Novel QO-STBC Scheme

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ABSTRACT
In order to satisfy the huge communications demands MIMO (Multiple input and Multiple Output) systems is one of the techniques which provide high data rates under the constraints of limited bandwidth and transmit power. Space-Time Block Coding (STBC) is based on MIMO transmission strategy which exploits transmit diversity. STBCs are divided into two main classes i.e. Orthogonal Space-Time Block Codes (OSTBCs) and Non-Orthogonal Space-Time Block Codes (NO-STBCs). The Quasi-Orthogonal Space-Time Block Codes (QO-STBCs) belong to class of NO-STBCs and have been our area of interest. Full data rate and full diversity can only achieved with QSTBCs with a small loss in the diversity gain. The foremost purpose of this work is to provide a unified theory of QSTBCs for four transmit antennas and one receive antennas.

Keywords
MIMO, STBC, OSTBC, QSTBC

1. INTRODUCTION
From the past few years, demand for mobile communication systems with high data rates has increased significantly. In order to meet these huge communications demands new methods has been devised that are exploiting the limited resources such as bandwidth and power in an efficient way in order to reduce the system deployment cost. MIMO (Multiple input and Multiple Output) systems is one of the techniques with multiple antenna elements at both the link ends which is an efficient solution to meet the future wireless communications demands as they provide more reliable connection. STBC is based on MIMO transmission strategy which encodes the data across multiple transmit antennas and time slots, such that multiple redundant copies of data are transmitted through independent fading channel. Alamouti proposed the transmit diversity scheme which is regarded as the first space time coding with two transmit antennas and thus achieved full code rate with full diversity for complex orthogonal design, with simple linear ML decoding. These kinds of space time coding are known as orthogonal space time codes (O-STBC). However we cannot achieve full diversity for complex orthogonal design for more than two antennas. The maximum code rate achieved with 3 or 4 Transmit Antennas was 3/4 with full diversity. And for more than four transmit antennas, the code rate cannot be achieved more than 1/2. In order to achieve the advantages of O-STBC schemes with properties close to such optimal codes providing full rate, the so called QO-STBCs were proposed. Here we relax the simple separate decoding property and its orthogonality to achieve higher code rates. A QO-STBC can achieve full rate but it also results in interference from neighbouring symbols during this leads to increasing the decoding complexity with respect to O-STBCS. Two ML detectors in parallel are used to decode the pairs of transmitted symbols in QOSTBC, which results in higher decoding complexity at the receiver. This leads to increase in the modulation level; receiver computes the decision metric over large number of symbols which subsequently increases the decoding complexity and thus transmission delay.

2. CONVENTIONAL QOSTBC
Jafarkhani code for four transmit antenna and one receive antenna, is given by [16]:

$$S = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ -s_4^* & -s_3^* & s_2^* & s_1^* \\ s_4 & -s_3 & -s_2 & s_1 \end{bmatrix} \quad (3.1)$$

where $s_i$ is input modulated symbols for the QO-STBC encoder. Corresponding equivalent virtual channel matrix (EVCM) of this code is given by

$$H = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3^* & h_4 & -h_1 & -h_2^* \\ h_4^* & -h_3 & -h_2 & h_1 \end{bmatrix} \quad (3.2)$$

where $h_i$ is channel coefficient for every transmit and receive antenna pair. Therefore, received signal vector $y$ can be written as:

$$y = Hs + \bar{n} \quad (3.3)$$

where $s = [s_1, s_2, s_3, s_4]^T$,  

$$\bar{n} = [n_1, n_2, n_3, n_4]^T$$

and $n_i$ is complex white Gaussian noise added at the i-th time slot. In this case of orthogonal scheme received signals were decoded with the help of detection matrix $D$ defined as $H^H$. In O-STBC scheme the detection matrix always comes out to be a diagonal matrix and thereby relaxing the decoding complexity at receiver. Although for a QO-STBC scheme, this method cannot be applied because detection matrix is not diagonal. For example, the detection matrix for the above mentioned four transmit antenna QO-STBC scheme is expressed by:

$$D = H^H H = \begin{bmatrix} a & 0 & 0 & b \\ 0 & a & -b & 0 \\ 0 & -b & a & 0 \\ b & 0 & 0 & a \end{bmatrix} \quad (3.4)$$

where, $a = \sum_{i=1}^{4} |h_i|^2$ is channel gain for four transmit antennas.

$$b = 2 \text{Re}(h_1 h_4^* - h_2 h_3^*)$$

is interference parameter.

A complex decoding method to find the estimate $\hat{C}$ was introduced which has the high decoding complexity due to process of the inverse of the matrix. This method is called as zero forcing decoding, and given by [37]:

$$\hat{C} = (H^H H)^{-1} H^H \bar{r} \quad (3.5)$$
3. PROPOSED QOSTBC

As the detection matrix \( D \) is symmetric, so using the property of symmetric matrix, we can express \( D \) as:

\[
D = QD_aQ^T \tag{4.1}
\]

where \( Q \) and \( D_a \) are orthogonal and diagonal matrix respectively where diagonal elements of \( D_a \) are eigenvalue of \( D \). Equation (4.1) can also be rewritten as

\[
Q^TDQ = D_a \tag{4.2}
\]

by pre multiplying detection matrix \( D \) with \( Q^T \) and post multiplying the detection matrix \( D \) with \( Q \), the diagonal matrix \( D_a \) is obtained which is interference free. In Z.Q.Taha

In matrix notation, \( D_a \) can be written as:

\[
D_a = \begin{bmatrix}
0.5 & 0.5 & -0.5 & 0.5 \\
0.5 & -0.5 & 0.5 & 0.5 \\
0.5 & 0.5 & -0.5 & 0 \\
0 & 0 & 0 & 0 \\
\end{bmatrix}
\]

(4.5)

So the new interference free detection matrix \( D_n \) becomes

\[
D_n = \begin{bmatrix}
a + b & 0 & 0 & 0 \\
0 & a + b & 0 & 0 \\
0 & 0 & a - b & 0 \\
0 & 0 & 0 & a - b \\
\end{bmatrix}
\]

(4.6)

New channel matrix is derived from \( D_n \) as:

\[
H_n = HQ^T, \quad \text{where:}
\]

\[
H_n = \begin{bmatrix}
(h_1 + h_2 - h_3 + h_4)/2 & (h_1 - h_2 + h_3 + h_4)/2 & (h_1 + h_2 + h_3 - h_4)/2 & (h_1 + h_2 - h_3 - h_4)/2 \\
(h_2 - h_1 - h_3 + h_4)/2 & (h_2 + h_1 - h_3 - h_4)/2 & (h_2 - h_1 + h_3 + h_4)/2 & (h_2 + h_1 + h_3 - h_4)/2 \\
(h_3 - h_4 + h_1 - h_2)/2 & (h_3 + h_4 - h_1 + h_2)/2 & (h_3 - h_4 - h_1 - h_2)/2 & (h_3 + h_4 + h_1 + h_2)/2 \\
(h_4 - h_3 + h_2 - h_1)/2 & (h_4 + h_3 - h_2 - h_1)/2 & (h_4 - h_3 - h_2 + h_1)/2 & (h_4 + h_3 + h_2 - h_1)/2 \\
\end{bmatrix}
\]

(4.7)

Now using the property of EVCM new encoding matrix is expressed as:

\[
S_n = \begin{bmatrix}
(s_1 + s_2 + s_3 - s_4)/2 & (s_1 - s_2 + s_3 + s_4)/2 & (s_1 + s_2 + s_3 + s_4)/2 & (s_1 + s_2 - s_3 + s_4)/2 \\
(-s_1 - s_2 + s_3 - s_4)/2 & (s_1 + s_2 + s_3 - s_4)/2 & (s_1 - s_2 + s_3 - s_4)/2 & (s_1 + s_2 - s_3 + s_4)/2 \\
(s_1 - s_2 - s_3 + s_4)/2 & (s_1 + s_2 - s_3 - s_4)/2 & (s_1 - s_2 - s_3 + s_4)/2 & (s_1 + s_2 + s_3 - s_4)/2 \\
(s_1 + s_2 + s_3 - s_4)/2 & (s_1 - s_2 + s_3 + s_4)/2 & (s_1 + s_2 + s_3 + s_4)/2 & (s_1 - s_2 - s_3 + s_4)/2 \\
\end{bmatrix}
\]

(4.8)

The new encoding matrix \( S_n \) is Quasi-orthogonal, but its channel matrix \( H_n \) is orthogonal matrix, so it enables simple linear decoding at the receiver thereby reducing decoding complexity without sacrificing in terms of bit error rate. The decoding matrix is given by:

\[
\tilde{C} = H_n^T C_n + H_n^T \tilde{n}
\]

(4.9)

4. SIMULATION RESULTS

Graph 4.1: Performance of conventional and proposed QO-STBC scheme.
5. CONCLUSION
A new QO-STBC is developed which has very low decoding complexity than the maximum likelihood decoder and zero forcing decoder. The proposed scheme is developed by using symmetry property of the gramman matrix. The encoding matrix $S_n$ is Quasi-Orthogonal but the virtual channel matrix $H_n$ is Orthogonal which results in simple linear decoding thereby reducing the transmission delay which in turn reduces the decoding complexity without any degradation in BER performance. It is well known that transmission strategy can be improved using the closed loop system in which the transmitter have aces to the channel state information. The proposed QO-STBC provides more power gain in comparison to the conventional QO-STBC thereby reducing decoding complexity and increased BER performance.

6. REFERENCES