Performance Evolution of Quasi Orthogonal Space Time Block Code using Bit Rate

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***Abstract*— This Multipath fading is inherent in wireless communication systems. Diversity is the technique which takes the advantage of multipath and mitigates the effect of fading and increase received signal strength. Space Time Block codes (STBC) is a promising way to improve the performance of wireless communication system by maximizing transmit diversity in space as well as time for flat fading channel using multiple antennas at the transmitter side and multiple antennas at the receiver side which is called as MIMO.**

In the previous paper, we presented the simulation results and comparison of various STBCs with fixed number of transmit and variable number of receive antennas because higher diversity can be achieved by increasing uncorrelated paths between transmitter and receivers. Simulation results also discussed on the comparison of different Scheme of OSTBC for QPSK Modulation and the BER Performance Comparison of Alamouti Scheme in Frequency Selective Channel Using BPSK Modulation. Additionally Simulation results of OSTBC using QPSK and 16QAM Modulation scheme.

In previous paper we have already pointed out that although OSTBC exploit MIMO communication systems to obtain full diversity and therefore high link reliability, unfortunately, it is not possible to construct OSTBC with a transmission rate equal one for more than two transmit antennas. Full rate orthogonal STBC only exist for two transmit antennas.

In this paper we discuses QUASI ORTHOGONAL SPACE TIME BLOCK CODE (QOSTBC) with the full rate non orthogonal STBC for flat fading as well as for frequency selective channel. This paper starts with QOSTBC which provides full rate and partial diversity. Latter on to improve the link reliability CR-QOSTBC is introduced. At last NOVEL QOSTBC is discussed which is derived by modifying the detection matrix of QOSTBC.

In this paper, we present simulation results and remarkable conclusions and also the comparison of Orthogonal STBC and non orthogonal STBC with the help of different parameters like diversity order, decoding complexity and decoding delay.

***Keywords*—** OSTBC, QPSK, QAM, STC, MULTI-INPUT MULTI-OUTPUT (MIMO)

I. Introduction

OSTBC can provide full diversity with a very simple ML decoding algorithm; but the rate of OSTBC only achieve 3/4 of the maximum rate when applying more than two transmit antennas. Then, Jafarkhani and Tirkkonen designed full rate quasi-orthogonal space-time block code (QOSTBC) that provide half of the maximum possible diversity for four transmit antennas [7], [3]. Papadias design a constellation rotation scheme to improve the performance of QOSTBC [9].

II. QOSTBC IN FLAT FADING CHANNEL

A. Theory

A full rate STBC for four transmit antennas, N_t= 4, was proposed in [7]. If we consider the following STBC for NT = k = p = 4 [7]

$$A_{12} = \begin{bmatrix} C_1 & C_2 \\ -C_2^* & C_1^* \end{bmatrix}$$

Here we use the subscript 12 to represent the indeterminate X_1 and X_2 in the transmission matrix. Now, let us consider the following space-time block code for N =T= K= 4

$$C = \begin{pmatrix} A_{12} & A_{34} \\ -A_{34}^* & A_{12}^* \end{pmatrix}$$

$$= \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ -c_2^* & c_1^* & -c_4^* & c_3^* \\ -c_3^* & -c_4^* & c_1^* & c_2^* \\ c_4 & -c_3 & -c_2 & c_1 \end{bmatrix} \text{............ (1)}$$

It is easy to see that code matrix given in eq. (1) is non orthogonal i.e. in this code matrix group of column one, four and column two, three are non orthogonal to each other because of this the minimum rank of matrix A where A = BB^H and B is r = 2. Therefore a diversity order of 2 is achieved while the rate of the STBC is one [7]. The maximum diversity that a MIMO system with four transmit and one receive antenna can provide is 4. Now if we define V_i, i = 1, 2, 3, 4 as the i[th] column of C, it is easy to see that [7]

$$\langle V_1, V_2 \rangle = \langle V_1, V_3 \rangle = \langle V_2, V_4 \rangle = \langle V_3, V_4 \rangle = 0$$

Where $\langle V_m, V_n \rangle = \sum_{l=1}^{4} (V_m)_l \; (V_m)_l^*$ is the inner product of vectors V_m and V_n. Therefore the subspace created by V_1 and V_2 is orthogonal to the subspace created by V_2 and V_3. Using this Orthogonality, the maximum likelihood decision metric can be calculated as the sum of two terms $f_{14}(C_1, C_4) + f_{23}(C_2, C_3)$ [52], where f_{14} is independent of C_2 and C_3, and f_{23} is independent of C_1 and C_4. The decoder can first find (C_1, C_4) that minimizes $f_{14}(C_1, C_4)$ among all possible (C_1, C_4) pairs. In parallel, the decoder selects the pair (C_2, C_3) that minimizes $f_{23}(C_2, C_3)$. The complexity of the decoder is reduced without sacrificing the performance. We can verify that matrix D = $C^H C$ is not diagonal. So this STBC is not an orthogonal STBC. But the subspace created by certain columns is orthogonal to the subspace created by other columns and hence this STBC is called a Quasi-Orthogonal STBC. Since this code detects the symbols in pairs, the complexity of its decoder is higher than the complexity of the decoder of the orthogonal STBC with N_t= 4. Decoding of it is carried out for modulated symbol C_1 and C_4 simultaneously by the following equation,

$$f_{14}(C_1, C_4) = \Sigma_{m=1}^{M}((\Sigma_{n=1}^{4}|\alpha_{n,m}|^2)\,(|C_1|^2+|C_4|^2) + 2\mathrm{Re}\{(\alpha_{1,m} r_{1,m}^* - \alpha_{2,m}^* r_{2,m} - \alpha_{3,m}^* r_{3,m} - \alpha_{4,m} r_{4,m}^*)\, C_1 + (-\alpha_{4,m} r_{1,m}^* + \alpha_{3,m}^* r_{2,m} + \alpha_{2,m}^* r_{3,m} - \alpha_{1,m} r_{4,m}^*) C_4 + (\alpha_{1,m}\alpha_{4,m}^* - \alpha_{2,m}^* \alpha_{3,m} - \alpha_{2,m}\alpha_{3,m}^* + \alpha_{1,m}^* \alpha_{4,m})\, C_1 C_4^*\}) \quad \ldots\ldots (2)$$

Decoding of modulated symbol C_2 and C_3 simultaneously by the following equation

$$f_{23}\,(C_2, C_3) = \Sigma_{m=1}^{M}((\Sigma_{n=1}^{4}|\alpha_{n,m}|^2)\,(|C_2|^2+|C_3|^2) + \mathrm{Re}\{(-\alpha_{2,m} r_{1,m}^* + \alpha_{1,m}^* r_{2,m} - \alpha_{4,m}^* r_{3,m} + \alpha_{3,m} r_{4,m}^*)\, C_2 + (-\alpha_{3,m} r_{1,m}^* - \alpha_{4,m}^* r_{2,m} + \alpha_{1,m}^* r_{3,m} + \alpha_{2,m} r_{4,m}^*) C_3 + (\alpha_{2,m}\alpha_{3,m}^* - \alpha_{1,m}^* \alpha_{4,m} - \alpha_{1,m}\alpha_{4,m}^* + \alpha_{2,m}^* \alpha_{3,m})\, C_2 C_3^*\}) \quad \ldots\ldots (3)$$

III. FULL RATE FULL DIVERSITY QSTBC (CR-QOSTBC) IN FLAT FADING CHANNEL

A. *Theory*

The performance of the quasi-orthogonal STBC code is better than that of the codes from orthogonal designs at low SNR, but worse at high SNR. As mentioned in [7], [2], [3] this is due to the fact that the slope of the performance curve depends on the diversity. As we have shown in previous section, for QOSTBC the signal constellations are chosen arbitrarily. With such a way to select the information symbols, the resulting STBCs cannot guarantee full diversity. The main idea CR-QOSTBC is to choose the signal constellations properly to ensure that the resulting codes achieve full diversity. In this section simulations are attempted for CR-QOSTBC to verify relative improvement in bit error rates (BER) with respect to number of receive antennas as increase in number of receive antennas would also increase diversity order. The relative performance with QOSTBC with similar number of receives antennas. CR-QOSTBC possesses full rate and full diversity which is reflecting in the results.

Criteria for achieving full diversity:

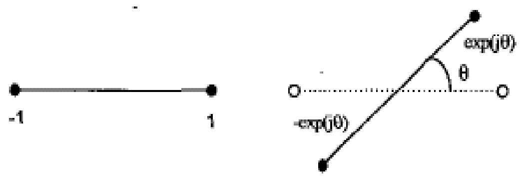
We assume that all the code words have equal transmission probability and consider the probability P(c $\rightarrow$ e) that c= $c_1^1 c_1^2 \ldots c_1^n c_2^1 \ldots c_2^n \ldots c_p^1 \ldots c_p^n$ was transmitted but the receiver decides erroneously in favor of a signal e= $e_1^1 e_1^2 \ldots e_1^n e_2^1 \ldots e_2^n \ldots e_p^1 \ldots e_p^n$. We have already defined this concept in chapter 4 but for simplicity it is given here. Let us define a codeword difference matrix B(c,e) as

$$B(c,e) = \begin{bmatrix} e_1^1 - c_1^1 & e_2^1 - c_2^1 & \cdots & e_t^1 - c_t^1 \\ e_1^2 - c_1^2 & e_2^2 - c_2^2 & \cdots & e_t^2 - c_t^2 \\ e_1^3 - c_1^3 & \ddots & \ddots & e_t^3 - c_t^3 \\ \cdots & \ddots & \ddots & \vdots \\ e_1^n - c_1^n & \cdots & \cdots & e_t^n - c_t^n \end{bmatrix}$$

Diversity product ς = $(1/2\sqrt{N_t})$ min $[\det(Bce)]^{1/2T}$ where $c \neq e$

$$\det(B_{ce}) = [(|\Delta_1 + \Delta_4|^2 + |\Delta_2 - \Delta_3|^2)(|\Delta_1 - \Delta_4|^2 + |\Delta_2 + \Delta_3|^2)]^2$$

For achieving full diversity, diversity product must be not equal to zero, which followed by non zero determinant value of codeword difference matrix. $\Delta_i = e_i - c_i$ where i=1, 2. . . N. from the above equation it should be noted that if Δ_i and Δ_j (i≠j) are chosen from same set of constellation point, determinant value of code word difference matrix could be zero. As a result the codeword difference matrix would not be full rank at all times and code would not be able to achieve full diversity. To prevent this Δ_i and Δ_j must not be equal for i≠j. one way to achieve this is to rotate the code symbol constellation



(a) (b)

Fig. 1. Constellation Rotation of BPSK Constellation Set

For simplicity consider BPSK constellation symbol i with value chosen from the set {1,-1} as shown in fig 1(a) the possible values for Δ_i include {2,-2}. For a rotated BPSK constellation symbol j with an angle of rotation ɵ rotation ɵ the constellation set becomes {-exp(jɵ), exp(jɵ)} as shown in fig 1 (b). In this case possible values for Δ_j include {2exp (jɵ), -2exp (jɵ)}. So such constellation will ensure that $\Delta_i \neq \Delta_j$ but $|\Delta_i| = |\Delta_j|$ as value of |Δ| is always 2 and it is independent of angle of rotation. From above discussion it is clear that half of the symbol should transmit from same constellation and other half are transmitted from the rotated constellation of it than we get full diversity. The optimum value of constellation rotation angle is found to be π/M for M-PSK constellation.

Transmitted codeword matrix for CR-QOSTBC is

$$C = \begin{bmatrix} C1 & C2 & C3e^{j\theta} & C4e^{j\theta} \\ -C2* & C1* & (-C4e^{j\theta})* & (C3e^{j\theta})* \\ (-C3e^{j\theta})* & (-C4e^{j\theta})* & C1* & C2* \\ (C4e^{j\theta}) & (-C3e^{j\theta}) & -C2 & C1 \end{bmatrix} \text{....... (4)}$$

Here the symbols C1 and C2 are transmitted from same constellation i.e. QPSK and symbols C3 and C4 are transmitted from the rotated constellation of first by $\pi/4$. Decoding and received symbol matrix is same as QOSTBC.

IV. NOVEL QOSTBC IN FLAT FADING CHANNEL

A. THEORY

A conventional QOSTBC described in section 5.1 can achieve the full rate, but at the cost of decoding complexity and diversity gain. These disadvantages of the conventional QO-STBC scheme are mainly a result of interference terms in the detection matrix. Novel QO-STBC scheme which eliminates interference terms and achieves improved diversity gain with respect to the conventional QO-STBC scheme, as well as a great reduction in decoding complexity [8].

In the case of an orthogonal scheme, the received signals are decoded using a detection matrix *D* defined as $H^H H$ where H^H is *Hermitian* of $H_{channel}$ matrix defined in previous chapter. For an O-STBC scheme, the detection matrix is always a diagonal matrix, and this enables the use of simple linear decoding. However, for QO-STBC schemes, this cannot be applied, because the detection matrices are not diagonal. For example, the detection matrix for the aforementioned four transmit antenna QO-STBC scheme is expressed as:

Channel matrix for conventional QOSTBC is given by

$$H = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix}$$

$$D = H^H H = \begin{bmatrix} \alpha & 0 & \beta & 0 \\ 0 & \alpha & 0 & \beta \\ \beta & 0 & \alpha & 0 \\ 0 & \beta & 0 & \alpha \end{bmatrix} \quad \text{....[5]}$$

where, diagonal elements α represents channel gains for the four transmit antennas, and β represents interference terms by neighboring signals, expressed as:

$$\alpha = \sum_{i=1}^{4}(|h_i|^2)$$

$$\beta = h_1 h_3^* + h_2 h_4^* + h_1^* h_3 + h_2^* h_4 \text{...[6]}$$

A Givens rotation is a matrix transformation that can eliminate any elements of a given matrix [5]. We first apply a Givens rotation to eliminate the interference terms in the detection matrix *D* in eq. (5) for a four transmit antenna system.

We eliminate *β* via two sequential steps, using two different Givens rotation matrices. In the first step, we define a Givens rotation matrix R_1 to eliminate *β* of *d*13 and *d*31, as given by eq. (6) where d_{ij} is the element at the *i*th row and *j*th column of *D*.

$$R_1 = \begin{bmatrix} \cos\left(\frac{\pi}{4}\right) & 0 & \sin\left(\frac{\pi}{4}\right) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\left(\frac{\pi}{4}\right) & 0 & \cos\left(\frac{\pi}{4}\right) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{....... [7]}$$

$$R_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\left(\frac{\pi}{4}\right) & 0 & \sin\left(\frac{\pi}{4}\right) \\ 0 & 0 & 1 & 0 \\ 0 & -\sin\left(\frac{\pi}{4}\right) & 0 & \cos\left(\frac{\pi}{4}\right) \end{bmatrix} \text{........ [8]}$$

By sequentially applying the rotation matrices R_1 and R_2, we derive a new interference-free detection matrix, *Dm*4, via eq. (9),

$$D_{m4} = R_2^T . R_1^T . D . R_1 . R_2$$

$$= \begin{bmatrix} \alpha-\beta & 0 & 0 & 0 \\ 0 & \alpha-\beta & 0 & 0 \\ 0 & 0 & \alpha-\beta & 0 \\ 0 & 0 & 0 & \alpha-\beta \end{bmatrix} \text{...[9]}$$

A new channel matrix is derived by expressing D_{m4} as follows:

$$\begin{aligned} D_{m4} &= R_2^T \,(R_1^T . D . R_1) . R_2 \\ &= (R_2^T \, R_1^T) . H^H H . (R_1 . R_2) \\ &= (R_2 R_1)^T . H^H H . (R_1 . R_2) \\ &= (H R_1 R_2)^H . (H R_1 . R_2) \quad \text{---- [10]} \end{aligned}$$

A new matrix, $H_{m4} \triangleq (HR_1R_2)$ is defined, which can be expressed as eq. (10), and used as the new channel matrix for the interference-free detection matrix given by eq. (10).

$$H_{m4} = \begin{bmatrix} h_1-h_3 & h_2-h_4 & h_1+h_3 & h_2+h_4 \\ h_2^*-h_4^* & h_3^*-h_1^* & h_2^*+h_4^* & -h_1^*-h_3^* \\ h_3-h_1 & h_4-h_2 & h_1+h_3 & h_2+h_4 \\ h_4^*-h_2^* & h_1^*-h_3^* & h_2^*+h_4^* & -h_1^*-h_3^* \end{bmatrix}$$

Since by eq. (9) and eq. (10) H_{m4}^H and H_{m4} is diagonal matrix, this achieves simple linear decoding, because of the orthogonal characteristics of the channel matrix H_{m4}. The encoding matrix corresponding to H_{m4} is derived from the relationship between an encoding matrix and its channel matrix given in eq. (3) of [5], which is expressed as:

$$X_{m4} = \begin{bmatrix} x_1+x_3 & x_2+x_4 & x_3-x_1 & x_4-x_2 \\ -x_2^*-x_4^* & x_1^*+x_3^* & x_2^*-x_4^* & x_3^*-x_1^* \\ x_3-x_1 & x_4-x_2 & x_1+x_3 & x_2+x_4 \\ x_2^*-x_4^* & x_3^*-x_1^* & -x_2^*-x_4^* & x_1^*+x_3^* \end{bmatrix} \text{...... [11]}$$

The new encoding matrix X_{m4} given in (11) is quasi orthogonal, rather than orthogonal. Nevertheless, since its channel matrix H_{m4} is an orthogonal matrix, ML decoding can be achieved via simple linear detection, as given by:

$$\hat{X} = H_{m4}^H \hat{Y} = H_{m4}^H H_{m4}^H X + H_{m4}^H N \quad \text{....... [12]}$$

V. QOSTBC IN FREQUENCY SELECTIVE CHANNEL

A. THEORY

In wireless communication scenarios, due to multipath fading and relative motion between transmitter and receiver undesirable Characteristics of fading channel are produced which are Doppler shift, delay spread. Because of these interface exits between consecutive symbols and channel becomes highly time dispersive. So in real time communication wireless channel is frequency selective.

To combat frequency-selective fading, diversity techniques must be resilient to ISI. Transmitter diversity techniques are attractive, especially for portable receivers where current drain and physical size are important constraints. Space-time block coding has emerged as an efficient means of achieving near optimal transmitter diversity gain as we have described in previous section. But existing implementations are sensitive to delay spreads and, therefore, are limited to flat fading environments, such as indoor wireless networks.

Therefore of it is of interest to extension of space-time codes from single-carrier to their application in multi-carrier communication systems like OFDM in order to transform a frequency-selective channel into several frequency non-selective channels (i.e. flat fading channel)

VI. SIMULATION RESULTS AND ANALYSIS

In this section we discuses about simulation results of all channels like

1. QOSTBC in flat fading channel
2. Full rate full diversity QSTBC (CR-QOSTBC) in flat fading channel
3. Novel QOSTBC in flat fading channel
4. QOSTBC in Frequency selective channel

A. Simulation results of QOSTBC IN FLAT FADING CHANNEL

a. Simulation Model

In this chapter we consider the model which is described in Fig. 5.1 and Fig. 5.2. Here the simulation is carried out in two part i.e. when CSI is perfectly known at the receiver and CSI is estimated at the receiver using four transmit and variable number of receive antennas. For the simulation code matrix defined in eq. is used.

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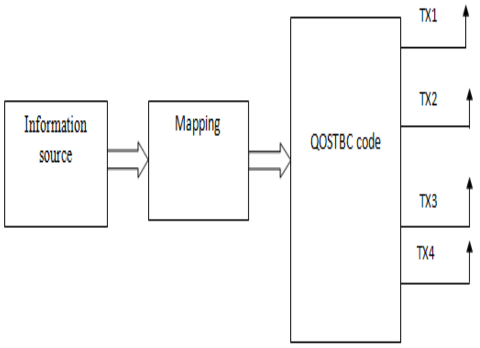

Fig. 2. Block Diagram of QOSTBC Encoder

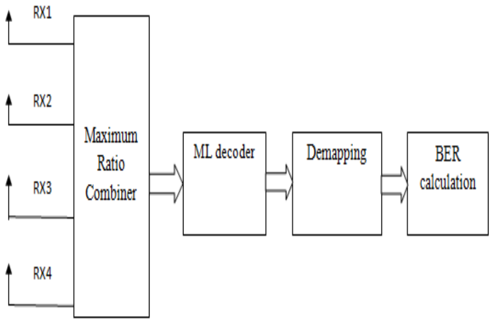

Fig. 3. Block Diagram of QOSTBC Decoder

Fig. 2 and 3 shows the block diagram of QOSTBC encoder and decoder. Explanation of mapping, MRC, ML decoder is explained earlier. For simplicity we consider received signal matrix for four transmit and one receives antennas it can be generalized to four receive antennas:

$$\begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix} = \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ -c_2^* & c_1^* & -c_4^* & c_3^* \\ -c_3^* & -c_4^* & c_1^* & c_2^* \\ c_4 & -c_3 & -c_2 & c_1 \end{bmatrix} * \begin{pmatrix} h_{11} \\ h_{21} \\ h_{31} \\ h_{41} \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{pmatrix}$$

In the above equation $\{r_1, r_2, r_3, r_4\}$ are the received signal at one receive antenna in four time slots respectively. $\{h_{11}, h_{21}, h_{31}, h_{41}\}$, $\{n_1, n_2, n_3, n_4\}$ are the complex channel impulse response coefficients and zero-mean, circularly symmetric, complex valued Gaussian noise terms with variance σ_n^2 respectively. This received signal after than applied to ML decoder followed by demapping block, and finally BER is calculated.

b. Simulation Parameter

Table 1 shows the number of transmit and receive antennas which are used for the simulation of QOSTBC in flat fading channel. As well as number of uncorrelated path are also described.

TABLE I
SIMULATION PARAMETER OF QOSTBC

Scheme	Number of uncorrelated path	Nu of TX	Nu of RX
4x1	4 (h11, h21, h31, h41)	4	1
4x2	8 (h11, h21, h31, h41, h12, h22, h32, h42)	4	2
4x3	12 (h11, h21, h31, h41, h12, h22, h32, h42, h13, h23, h33, h43)	4	3
4x4	16 (h11, h21, h31, h41, h12, h22, h32, h42, h13, h23, h33, h43, h14, h24, h34, h44)	4	4
4x1	4 (h11, h21, h31, h41)	4	1

Modulation scheme: - QPSK/16QAM
Channel: - flat fading channel is used it remains constant for four time slot.
Noise: - AWGN
Combiner: - Maximum Ratio receiving combiner
Decoder: - Maximum likelihood decoder

c. Assumptions:

- Total transmit power from the two antennas used with the Alamouti scheme is the same as transmit power sent from a single transmit antenna to two receive antennas and applying an MRC at the receiver.

- The amplitudes of fading from each transmit antenna to each receive antenna are mutually uncorrelated Rayleigh distributed and that the average signal powers at each receive antenna from each transmit antenna are the same.

- Receiver has perfect knowledge of channel

- Channel remains constant for two timeslot in the case of 2x1 and 2x2 schemes

d. Results: Figure 4 shows the simulation results of QPSK QOSTBC with four transmit and variable receive antennas assuming the perfect CSI is available at the receiver. It is noted from the figure 4 that there is improvement in BER performance with reference to number of receive antennas as number of receive antennas are increasing, diversity order is also .As shown in figure 4 that there is 4dB improvement in SNR at BER of 10^{-3} for 4x2 scheme, as compared to 4x1 scheme while this improvement becomes 3db for 4x4 scheme as compared to 4x2. From this we can say that improvement is not linear with reference to receive antennas but rate of improvement in BER is decrease as d^{th} (d=diversity) power of SNR.

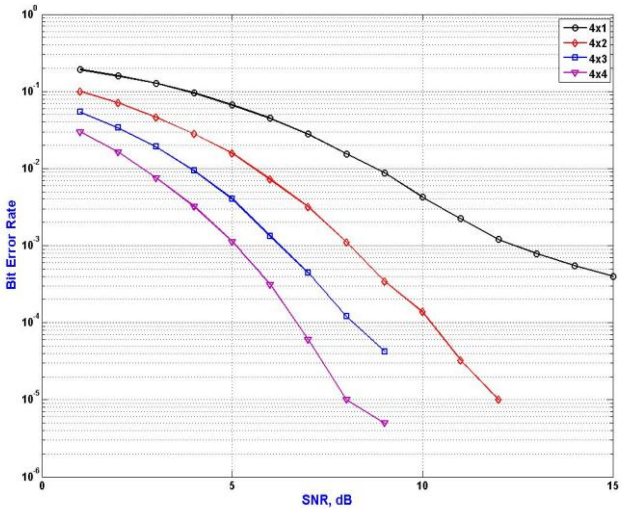

Fig. 4 QPSK-QOSTBC with Perfect CSI Available at the Receiver

Fig. 5 shows the results of QOSTBC with 16QAM modulation with variable number of receive antennas by considering perfect CSI is available at the receiver. From this figure it is noted that effect of diversity is enhance at higher SNR because of this we get 5dB improvement when we move from 4x1 to 4x 2 schemes but this improvement becomes 3dB for the case of 4x2 to 4x4 this occurs.

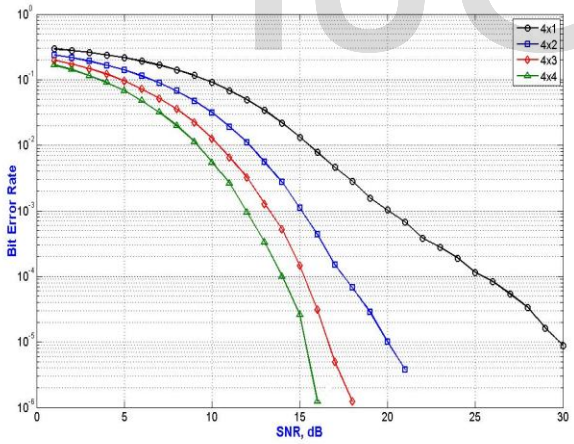

Fig. 5. 16QAM-QOSTBC with Perfect CSI Available at the Receiver

Fig. 5. Shows simulation of QPSK-QOSTBC with perfect CSI and estimated CSI at the receiver. For the estimation of channel least square method is used. We can observe from the figure 6 that there is 2dB degradation in performance for BER = 10^{-3} for all the schemes i.e. 4x1, 4x2, 4x3 and 4x4, because of channel estimation error.

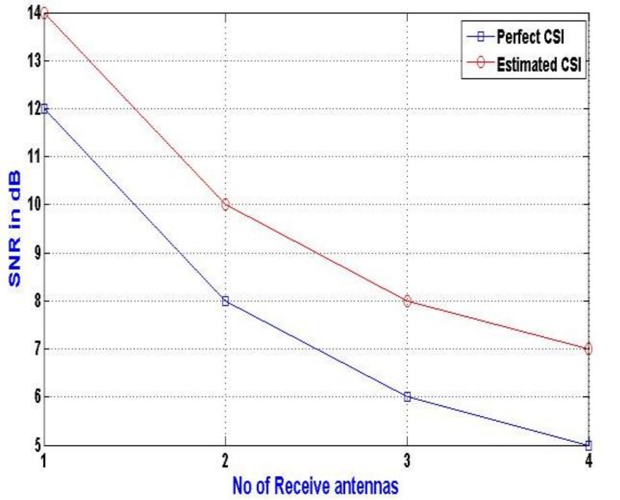

Fig. 6. Comparison of QOSTBC with and without CSI at BER=10^{-3}

e. Observation table: Table 2 shows the observation table of QOSTBC with variable number of receive antennas and different modulation technique.

TABLE III
COMPARISON OF QOSTBC WITH PERFECT CSI FOR FLAT FADING CHANNEL

	QPSK 16QAM	
QOSTBC scheme	**SNR at BER of 10^{-3}**	**Diversity order**
4x1	12dB	20dB
4x2	8dB	15dB
4x3	6dB	13dB
4x4	5dB	12dB
4x1	12dB	20dB

Decoding delay: - Four time slot
Complexity: -
B^K (where B=constellation point, K=information symbol)

f. Observation:

- QOSTBC provides partial diversity because of this its performance is lower than OSTBC which is described in previous chapter.

- Because of non orthogonal structure of QOSTBC it has to decode two symbols in pairs so interference will be there between these two symbols so we get performance degradation and the property of QOSTBC to decode two symbols in pair will increase its decoder complexity exponential with increase in modulation scheme.

- Performance improvement because of diversity order is depend of SNR as diversity gain is given by (SNR)-d because of this when we shifted from 4x1 to 4x2 we get performance improvement of 4dB in case of QPSK and 5dB in case of 16QAM. But when we shifted from 4x2 to 4x 4 still diversity orders becoming double but we get performance improvement of 3dB in case of QPSK and 16QAM.

- There is 2dB degradation in performance when CSI is estimated at the receiver and this degradation is followed in all the QOSTBC schemes and for all modulation schemes.

B. Simulation results of Full rate full diversity QSTBC (CR-QOSTBC) in flat fading channel

a. Simulation Model

Transmitter and receiver structure of CR-QOSTBC are same as defined in Fig. 2, and 3. There is only a difference of transmitted code matrix between QOSTBC and CR-QOSTBC remaining things are same.

b. Simulation Parameter

Simulation parameters are same as in Table I.

c. Results:

Simulations are attempted for CR-QOSTBC to verify relative improvement in bit error rates (BER) with respect to number of receive antennas as increase in number of receive antennas would also increase diversity order. Fig. 7 compares CR-QOSTBC with 4 transmit and 1, 2, 3 and 4 receive antennas. The slope of BER-SNR graph is function of $(SNR)^{-d}$, where d is diversity order. A rapid performance improvement is observed as we increase diversity order. If we observe improvement for BER 10^{-3}, 3dB improvement is found for 4X2 as compared to 4x1.

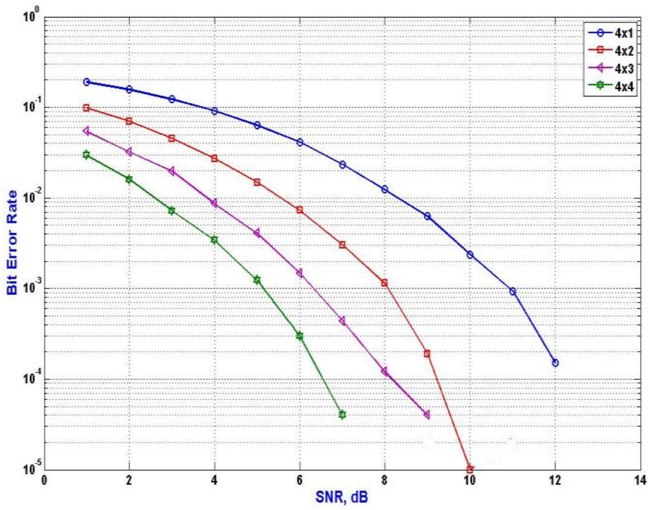

Fig. 7 CR-QOSTBC with Perfect CSI Available at the Receiver for QPSK

d. Observation:

- Table 3 shows the comparison of CR-QOSTBC with four transmit and variable number of receive antennas.

TABLE IIIII
COMPARISON OF CR-QOSTBC WITH PERFECT CSI

CR-QOSTBC scheme	**BER (perfect CSI)**		**Diversity order**
	SNR at 10^{-2}	SNR at 10^{-4}	
4x1	8dB		12dB
4x2	5.5dB		9.2dB
4x3	3.5dB		8dB
4x4	2dB		6.5dB

Decoding delay: - Four time slot
Complexity: -
B^K (where B=constellation point, K=information symbol)

C. Simulation results of Novel QOSTBC in flat fading channel

a. Simulation Model

Same as QOSTBC simulation model

b. Simulation Parameter

Same as QOSTBC simulation parameter with QPSK modulation

c. Results: Fig. 8 shows the comparison of conventional QOSTBC and novel QOSTBC.As noted from the figure conventional QOSTBC schemes has lower performance compared to novel QOSTBC. A conventional QOSTBC scheme can achieve the full rate, but at the cost of decoding complexity and diversity gain. These disadvantages of the conventional QO-STBC scheme are mainly a result of interference terms in the detection matrix because it is non orthogonal. In novel QOSTBC We apply a Givens rotation to the detection matrix of a conventional QO-STBC scheme, in order to eliminate interference terms, and derive an encoding matrix corresponding to the interference-free detection matrix which is identical to OSTBC. Because of this Novel QOSTBC achieves improved diversity gain with respect to conventional QOSTBC as well as a great reduction in decoding complexity

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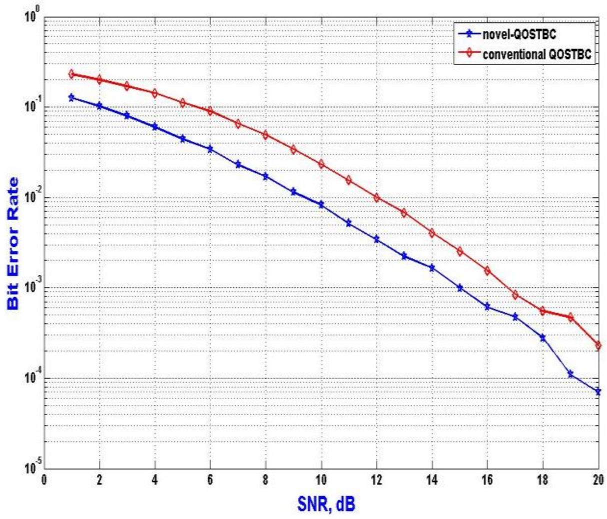

Fig. 8. Comparison of Conventional QOSTBC with Novel QOSTBC for QPSK Modulation

d. Observation:

- Conventional QOSTBC scheme can achieve full rate but at the cost of decoding complexity and diversity gain.
- By transforming the detection matrix of the conventional QO-STBC scheme, we derived an orthogonal channel matrix, resulting in a simple linear decoder identical to that of an O-STBC scheme.
- Novel QOSTBC achieves improved diversity gain with respect to conventional QOSTBC as well as a great reduction in decoding complexity.

D. Simulation results of QOSTBC in Frequency selective channel

a. Simulation Model

Fig. 9 shows the transmitter and receiver block diagram for QOSTBC with OFDM under frequency selective channel.

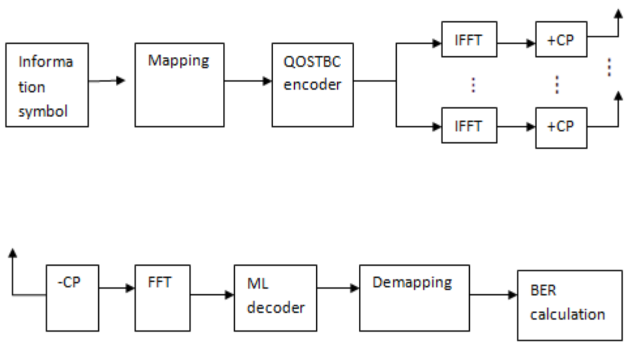

Fig. 9 Transmitter and receiver block diagram QOSTBC with OFDM under frequency selective channel

b. Simulation Parameter

same as describe in section 4.3.1

c. Results:

Fig. 10 shows the simulations of MIMO OFDM with QOSTBC in frequency selective channel for different modulation schemes.

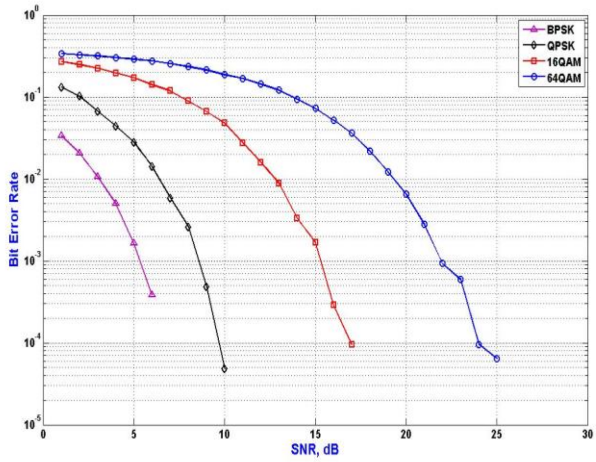

Fig. 10 BER Performance Comparison of QOSTB-OFDM with Different Modulation Schemes in Frequency Selective Channel

d. Observation Table:

TABLE IVV
COMPARISONS OF MIMO OFDM WITH QOSTBC DIFFERENT MODULATION SCHEMES

Modulation scheme	BPSK	QPSK	16QAM	64QAM
	SNR at 10^{-4}			
OFDM	7.5dB	12.2 dB	20.2 dB	35 dB
QOSTBC	7 dB	9.5 dB	17 dB	24 dB

e. Observation :

- Performance of MIMO- OFDM with QOSTBC is better compared to only OFDM because of diversity.
- From the above table it is noted that very negligible diversity gain for BPSK and it is continuously increases for higher modulation level and it reaches up to 11dB for 64QAM modulation. This occurs because the diversity gain is given by (SNR)-d i.e. we get the advantage of diversity at higher SNR.

- 2x1 Alamouti and 4x1 QOSTC has same diversity order because of this the gain(OFDM-STBC) is almost same for this two scheme

VII. CONCLUSIONS

In this paper we perform the different simulation results of OSTBC. From that we conclude that implementation of the QOSTBC which provides full rate. To eliminate data rate disadvantage of OSTBC, QOSTBC is explained which provides full rate but partial diversity. Novel QO-STBC scheme which eliminates interference terms of detection matrix of conventional QOSTBC and achieves improved diversity gain with respect to the conventional QO-STBC scheme, as well as a great reduction in decoding complexity. For further improvement in BER CR-QOSTBC is considered which is full rate and full diversity STBC.

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