A New Approach for Implementing QO-STBC Over OFDM

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Abstract. A new approach for implementing QO-STBC and DHSTBC over OFDM for four, eight and sixteen transmitter antennas is presented, which eliminates interference from the detection matrix and improves performance by increasing the diversity order on the transmitter side. The proposed code promotes diversity gain in comparison with the STBC scheme, and also reduces Inter Symbol Interference.

Keywords: MIMO-OFDM system · Quasi-Orthogonal space time block coding (QO-STBC) over OFDM · Full rate, full diversity order · Eigenvector · Diagonalized hadamard space time code (DHSTBC) over OFDM

1 Introduction

Single-Input Single-Output (SISO) communication systems have a single antenna at both the transmitter and the receiver, with resulting limitations in capacity. To increase the capacity of SISO systems, large bandwidths and high transmit power would be required. Alternatively, MIMO systems could give improvements without the need to increase the transmission power or the bandwidth, also decreasing the error rates in comparison with single-antenna systems [1].

High data-rate wireless systems with very small symbol periods usually face unacceptable Inter-Symbol Interference (ISI) originating from multipath propagation and the resulting delay spread. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier-based technique for mitigating ISI whose spectral efficiency improves capacity. [2]

The structure of a MIMO-OFDM system is described in Fig. 1

In 2013, Dama et al. proposed a new approach for Quasi-Orthogonal Space-Time Block Coding (QO-STBC), which eliminated interference from the detection matrix, thus improving the diversity gain compared with the conventional QO-STBC scheme

P. Pillai et al. (Eds.): WiSATS 2015, LNICST 154, pp. 249–259, 2015.
DOI: 10.1007/978-3-319-25479-1_19

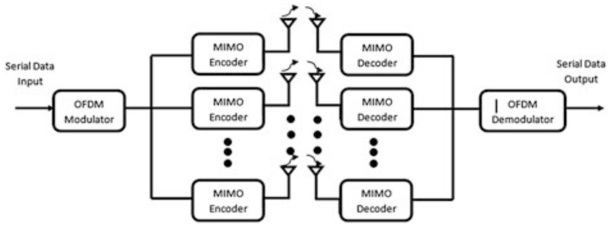

Fig. 1. MIMO-OFDM block diagram

[3]. The method was then extended to Diagonalized Hadamard Space-Time Block Coding (DHSTBC), to provide full rate diversity. These approaches were implemented for MIMO systems with three and four transmitter antennas [3–5].

In the present paper, QO-STBC and DHSTBC are implemented for OFDM systems using four, eight and sixteen transmitter antennas.

2 Quasi-Orthogonal Space Time Block Coding (QO-STBC)

2.1 QO-STBC with Four Transmit Antennas

In quasi-orthogonal coding, the columns of the transmission matrix are divided into groups. Columns within each group are not orthogonal to each other but those from different groups are mutually orthogonal [6]. Pairs of transmitted symbols can be decoded independently, but there is some loss of diversity in QOSTBC due to coupling terms between the estimated symbols [7].

For four symbols $x_1, x_2, x_3\, and\, x_{41}$, the encoding matrix X_{ABBA} is formed from two (2 × 2) Alamouti code matrices X_{12} and X_{34}:

$$X_{12} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} X_{34} = \begin{bmatrix} x_3 & x_4 \\ -x_4^* & x_3^* \end{bmatrix} \quad (1)$$

And so

$$X_{ABBA} = \begin{bmatrix} X_{12} & X_{34} \\ X_{34} & X_{12} \end{bmatrix} \quad (2)$$

The equivalent virtual channel matrix H_v can be written as:

$$H_v = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix} \quad (3)$$

Considering a linear system of the form

$$Y = HX + n \tag{4}$$

A simple method to decode QO-STBC over OFDM is by applying the maximum ratio combining (MRC) technique: the received vector Y is multiplied by H_v^H thus:

$$\begin{aligned} X = H_v^H Y = H_v^H . H_v X_{ABBA} + H_v^H n \\ = D_4 X_{ABBA} + H_v^H n \end{aligned} \tag{5}$$

where $D_4 = H_v^H H_v$ is a non-diagonal detection matrix, H_v^H is the Hermitian of H_v and n is the noise vector of AWGN channel.

$$D_4 = \begin{bmatrix} \alpha & 0 & \beta & 0 \\ 0 & \alpha & 0 & \beta \\ \beta & 0 & \alpha & 0 \\ 0 & \beta & 0 & \alpha \end{bmatrix} \tag{6}$$

The diagonal elements α and β in Eq. 6 α represent the channel gain and the interference from other signals respectively, and they are defined as follows,

$$\begin{aligned} \alpha = |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ \beta = h_1^* h_3 + h_2 h_4^* + h_3^* h_1 + h_4 h_2^* \end{aligned} \tag{7}$$

Since the interference terms β will cause performance degradation, more complex decoding methods have been introduced to estimate $\hat{X}$ [3, 4].

The solution of the eigenvalue problem of the detection matrix D_4 can be written as,

$$D_4 V_{QO-STBC} - V_{QO-STBC} D_{QO-STBC} = 0 \tag{8}$$

where $D_{QO-STBC}$ and $V_{QO-STBC}$ are the eigenvectors and eigenvalues of D_4 respectively,

$$D_{4QO-STBC} = \begin{bmatrix} \alpha+\beta & 0 & 0 & 0 \\ 0 & \alpha+\beta & 0 & 0 \\ 0 & 0 & \alpha-\beta & 0 \\ 0 & 0 & 0 & \alpha-\beta \end{bmatrix} \tag{9}$$

$$V_{4QO-STBC} = \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \tag{10}$$

From this basis, the channel matrix for four transmit antennas can be defined as:

$$H_{4QO-STBC} = H_v V_{4QO-STBC} \tag{11}$$

where $\mathrm{H}_{4\mathrm{QO-STBC}}$ is given by:

$$H_{4QO-STBC} = \begin{bmatrix} h_1 + h_3 & h_2 + h_4 & h_3 - h_1 & h_4 - h_2 \\ h_2^* + h_4^* & -h_1^* - h_3^* & h_4^* - h_2^* & h_1^* - h_3^* \\ h_1 + h_3 & h_2 + h_4 & h_1 - h_3 & h_2 - h_4 \\ h_2^* + h_4^* & -h_1^* - h_3^* & h_2^* - h_4^* & h_3^* - h_1^* \end{bmatrix} \tag{12}$$

$H^H_{4\mathrm{QO-STBC}}.\mathrm{H}_{4\mathrm{QO-STBC}}$ is a diagonal matrix which can achieve simple linear decoding, because of the orthogonal characteristics of the channel matrix $\mathrm{H}_{4\mathrm{QO-STBC}}$

The encoding matrix $\mathrm{X}_{4\mathrm{QO-STBC}}$ corresponding to the channel matrix $\mathrm{H}_{4\mathrm{QO-STBC}}$ can be derived as follows:

$$X_{4QO-STBC} = \begin{bmatrix} x_1 - x_3 & x_2 - x_4 & x_1 + x_3 & x_2 + x_4 \\ x_4^* - x_2^* & -x_3^* + x_1^* & -x_4^* - x_2^* & x_3^* + x_1^* \\ x_1 + x_3 & x_2 + x_4 & x_3 - x_1 & x_4 - x_2 \\ -x_4^* - x_2^* & x_3^* + x_1^* & x_4^* - x_2^* & -x_3^* + x_1^* \end{bmatrix} \tag{13}$$

2.2 QO-STBC for Eight and Sixteen Transmit Antennas

In the case of four transmitter antennas the diagonal terms α are the channel gains and off-diagonal terms β represent interference. With eight and sixteen transmitter antennas α_8, α_{16} are the channel gains described in Eqs. (14) and (15) respectively, and β_8,γ_8, σ_8, β_{16}, γ_{16}, σ_{16}, ω_{16}, ζ_{16},η_{16} and φ_{16} are the interference from neighboring signals

Using the same methodology as in section the channel gains and the interference terms for eight transmitter antennas can be written as follows,

$$\begin{aligned} \alpha_8 &= \alpha + |h_5|^2 + |h_6|^2 + |h_7|^2 + |h_8|^2 \\ \beta_8 &= \beta + h_5^* h_7 + h_6 h_8^* + h_7^* h_5 + h_8 h_6^* \\ \gamma_8 &= h_1^* h_5 + h_2 h_6^* + h_3^* h_7 + h_4 h_8^* + h_5^* h_1 + h_6 h_2^* + h_7^* h_3 + h_8 h_4^* \\ \sigma_8 &= h_1^* h_7 + h_2 h_8^* + h_3^* h_5 + h_4 h_6^* + h_5^* h_3 + h_6 h_4^* + h_7^* h_1 + h_8 h_2^* \end{aligned} \tag{14}$$

In the same way the channel gains and the interference terms are derived for sixteen transmitter antennas:

$$\begin{aligned} \alpha_{16} &= \alpha_8 + |h_9|^2 + |h_{10}|^2 + |h_{11}|^2 + |h_{12}|^2 + |h_{13}|^2 + |h_{14}|^2 + |h_{15}|^2 + |h_{16}|^2 \\ \beta_{16} &= \beta_8 + h_9^* h_{11} + h_{10} h_{12}^* + h_{11}^* h_9 + h_{12} h_{10}^* + h_{13}^* h_{15} + \; + h_{14} h_{16}^* + h_{15}^* h_{13} + h_{16} h_{14}^* \\ \gamma_{16} &= \gamma + h_9^* h_{13} + h_{10} h_{14}^* + h_{11}^* h_{15} + h_{12} h_{16}^* + h_{13}^* h_9 + h_{10}^* + h_{15}^* h_{11} + h_{16} h_{12}^* \\ \sigma_{16} &= \sigma + h_9^* h_{15} + h_{10} h_{16}^* + h_{11}^* h_{13} + h_{12} h_{14}^* + h_{13}^* h_{11} + h_{14} h_{12}^* + h_{15}^* h_9 + h_{16} h_{10}^* \end{aligned}$$

$$\begin{aligned}
\omega_{16} &= h_1^* h_9 + h_2 h_{10}^* + h_3^* h_{11} + h_4 h_{12}^* + h_5^* h_{13} + h_6 h_{14}^* + h_7^* h_{15} + h_8 h_{16}^* + h_9^* h_1 + h_{10} h_2^* \\
&\quad + h_{11}^* h_3 + h_{12} h_{14}^* + h_{13}^* h_{11} + h_{14} h_{12}^* + h_{15}^* h_9 + h_{16} h_{10}^* \\
\zeta_{16} &= h_1^* h_{11} + h_2 h_{12}^* + h_3^* h_9 + h_4 h_{10}^* + h_5^* h_{15} + h_6 h_{16}^* + h_7^* h_{13} + h_8 h_{14}^* + h_9^* h_3 + h_{10} h_4^* \\
&\quad + h_{11}^* h_1 + h_{12} h_2^* + h_{13}^* h_7 + h_{14} h_8^* + h_{15}^* h_5 + h_{16} h_6^* \\
\eta_{16} &= h_1^* h_{13} + h_2 h_{14}^* + h_3^* h_{15} + h_4 h_{16}^* + h_5^* h_9 + h_6 h_{10}^* + h_{13}^* h_1 + h_{14} h_2^* + h_{15}^* h_3 + h_{16} h_4^* \\
\varphi_{16} &= h_1^* h_{15} + h_2 h_{16}^* + h_3^* h_{13} + h_4 h_{14}^* + h_5^* h_{11} + h_6 h_{12}^* + h_7^* h_9 + h_8 h_{10}^* + h_9^* h_7 + h_{10} h_8^* \\
&\quad + h_{11}^* h_5 + h_{12} h_6^* + h_{13}^* h_3 + h_{14} h_4^* + h_{15}^* h_1 + h_{16} h_2^*
\end{aligned} \tag{15}$$

The eigenvalues matrix $D_{8QO-STBC}$ and the corresponding eigenvectors $V_{8QO-STBC}$ for eight transmitter antennas are given by Eqs. (16) and (17).

$$D_{8QO-STBC} = \begin{bmatrix}
\beta+\alpha-\sigma-\gamma & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \beta+\alpha-\sigma-\gamma & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -\beta-\alpha+\sigma+\gamma & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -\beta-\alpha+\sigma+\gamma & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -\beta+\alpha+\sigma-\gamma & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -\beta+\alpha+\sigma-\gamma & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \beta+\alpha+\sigma+\gamma & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \beta+\alpha+\sigma+\gamma
\end{bmatrix} \tag{16}$$

$$V_{8QO-STBC} = \begin{bmatrix}
-1 & 0 & -1 & 0 & 1 & 0 & 1 & 0 \\
0 & -1 & 0 & -1 & 0 & -1 & 0 & 1 \\
-1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 \\
0 & -1 & 0 & 1 & 0 & 1 & 0 & 1 \\
1 & 0 & -1 & 0 & -1 & 0 & 1 & 0 \\
0 & 1 & 0 & -1 & 0 & 1 & 0 & 1 \\
1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 & 0 & -1 & 0 & 1
\end{bmatrix} \tag{17}$$

From Eq. (18), the new channel matrix is derived based on the virtual channel matrix as shown in Eq. (19).

$$H_{8QO-STBC} = H_{v8} V_{8QO-STBC} \tag{18}$$

Where,

$$H_{v8} = \begin{bmatrix}
h_1 & h_2 & h_3 & h_4 & h_5 & h_6 & h_7 & h_8 \\
h_2^* & -h_1^* & h_4^* & -h_3^* & h_6^* & -h_5^* & h_8^* & -h_7^* \\
h_3 & h_4 & h_1 & h_2 & h_7 & h_8 & h_5 & h_6 \\
h_4^* & -h_3^* & h_2^* & -h_1^* & h_8^* & -h_7^* & h_6^* & -h_5^* \\
h_5 & h_6 & h_7 & h_8 & h_1 & h_2 & h_3 & h_4 \\
h_6^* & -h_5^* & h_8^* & -h_7^* & h_2^* & -h_1^* & h_4^* & -h_3^* \\
h_7 & h_8 & h_5 & h_6 & h_3 & h_4 & h_1 & h_2 \\
h_8^* & -h_7^* & h_6^* & -h_5^* & h_4^* & -h_3^* & h_2^* & -h_1^*
\end{bmatrix} \tag{19}$$

Then the encoding matrix $X_{8QO-STBC}$ is derived corresponding to the channel matrix $H_{8QO-STBC}$ as in Eqs. (20) and (21)

$$H_{8\,QO-STBC} = \begin{bmatrix} -h_1-h_3+h_5+h_7 & -h_2-h_4+h_6+h_8 & h_1+h_3+h_5+h_7 & h_2+h_4+h_6+h_8 & h_1-h_3+h_5-h_7 & h_2-h_4+h_6-h_8 & h_2-h_4-h_6+h_8 & -h_1+h_3+h_5-h_7 \\ -h_2^*-h_4^*+h_6^*+h_8^* & h_1^*+h_3^*-h_5^*-h_7^* & h_2^*+h_4^*+h_6^*+h_8^* & -h_1^*-h_3^*-h_5^*-h_7^* & h_2^*-h_4^*+h_6^*-h_8^* & -h_1^*+h_3^*-h_5^*+h_7^* & -h_1^*+h_3^*+h_5^*-h_7^* & -h_2^*+h_4^*+h_6^*-h_8^* \\ -h_1-h_3+h_5+h_7 & -h_2-h_4+h_6+h_8 & h_1+h_3+h_5+h_7 & h_2+h_4+h_6+h_8 & h_3-h_1+h_7-h_5 & h_4-h_2+h_8-h_6 & h_4-h_2-h_8+h_6 & -h_3+h_1+h_7-h_5 \\ -h_2^*-h_4^*+h_6^*+h_8^* & h_1^*+h_3^*-h_5^*-h_7^* & h_2^*+h_4^*+h_6^*+h_8^* & -h_1^*-h_3^*-h_5^*-h_7^* & h_4^*-h_2^*+h_8^*-h_6^* & -h_3^*+h_1^*-h_7^*+h_5^* & -h_3^*+h_1^*+h_7^*-h_5^* & -h_4^*+h_2^*+h_8^*-h_6^* \\ -h_5-h_7+h_1+h_3 & -h_6-h_8+h_2+h_4 & h_1+h_3+h_5+h_7 & h_2+h_4+h_6+h_8 & h_1-h_3+h_5-h_7 & h_2-h_4+h_6-h_8 & h_4-h_2-h_8+h_6 & -h_3+h_1+h_7-h_5 \\ -h_6^*-h_8^*+h_2^*+h_4^* & h_5^*+h_7^*-h_1^*-h_3^* & h_2^*+h_4^*+h_6^*+h_8^* & -h_1^*-h_3^*-h_5^*-h_7^* & h_2^*-h_4^*+h_6^*-h_8^* & -h_1^*+h_3^*-h_5^*+h_7^* & -h_3^*+h_1^*+h_7^*-h_5^* & -h_4^*+h_2^*+h_8^*-h_6^* \\ -h_5-h+h_1+h_3 & -h_6-h_8+h_2+h_4 & h_1+h_3+h_5+h_7 & h_2+h_4+h_6+h_8 & h_3-h_1+h_7-h_5 & h_4-h_2+h_8-h_6 & h_2-h_4-h_6+h_8 & -h_1+h_3+h_5-h_7 \\ -h_6^*-h_8^*+h_2^*+h_4^* & h_5^*+h_7^*-h_1^*-h_3^* & h_2^*+h_4^*+h_6^*+h_8^* & -h_1^*-h_3^*-h_5^*-h_7^* & h_4^*-h_2^*+h_8^*-h_6^* & -h_3^*+h_1^*-h_7^*+h_5^* & -h_1^*+h_3^*+h_5^*-h_7^* & -h_2^*+h_4^*+h_6^*-h_8^* \end{bmatrix} \tag{20}$$

$$X_{8\,QO-STBC} = \begin{bmatrix} -x_1-x_3+x_5+x_7 & -x_2-x_4-x_6+x_8 & -x_1+x_3-x_5+x_7 & -x_2+x_4+x_6+x_8 & x_1-x_3-x_5+x_7 & x_2-x_4+x_6+x_8 & x_1+x_3+x_5+x_7 & x_2+x_4-x_6+x_8 \\ x_2^*+x_4^*+x_6^*-x_8^* & -x_1^*-x_3^*+x_5^*+x_7^* & x_2^*-x_4^*-x_6^*-x_8^* & -x_1^*+x_3^*-x_5^*+x_7^* & -x_2^*+x_4^*-x_6^*-x_8^* & x_1^*-x_3^*-x_5^*+x_7^* & -x_2^*-x_4^*+x_6^*-x_8^* & x_1^*+x_3^*+x_5^*+x_7^* \\ -x_1+x_3-x_5+x_7 & -x_2+x_4+x_6+x_8 & -x_1-x_3+x_5+x_7 & -x_2-x_4-x_6+x_8 & x_1+x_3+x_5+x_7 & x_2+x_4-x_6+x_8 & x_1-x_3-x_5+x_7 & x_2-x_4+x_6+x_8 \\ x_2^*-x_4^*-x_6^*-x_8^* & -x_1^*+x_3^*-x_5^*+x_7^* & x_2^*+x_4^*+x_6^*-x_8^* & -x_1^*-x_3^*+x_5^*+x_7^* & -x_2^*-x_4^*+x_6^*-x_8^* & x_1^*+x_3^*+x_5^*+x_7^* & -x_2^*+x_4^*-x_6^*-x_8^* & x_1^*-x_3^*-x_5^*+x_7^* \\ x_1-x_3-x_5+x_7 & x_2-x_4+x_6+x_8 & x_1+x_3+x_5+x_7 & x_2+x_4-x_6+x_8 & -x_1-x_3+x_5+x_7 & -x_2-x_4-x_6+x_8 & -x_1+x_3-x_5+x_7 & -x_2+x_4+x_6+x_8 \\ -x_2^*+x_4^*-x_6^*-x_8^* & x_1^*-x_3^*-x_5^*+x_7^* & -x_2^*-x_4^*+x_6^*-x_8^* & x_1^*+x_3^*+x_5^*+x_7^* & x_2^*+x_4^*+x_6^*-x_8^* & -x_1^*-x_3^*+x_5^*+x_7^* & x_2^*-x_4^*-x_6^*-x_8^* & -x_1^*+x_3^*-x_5^*+x_7^* \\ x_1+x_3+x_5+x_7 & x_2+x_4-x_6+x_8 & x_1-x_3-x_5+x_7 & x_2-x_4+x_6+x_8 & -x_1+x_3-x_5+x_7 & -x_2+x_4+x_6+x_8 & -x_1-x_3+x_5+x_7 & -x_2-x_4-x_6+x_8 \\ -x_2^*-x_4^*+x_6^*-x_8^* & x_1^*+x_3^*+x_5^*+x_7^* & -x_2^*+x_4^*-x_6^*-x_8^* & x_1^*-x_3^*-x_5^*+x_7^* & x_2^*-x_4^*-x_6^*-x_8^* & -x_1^*+x_3^*-x_5^*+x_7^* & x_2^*+x_4^*+x_6^*-x_8^* & -x_1^*-x_3^*+x_5^*+x_7^* \end{bmatrix} \tag{21}$$

Similarly, the detection matrix for sixteen transmitters can be derived to eliminate the interference terms. The resultant channel model and coding matrices result in an interference-free detection matrix.

3 DHSTBC for Multiple Transmit Antennas

In this section a full-rate full-diversity order Diagonalized Hadamard Space-Time Code (DHSTBC) over OFDM for 4, 8 and 16 transmitter antennas is implemented. The detection matrix generated, $D = X.X^H$, is a diagonal matrix [5, 8]. The generated codes provide full rate and full diversity when the number of the receiver antennas are at least equal to the number of transmitter antennas, the code matrices for DHSTBC are Hadamard matrices of size $N = 2^n$ where $n \geq 1$.

Let $s_1, s_2, \ldots\ldots, s_N$ be the transmitted symbols. These symbols are sorted to form the cyclic matrix S_8 as in Eqs. (22) to (24) as follows,

$$\begin{aligned} S_{12} &= \begin{bmatrix} s_1 & s_2 \\ s_2 & s_1 \end{bmatrix} & S_{34} &= \begin{bmatrix} s_3 & s_4 \\ s_4 & s_3 \end{bmatrix} \\ S_{56} &= \begin{bmatrix} s_5 & s_6 \\ s_6 & s_5 \end{bmatrix} & S_{78} &= \begin{bmatrix} s_7 & s_8 \\ s_8 & s_7 \end{bmatrix} \\ S_4 &= \begin{bmatrix} S_{12} & S_{34} \\ S_{34} & S_{12} \end{bmatrix} & S_5 &= \begin{bmatrix} S_{56} & S_{78} \\ S_{78} & S_{56} \end{bmatrix} \end{aligned} \tag{22}$$

The transmitted matrix is,

$$S_8 = \begin{bmatrix} S_4 & S_5 \\ S_5 & S_4 \end{bmatrix} \tag{23}$$

The same procedure is applied to form the transmitted matrix S_{16}, as follows,

$$S_9 = \begin{bmatrix} S_{9-10} & S_{11-12} \\ S_{11-12} & S_{9-10} \end{bmatrix} \quad S_{10} = \begin{bmatrix} S_{13-14} & S_{15-16} \\ S_{15-16} & S_{13-14} \end{bmatrix} \tag{24}$$

$$S_{11} = \begin{bmatrix} S_9 & S_{10} \\ S_{10} & S_9 \end{bmatrix} \quad S_{16} = \begin{bmatrix} S_8 & S_{11} \\ S_{11} & S_8 \end{bmatrix} \tag{25}$$

The Hadamard matrices of order four, eight and sixteen which are used to form the new channel matrix are given in Eqs. (26, 27 and 28) respectively:

$$H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \tag{26}$$

$$H_8 = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix} \tag{27}$$

$$H_{16} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 \end{bmatrix} \tag{28}$$

The resultant encoding matrix X. for 4, 8 and 16 transmitter antennas is a DHSTBC over OFDM and hence, the overall expression is given by,

$$X = H.S \tag{29}$$

The encoding matrix for four transmitter antennas can be generated using Eq. (30) as,

$$X_4 = \begin{bmatrix} s_1+s_2+s_3+s_4 & s_1+s_2+s_3+s_4 & s_1+s_2+s_3+s_4 & s_1+s_2+s_3+s_4 \\ s_1-s_2+s_3-s_4 & s_2-s_1+s_4-s_3 & s_1-s_2+s_3-s_4 & s_2-s_1+s_4-s_3 \\ s_1+s_2-s_3-s_4 & s_1+s_2-s_3-s_4 & s_3+s_4-s_1-s_2 & s_3+s_4-s_1-s_2 \\ s_1-s_2-s_3+s_4 & s_2-s_1-s_4+s_3 & s_2-s_1-s_4+s_3 & s_1-s_2-s_3+s\_4 \end{bmatrix} \tag{30}$$

The Same Procedure Can Be Followed to Generate the Encoding Matrices for 8 and 16 Transmit Antennas

$$X_4.X_4^H = \begin{bmatrix} 4(s_1+s_2+s_3+s_4) & 0 & 0 & 0 \\ 0 & 4(s_1-s_2+s_3-s_4) & 0 & 0 \\ 0 & 0 & 4(s_1+s_2-s_3-s_4) & 0 \\ 0 & 0 & 0 & 4(s_1-s_2-s_3+s_4) \end{bmatrix} \tag{31}$$

One can notice that the detection $X_4X_4^H$ is diagonal matrix where the interference terms have been eliminated which can achieve simple linear decoding as the shown in Eq. (31).

4 Simulation and Results

The performance of QO-STBC and DHSTBC over OFDM was evaluated over Rayleigh fading channel using MATLAB. The signals were modulated using 16-QAM, and the total transmit power was divided equally among the number of transmitter antennas. The fading was assumed to be constant over four, eight and sixteen consecutive symbol periods for four, eight and sixteen transmitter antennas respectively and the channel was known at the receiver. Finally the results of these methods were compared with STBC results, using the same data and channel parameters. Table 1 shows the simulation parameters.

Table 1. OFDM Simulation Parameter

Parameter	Specifications
Carrier frequency (MHz)	5.8
Sample frequency (MHz)	40
Bandwidth (MHz)	40
FFT size	128
Cyclic prefix ratio	0.25
Constellation	16-QAM
Data subcarrier/Pilots	108/6
Virtual carrier	14

Figure 2 shows the BER performance of QO-STBC over OFDM for four, eight and sixteen transmit antennas. The best BER is achieved by using sixteen transmitter antennas, since this gives the largest diversity order.

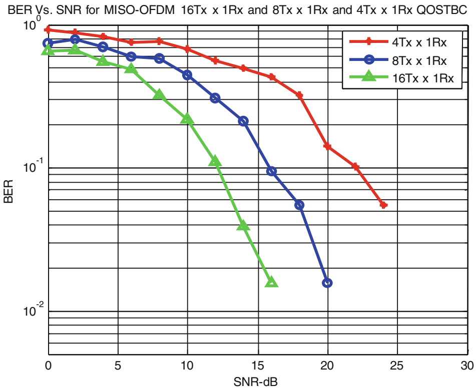

Fig. 2. BER performance of QO-STBC over OFDM for Four, Eight and Sixteen Transmitter Antennas.

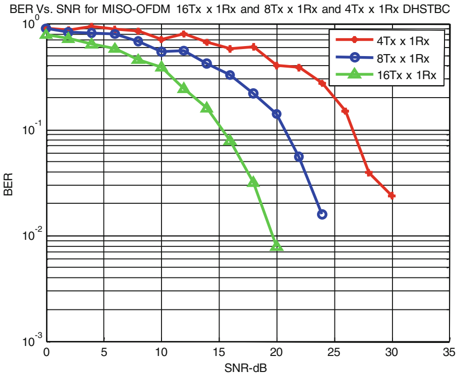

Fig. 3. BER performance of DHSTBC over OFDM for Four, Eight and Sixteen Transmitter Antennas

Figure 3 shows BER performance of DHSTBC over OFDM for four, eight and sixteen transmitter antennas. Again the best BER performance is achieved using sixteen transmitter antennas.

Next we compare the BER performances of QO-STBC, DHSTBC and the conventional STBC method with the same number of transmitter antennas. It's noticeable in Figs. 4, 5 and 6 that proposed DHSTBC achieves the best performance, and proposed QO-STBC outstrips conventional STBC.

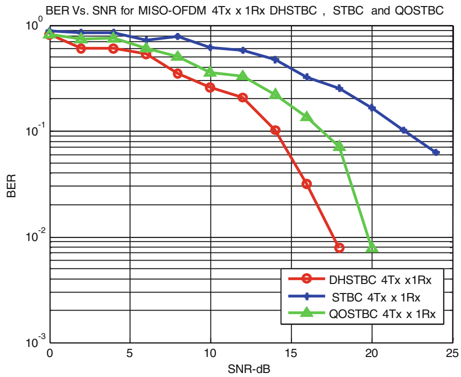

Fig. 4. BER performance of STBC, QO-STBC and DHSTBC over OFDM for Four Transmitter Antennas.

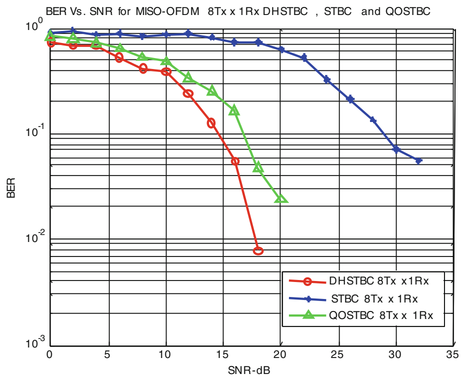

Fig. 5. BER performance of STBC, QO-STBC and DHSTBC over OFDM for Eight Transmitter Antennas

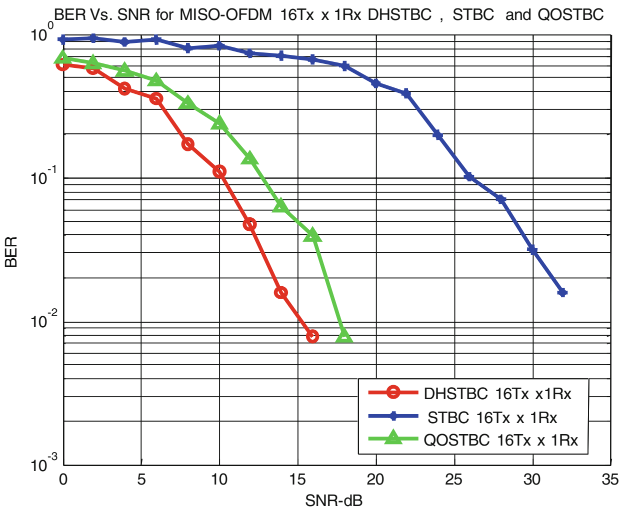

Fig. 6. BER performance of STBC, QO-STBC and DHSTBC over OFDM for Sixteen Transmitter Antennas.

5 Conclusions

New methods for QO-STBC and DHSTBC over OFDM for four, eight and sixteen transmitter antenna were implemented by deriving the orthogonal channel matrix that results in simple decoding scheme. The performance of QO-STBC and DHSTBC over OFDM was evaluated by varying the number of transmitter antennas and tested with different modulation schemes. When these compared with real STBC it shows a better performance.

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