 1 shows the block diagram for the Hybrid STBC-VBLAST transmitter.

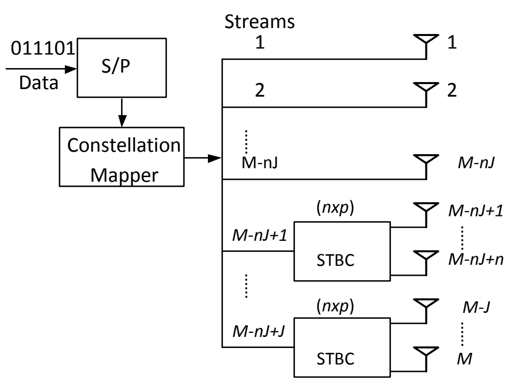

Fig. 1: Block Diagram for Hybrid STBC-VBLAST Transmitter

The information symbol sequence is divided into $M-(n-1)J$ streams. Streams 1 to $M-nJ$ are transmitted on the first $M-nJ$ antennas.

But the other J streams are passed through J-STBC encoders (STBC Layers) and they are transmitted on nJ antennas.

Furthermore, each group of n antennas is used to transmit an $n \times p$ STBC symbols, denoted by $\boldsymbol{G}_n$, where n and p indicate the number of transmit antennas for each encoder and symbol intervals occupied by the STBC respectively. We call each of the J STBC encoded streams a STBC layer and the system a (n, p, J) STBC-VBLAST system [14] and (G_n + 1 + 1…) in [20] where those ones refer to number of transmit antennas appointed to V-BLAST transmission. The transmitted signal can be expressed in matrix form as

$$\boldsymbol{x} = \begin{pmatrix} \boldsymbol{x}_{spa} \\ \boldsymbol{G}_n \end{pmatrix}, \qquad (30)$$

where $\boldsymbol{x}_{spa}$ contains the independent symbols (VBLAST)

$$x_{spa} = \begin{pmatrix} x_1^1 & x_1^2 & \cdots & x_1^p \\ x_2^1 & x_2^2 & \cdots & x_2^p \\ \vdots & \vdots & \ddots & \vdots \\ x_{M-nJ}^1 & x_{M-nJ}^2 & \cdots & x_{M-nJ}^p \end{pmatrix}, \qquad (31)$$

And $\boldsymbol{G}_n$ is the transpose of one of encoding matrices of STBC ($\boldsymbol{G}_2$,$\boldsymbol{G}_3$,$\boldsymbol{G}_4$....etc).

An efficient encoder and decoder was proposed in [21], it aims to send symbols and their negative conjugates in the second time slot excepts that of the Alamouti encoded layers, then eq.(31) will be

$$x_{spa} = \begin{pmatrix} x_1 & -x_2^* \\ x_3 & -x_4^* \\ \vdots & \vdots \\ x_{2(M-nJ)-1} & -x_{2(M-nJ)}^* \end{pmatrix}, \qquad (32)$$

$$(\boldsymbol{r}) = (\boldsymbol{H})\begin{pmatrix} \boldsymbol{x}_{spa} \\ \boldsymbol{G}_2 \end{pmatrix} + (\boldsymbol{n}). \qquad (33)$$

After arranging eq.(3.5) it will has the form of

$$\begin{pmatrix} r_1 \\ r_2^* \\ \vdots \\ r_{N-1} \\ r_N^* \end{pmatrix} = \left(\boldsymbol{H}_{spa} \quad \boldsymbol{H}_A\right)\boldsymbol{x} + \begin{pmatrix} n_1 \\ n_2^* \\ \vdots \\ n_{N-1} \\ n_N^* \end{pmatrix} \qquad (34)$$

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

Where $\boldsymbol{H}_A$ is the Alamouti channel matrix for groups of two and it has the form of

$$\boldsymbol{H}_A = \begin{pmatrix} \boldsymbol{H}^A_{1,1} & \boldsymbol{H}^A_{1,2} & \cdots & \boldsymbol{H}^A_{1,J} \\ \boldsymbol{H}^A_{2,1} & \boldsymbol{H}^A_{2,2} & \cdots & \boldsymbol{H}^A_{2,J} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{H}^A_{N,1} & \boldsymbol{H}^A_{N,2} & \cdots & \boldsymbol{H}^A_{N,J} \end{pmatrix}, \quad (35)$$

Where every element of eq.(3.7) is given by:

$$\boldsymbol{H}^A_{a,b} = \begin{pmatrix} h_{a,2b+M-nJ-1} & h_{a,2b+M-nJ} \\ h^*_{a,2b+M-nJ} & -h^*_{a,2b+M-nJ-1} \end{pmatrix} \quad (36)$$

For $a = 1, 2, \ldots, N$ and $b = 1, 2, \ldots, J$ and $\boldsymbol{H}_{spa}$ is

$$\boldsymbol{H}_{spa} = \begin{pmatrix} \boldsymbol{H}^{spa}_{1,1} & \boldsymbol{H}^{spa}_{1,2} & \cdots & \boldsymbol{H}^{spa}_{1,M-nJ} \\ \boldsymbol{H}^{spa}_{2,1} & \boldsymbol{H}^{spa}_{2,2} & \cdots & \boldsymbol{H}^{spa}_{2,M-nJ} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{H}^{spa}_{N,1} & \boldsymbol{H}^{spa}_{N,2} & \cdots & \boldsymbol{H}^{spa}_{N,M-nJ} \end{pmatrix}, \quad (37)$$

Where every element of eq.(37) is given by:

$$\boldsymbol{H}^{spa}_{i,j} = \begin{pmatrix} h_{i,j} & 0 \\ 0 & -h^*_{i,j} \end{pmatrix} \quad (38)$$

For $i = 1, 2, \ldots, N$ and $j = 1, 2, \ldots, M\text{-}nJ$.

Now for 4 × 4 MIMO system, Alamouti scheme can be used so $M = 4$, $J = 1$, $n = 2$ and $p = 2$.

$$x = \begin{pmatrix} x_1 & -x_2^* \\ x_3 & -x_4^* \\ x_5 & -x_6^* \\ x_6 & x_5^* \end{pmatrix} \quad (39)$$

$$\boldsymbol{H}_{Hibrid} = \begin{pmatrix} \boldsymbol{H}_{4x6} \\ \boldsymbol{H}^*_{4x6} \end{pmatrix}_{8x6} = \begin{pmatrix} \boldsymbol{h}_1 & 0 & \boldsymbol{h}_2 & 0 & \boldsymbol{h}_3 & \boldsymbol{h}_4 \\ 0 & -\boldsymbol{h}_1^* & 0 & -\boldsymbol{h}_2^* & \boldsymbol{h}_4^* & -\boldsymbol{h}_3^* \end{pmatrix}_{8x6} \quad (40)$$

Where $\boldsymbol{h}_n$ is the n^{th} column vector of $\boldsymbol{H}_{4\times4}$.

$$\begin{pmatrix} \boldsymbol{r}_1 \\ \boldsymbol{r}_2^* \end{pmatrix} = \begin{pmatrix} \boldsymbol{h}_1 & 0 & \boldsymbol{h}_2 & 0 & \boldsymbol{h}_3 & \boldsymbol{h}_4 \\ 0 & -\boldsymbol{h}_1^* & 0 & -\boldsymbol{h}_2^* & \boldsymbol{h}_4^* & -\boldsymbol{h}_3^* \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{pmatrix} + \begin{pmatrix} \boldsymbol{n}_1 \\ \boldsymbol{n}_2^* \end{pmatrix} \quad (41)$$

$$\tilde{\boldsymbol{r}} = \boldsymbol{H}^H_{Hibrid}\, \boldsymbol{r} = \boldsymbol{H}^H_{Hibrid}\, \boldsymbol{H}_{Hibrid}\, \boldsymbol{x} + \boldsymbol{H}^H_{Hibrid}\, \boldsymbol{n} \quad (42)$$

Hybrid BLAST STBC System (Layered Space-Time Codes)

This is the second type of hybrid system; combining BLAST and STBC performance in a layered architecture with transmit diversity in each layer. This is called a Multi-Layered STBC (MLSTBC) system [4], [22]. It is called in some references a hybrid BLAST-STBC system [15], it may be called a combined STBC and BLAST or combined STBC and SM system [23]. This architecture was first considered in [4] but with space time trellis codes (STTC). One advantage of using STBC over STTC is that the orthogonal structure and the short code length can be exploited at the receiver to reduce the minimum required number of receive antennas [24]. For MLSTTC, the number of receive antennas should be at least equal to the total number of transmit antennas. However, for MLSTBC, the number of receive antennas is equal to the number of layers. Fig. 2 shows the architecture of the Hybrid BLAST STBC system.

For 4 × 4 MIMO system, Alamouti scheme can be used so $M = 4$, $J = 2$, $n = 2$ and $p = 2$.

$$\boldsymbol{x} = \begin{pmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \\ x_3 & -x_4^* \\ x_4 & x_3^* \end{pmatrix}, \quad (43)$$

And for the channel matrix in eq.(40) and eq.(42) will be

$$\begin{pmatrix} r_1 \\ r_2^* \end{pmatrix} = \begin{pmatrix} \boldsymbol{H}^1_A & \boldsymbol{H}^2_A \end{pmatrix} \boldsymbol{x} + \begin{pmatrix} n_1 \\ n_2^* \end{pmatrix}. \quad (44)$$

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

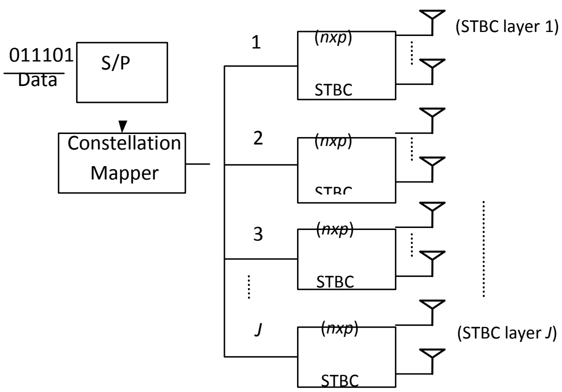

Fig. 2: Architecture of the Hybrid BLAST STBC System

And according to the criteria in eq.(2.12) to eq.(2.20) the channel matrix is will be

$$\boldsymbol{H}_{Hibrid} = \begin{pmatrix} \boldsymbol{H}_A^1 & \boldsymbol{H}_A^2 \end{pmatrix} = \begin{pmatrix} \boldsymbol{H}_{4x4} \\ \boldsymbol{H}_{4x4}^* \end{pmatrix}_{8x\,4}$$

$$\boldsymbol{H}_{Hibrid} = \begin{pmatrix} \boldsymbol{h}_1 & \boldsymbol{h}_2 & \boldsymbol{h}_3 & \boldsymbol{h}_4 \\ \boldsymbol{h}_2^* & -\boldsymbol{h}_1^* & \boldsymbol{h}_4^* & -\boldsymbol{h}_3^* \end{pmatrix}_{8x\,4} \quad (45)$$

where $\boldsymbol{h}_n$ is the n^{th} column vector of $\boldsymbol{H}_{4x4}$.

$$\tilde{\boldsymbol{r}} = \boldsymbol{H}_{Hibrid}^H \boldsymbol{r} = \boldsymbol{H}_{Hibrid}^H \boldsymbol{H}_{Hibrid} \boldsymbol{x} + \boldsymbol{H}_{Hibrid}^H \boldsymbol{n} . \quad (46)$$

$\boldsymbol{H}_{Hibrid}^H \boldsymbol{H}_{Hibrid}$ will be a 4 × 4 matrix where any detecting scheme can be applied.

The general formula for the capacity of the Hybrid BLAST-STBC system for any STBC scheme is,

$$C_{Hibrid} = \frac{1}{p} log_2 (det \,|\, \boldsymbol{I}_N + \frac{\gamma}{M} \boldsymbol{H}_{Hibrid}^H \boldsymbol{H}_{Hibrid} |) \; bps/Hz \quad (47)$$

III. Comparison

The BER performance and the capacity of Hybrid BLAST-STBC (G2 + 1 + 1) and (G2 + 1), MLSTBC (G2 + G2), V-BLAST, QOSTBC and G4-OSTBC will be compared. In addition, we provide performance comparison between the Hybrid BLAST-STBC and MLSTBC and the former systems and investigate the advantages of the Hybrid system.

One of the main differences between ML-STBC and V-BLAST at the same number of transmit/receive antennas is that ML-STBC has more transmit diversity than V-BLAST while V-BLAST has more layers.

For example, with a 4 × 4 MIMO system, hybrid system has at least one layer with a transmit diversity of two with receive diversity of four with ML detector at the receiver. On the other hand, V-BLAST has four layers and no transmit diversity with the same receive diversity. The concerned systems in the current simulation are V-BLAST, Hybrid G2 + 1 + 1, Hybrid G2 + G2, Hybrid G2 + 1, QOSTBC and OSTBC systems.

Comparing Hybrid G2 + 1 + 1, G2 + G2 and G2 + 1 systems

It is important to see the hybrid system's performances and capacities which are depicted on Fig. 3 and Fig. 4.

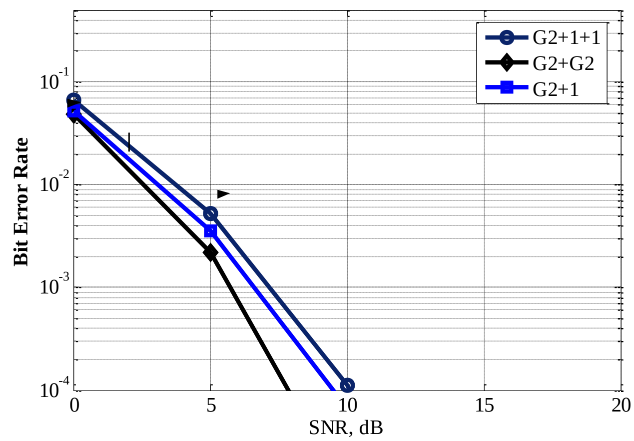

Fig. 3: BER of Hybrid systems G2 + 1 + 1, G2 + G2 and G2 + 1.

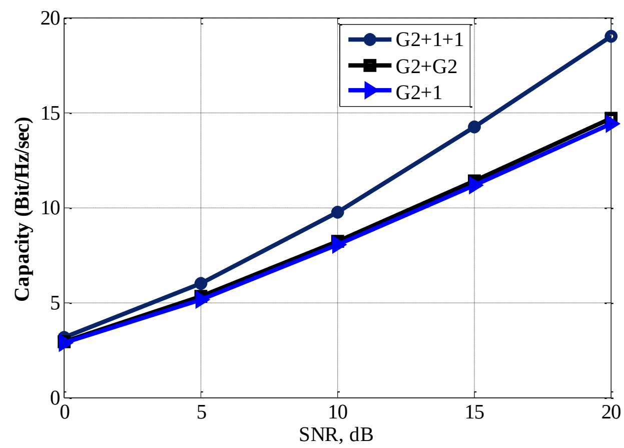

Fig. 4: Capacity of Hybrid systems G2 + 1 + 1, G2 + G2 and G2 + 1.

The hybrid system G2 + G2 presents the best performance compared to others since it has two transmit diversity (one for each layer).

Conversely, the hybrid system G2 + 1 + 1 with M = 4 and J = 1 Alamouti encoder has the worst performance because it has two pure spatial multiplexing layers with additional layer which having a transmit diversity of Alamuoti [1], but its ergodic capacity according to eq.(47) is the best since it has 6 bit/sec/Hz spectral efficiency at QPSK modulated signals. Regarding to hybrid system G2 + 1 with M = 3 and J = 1 Alamouti encoder, it has a worse performance than G2 + G2 by about 1 dB in SNR at 10^{-3} BER and better than G2 + 1 + 1 by 0.75 dB in SNR at 10^{-3} BER. At 10^{-3} BER there is about 0.75 dB improvement in SNR between G2 + 1 + 1 and G2 + 1. Both of G2 + G2 and G2 + 1 hybrid systems have a spectral efficiency of 4 bit/sec/Hz but the upper bound Shannon capacity of G2 + G2 is better by about 0.25 bit/sec/Hz since it has one more transmit diversity layer.

Comparing 3 × 3, 3 × 4, 4 × 4 VBLAST and Hybrid G2 + 1 + 1 systems

It is expected that G2 + 1 + 1 hybrid system has better performance than pure spatial multiplexing scheme.

By logical inference, both of them have 4-Tx and 4-Rx antennas with the same symbol power and the same receive diversity, so only one thing is varied, it is the last two layers of the transmitter in which it replaced by an Alamouti encoder then this encoder considered as a third layer with transmit diversity. Unfortunately, transmitting over two time slots causes a decrease in spectral efficiency or average channel capacity since 4 × 4 MIMO loses one transmitting layer, Fig. 5 shows the results.

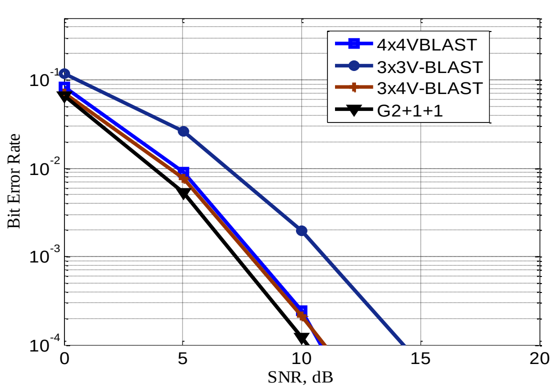

Fig. 5: Performance comparison for 3 × 3, 4 × 4, 3 × 4 and G2 + 1 + 1 systems.

As expected the performance of G2 + 1 + 1 hybrid system is better than pure 4 × 4 and 3 × 3 VBLAST system due to transmit diversity benefit of Alamouti in the last layer.

An 4 × 4 blast system has 4 layers to be transmitted and 3×3 BLAST system has 3 layers as 3 × 4 BLAST system with receive diversity of 4 but with no transmit diversity, a hybrid system G2 + 1 + 1 has 3 layers, two of them are pure uncoded layers and one of them has Alamouti encoder with receive diversity of 4 using ML detector.

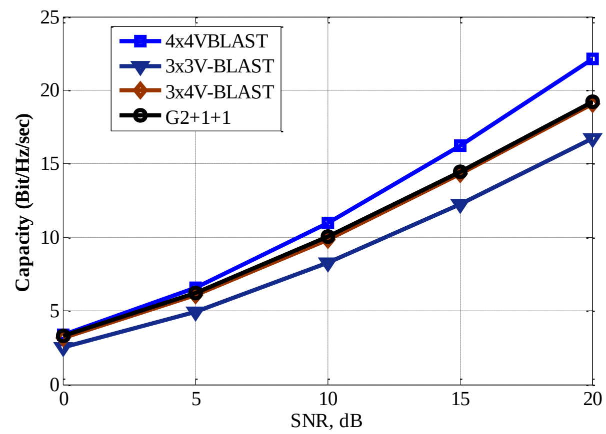

Fig. 6: Capacity comparison for 3 × 3, 4 × 4, 3 × 4 and G2 +1+1 system.

4 × 4 BLAST system has a 8 bps/Hz spectral efficiency with the greatest upper bound Shannon capacity and 3 × 3 and 3 × 4 and G2 + 1 + 1 system has 6 bps/Hz with lower bound of Shannon capacities. However, G2 + 1 + 1 hybrid system has better capacity than both of 3 × 3 and 3 × 4 BLAST systems. Finally, the results give a conclusion that G2 + 1 + 1 hybrid system has a better performance and capacity than switching off one transmit antenna or one receive antenna.

Comparing 2 × 2, 2 × 4 VBLAST, Hybrid G2 + G2 and G2 + 1 systems

2 × 2, 2 × 4, G2 + G2 and G2 + 1 system have the same spectral efficiency of 4 bps/Hz, Fig. 7 presents the performance results of them.

2 × 4, G2 + G2 and G2 + 1 have the same number of receive antennas but they have different number of transmit antennas 2, 3, and 4 respectively, they have another different thing it is a transmit diversity layers, 2 × 2 and 2 × 4 have no transmit diversity layers while G2 + 1 has one transmit diversity layer and G2 + G2 has two transmit diversity layers. The benefits of hybridizing scheme is clearly appeared in Fig. 8, even though all these scheme have the same transmit signal power of 2*Es* at each time slot. It can be seen that at 10^{-3} BER there is about 1 dB improvement in SNR respect to G2 + 1 and 2 × 4 and 11 dB improvement in SNR respect to 2 × 2 VBLAST.

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

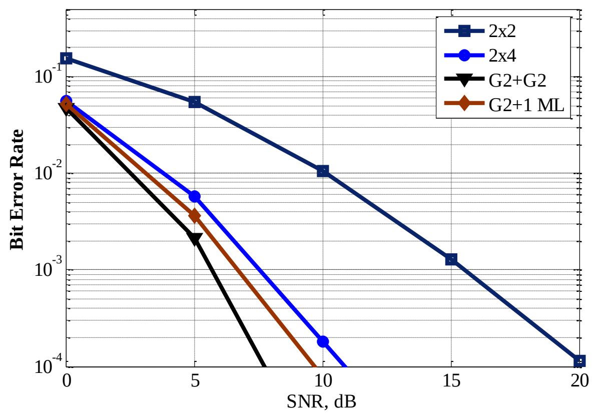

Fig. 7: Performance comparison for 2 × 2, 2 × 4, G2 + G2 and G2 + 1 system

Accordingly, these systems have the same spectral efficiency of 4 bps/Hz and there is no large difference in Shannon capacity as illustrated in Fig. 4.8 below

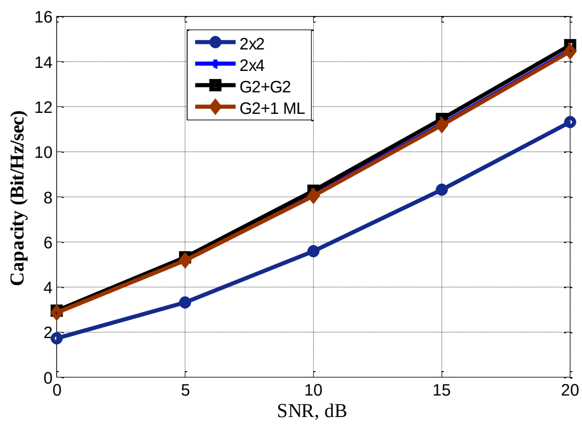

Fig. 8 Capacity comparison for 2 × 2, 2 × 4, G2 + G2 and G2 + 1 + 1 systems.

As seen in this Fig. 8, there is slight difference between hybrid systems and receive diversity technique about 0.25 dB in SNR but high for 2 × 2 VBLAST about additional 5 dB improvement in SNR to reach 11 bps/Hz. G2 + G2 hybrid structure has the best performance and capacity with equal transmit power and spectral efficiency respect to pure 2 × 2 VBLAST system, switching off two transmit antenna of 4 × 4 system to be 2 × 4 VBLAST or switching off one transmit antenna of 4 × 4 system and hybridizing it with Alamouti encoder applied to one layer to be G2 + 1 hybrid system.

Comparing 1 × 1, 1 × 4 VBLAST, G4-OSTBC, G2-OSTBC and QOSTBC systems

An 1 × 1 system has no diversity benefits while 1 × 4 structure has four receive diversity order when using ML detector whereas G4-OSTBC, G2-OSTBC (Alamouti) and QOSTBC have both transmit and receive diversity benefits, Fig. 9 show the performance results in a comparable way. Clearly, it is seen in Fig. 9 that at 10^{-3} BER QOSTBC scheme needs more 4 dB improvement in SNR, 6 dB for 1 × 4 system, 9 dB for 2 × 2 Alamouti system and more than 20 dB for 1 × 1 VBLAST system to reach G4-OSTBC performance with the same transmit power. All these system have a spectral efficiency of 2 bps/Hz except G4-OSTBC system which has a 1 bps/Hz and half transmitted power of them. Fig. 10 shows the Shannon capacity of them in a comparable way.

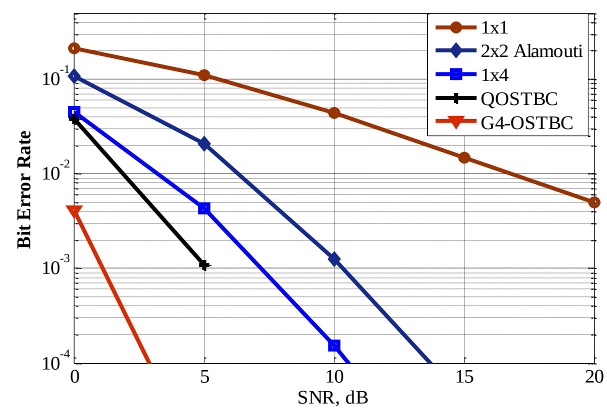

Fig. 9: Performance comparison for 1 × 1, 1 × 4, 2 × 2 Alamouti, QOSTBC and G4-OSTBC systems

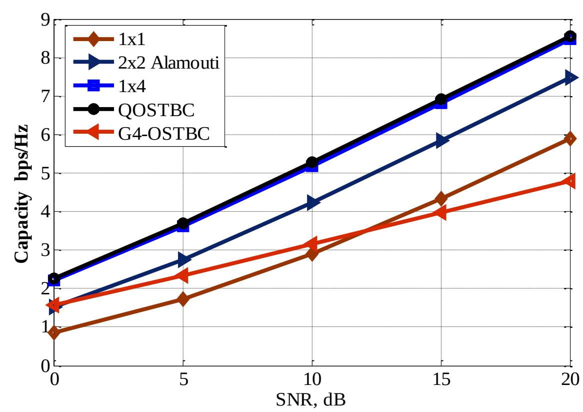

Fig. 10: Capacity comparison for 1 × 1, 1 × 4, 2 × 2 Alamouti, QOSTBC and G4-OSTBC systems

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

G4-OSTBC system has better capacity than 1 × 1 VBLAST for SNR below than 12 dB since it enjoys both transmit diversity on 4 transmit antennas and receive diversity benefits of 4 receive antennas but both of them have lower capacity than other systems, QOSTBC scheme achieve better capacity than others with the same transmit power, for example to achieve 4 bps/Hz 1 × 4 system needs more about 0.25 dB improvement in SNR, 3.25 dB for 2 × 2 Alamouti system, 8 dB for 1 × 1 system and 9.5 dB for G4-OSTBC system to reach the bound of QOSTBC system. Finally, QOSTBC has a very good performance compared to other systems with the best capacity for the same transmit power.

Comparing 4 × 4 VBLAST, Hybrid G2 + 1 + 1, G2 + G2 and QOSTBC systems

Now a comparison of the best performances and capacities of the above case or for cases of the same transmit power must be introduced. Fig. 4.11 and Fig. 4.12 show the compared performances and capacities of 4 × 4, G2 + 1 + 1, G2 + G2 and QOSTBC systems.

Form Fig. 11 and Fig. 12 a good comparison could be done that a 4 × 4 VBLAST system needs 3.75 dB improvements in received SNR to reach the performance of QOSTBC system of 10^{-3} BER. Conversely, a 6 dB improvement in SNR is needed for QOSTBC system to reach the capacity of 4 × 4 system of 5 bps/Hz. Also a 2.5 dB improvement in SNR needed for 4 × 4 system to achieve 10^{-3} BER performances of G2 + G2 system, but G2 + G2 need 2 dB improvement in SNR to reach the capacity of 4 × 4 system of 5 bps/Hz. Finally, G2 + 1 + 1 needs more 0.75 dB in SNR to reach a 4 × 4 capacity bound of 5 bps/Hz, but 4 × 4 system needs 1 dB improvement in SNR to achieve G2 + 1 + 1 performance of 10^{-3} BER.

IV. Conclusion

A comparison for the BER performance and the capacity of V-BLAST, QOSTBC, G4-OSTBC and Hybrid systems G2 + 1 + 1, G2 + 1 and G2 + G2 are done using simulation. It is shown that the Hybrid systems better than pure VBLAST in both BER and outage capacity but neither for QOSTBC nor OSTBC for BER. At the same transmit power and spectral efficiency of the hybrid system G2 + G2 presents better performance and capacity than G2 + 1 system since it has two transmit diversity layers, it has better performance than G2 + 1 + 1 system too but not for the capacity with different transmitting power and spectral efficiency at QPSK modulated signals. The results give that G2 + 1 + 1 hybrid system has a better performance and capacity than switching off one transmit antenna.

The G2 + G2 hybrid structure has better performance and capacity than switching off two transmit antennas of 4 × 4 system.

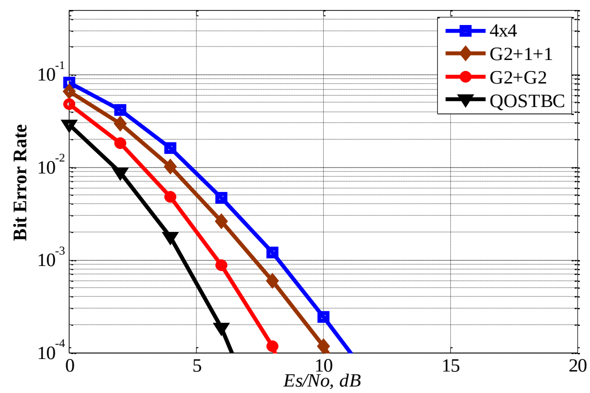

Fig. 11. Performance comparison for 4 × 4, G2 + 1 + 1, G2 + G2 and QOSTBC systems.

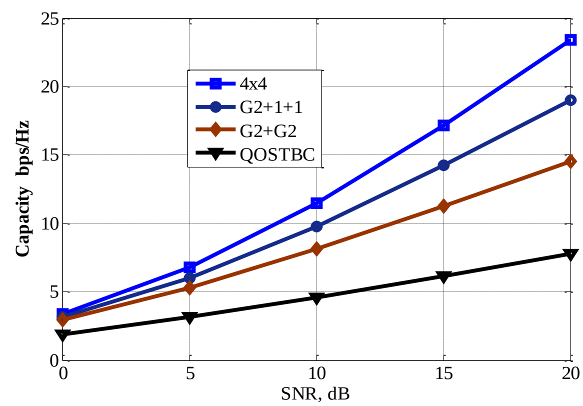

Fig. 12. Capacity comparison for 4 × 4, G2 + 1 + 1, G2 + G2 and QOSTBC systems.

REFERENCES

[1] S. M. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE J. Sel. Areas Commun., vol. 16, pp. 1451–1458, Oct. 1988.

[2] P. Wolniansky, G. Foschini, G. Golden, and R. Valenzuela, "V-blast: an architecture for realizing very high data rates over the rich-scattering wireless channel," in Proc. 1998 International Symp. Signals, Syst., Electron., pp. 295–300.

[3] H. Jafarkhani, Space-Time Coding, Theory and Practice. Cambridge University Press, 2005.

[4] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," IEEE Trans. Inf. Theory, vol. 45, no. 5, pp. 1456–1467, July 1999.

[5] E.Biglieri, Y. Hong, and E. Viterbo, "On fast-decodable space-time block codes," IEEE Trans. Inf. Theory, vol. 55, no. 2, pp. 524–530, Feb. 2009.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 10, October 2012)

[6] E. Ba¸sar and Ümit Aygölü, “High-rate full-diversity space-time block codes for three and four transmit antennas,” IET Commun., vol. 3, no. 8, pp. 1371–1378, Aug. 2009.

[7] ——, “Full-rate full-diversity STBCS for three and four transmit antennas,” Electron. Lett., vol. 44, no. 18, pp. 1076–1077, Aug. 2008.

[8] L. G. Barbero, T. Ratnarajah, and C. Cowan, "A low-complexity soft-MIMO detector based on the fixed-complexity sphere decoder," IEEE Intern.l Conf. on Acoustics, Speech and Signal Processing (ICASSP 2008), pp.2669-2672, 2008.

[9] C.-T. Lin, and W.-R. Wu , "QRD-based antenna selection for ML detection of spatial multiplexing MIMO systems: algorithms and applications," , IEEE Transactions on Vehicular Technology, vol.60, no.7, pp.3178-3191, Sept. 2011.

[10] H. Bocskei and A. J. Paulraj, "Multiple-Input Multiple-Output (MIMO) Wireless Systems" Cambridge University Press, 2003.

[11] I. Berenguer and X. Wang, "Coding and Signal Processing for MIMO Communications," IEEE Journal of Computer Science and Technology, vol. 18, issue 6, pp. 689-702, November 2003.

[12] V. Tarokh, N. Seshadri, and A. Calderbank. "Space-Time Codes for High Data Rate Wireless Communications: Performance Criterion and Code Construction," IEEE Trans. Inform. Theory, vol. 44, no. 2, pp. 744-765, Mar. 1998.

[13] C. Schlegel and Z. Bagley "MIMO Channels and Space-Time Coding" IASTED Tutorial, WOC, Banff, Alberta, CANADA, July 18, 2002.

[14] H. Jafarkhani, "A quasi-orthogonal space-time block code," IEEE Transactions on Communications, vol. 49, pp. 1-4, 2001.

[15] N. Sinha, S. Chakraborty and A. Bera, "Capacity Enhancement of 4G- MIMO Using Hybrid Blast STBC Systems" Journal of Telecommunications, vol. 3, issue 1, pp. 115-124, June 2010.

[16] X. Tran, H. Ho, T. Fujino and Y. Karasawa, "Performance of Detectors for Combined STBC-SM Systems," Int. Symp. Antennas Propagat. (ISAP2007), pp.1362-1365, Japan, 2007.

[17] T Mao, M Motani, "STBC-VBLAST for MIMO Wireless Communication Systems, " IEEE intern. Conference on Communications vol. 4, pp. 2266 – 2270, 2005.

[18] W. Freitas Jr., "Performance of MIMO Antenna Systems with Hybrids of Transmit Diversity and Spatial Multiplexing Using Soft-Output Decoding" Lecture Notes in Computer Science, Springer-Verlag Heidelberg, v.3124, p.28–37, Aug. 2004.

[19] W. Freitas Jr., F. Cavalcanti and R. Lopes, "Hybrid MIMO Transceiver Scheme With Antenna Allocation and Partial CSI at Transmitter Side," IEEE 17th Annual Intern. Symp. on Personal, Indoor and Mobile Radio Commu., pp. 1-5, 2006.

[20] W. Freitas, F. Cavalcanti and R. Lopes, "Hybrid Transceiver Schemes for Spatial Multiplexing and Diversity in MIMO Systems, " IEEE Journal of Commu. and Inform. Systems, vol. 20, no. 3, pp. 63–76, 2005.

[21] J. Cortez, M. Bazdresch, A. Garcia, J. Campoy and A. Pizarro "An Efficient Detector for STBC-VBLAST Space-Time Code for MIMO Wireless Communications," IEEE Electronics, Robotics and Automotive Mechanics Conference pp. 44, 2009.

[22] N. Sinha, P. Sutradhar, S. Chakraborty, R. Bera and M. Mitra, " Hybrid Multilayer Schemes for Achieving The Maximum Possible Diversity Gain," International Journal of Research and Reviews in Applied Sciences, vol. 2, issue 3, March 2010 .

[23] A. Doufexi, A. Nix and M. Beach "Combined Spatial Multiplexing and STBC to Provide Throughput Enhancements to Next Generation WLANs" IST Mobile and Wireless Communications Summit, Germany, 2005.

[24] S. Al-Ghadhban "Multi-layered Space Frequency Time Codes" Blacksburg, Virginia, PhD Dissertation, 2005.