Performance Analysis of Qo-Stbc for Increasing Transmit Diversity in Rayleigh Fading Environment: A Review

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ABSTRACT:

The demand for mobile communication systems with high data rates has dramatically increased in recent years. New methods are necessary in order to satisfy this huge communications demand, exploiting the limited resources such as bandwidth and power as efficient as possible. MIMO systems with multiple antenna elements at both link ends are an efficient solution for future wireless communications systems as they provide high data rates by exploiting the spatial domain under the constraints of limited bandwidth and transmit power. In this paper, a comprehensive study of STBC is done. Furthermore, advanced QOSTBC codes are also discussed in this paper. These codes have the advantage of providing full rate as well as diversity gains. In this paper, schemes which makes possible the QOSTBC codes to gain full transmission diversity by upsetting the balance of the transmit power and rotating constellations have been discussed.

KEYWORDS: Space time block code(STBC); Quasi Orthogonal Space Time Block Codes(QO-STBC); Multiple Input Multiple Output(MIMO); transmit diversity

INTRODUCTION: Because of the enormous capacity increase MIMO systems offer, such systems gained a lot of interest in mobile communication research [1], [2]. One essential problem of the wireless channel is fading, which occurs as the signal follows multiple paths between the trransmit and the receive antennas. Under certain, not uncommon conditions, the arriving signals will add up destructively, reducing the received power to zero (or very near to zero). In this case no reliable communication is possible.

Fading can be mitigated by diversity, which means that the information is transmitted not only once but several times, hoping that at least one of the replicas will not undergo severe fading. Diversity makes use of an important property of wireless MIMO channels: different signal paths can be often modeled as a number of separate, independent fading channels. These channels can be distinct in frequency domain or in time domain.

Several transmission schemes have been proposed that utilize the MIMO channel in different ways, e.g., spatial multiplexing, space-time coding or beamforming. Space-time coding (STC), introduced first by Tarokh at el. [3], is a promising method where the number of the transmitted code symbols per time slot are equal to the number of transmit antennas. These code symbols are generated by the space-time encoder in such a way that diversity gain, coding gain, as well as high spectral efficiency are achieved. STC schemes optimize a trade-off between the three conflicting goals of maintaining a simple decoding algorithm,

obtaining low error probability, and maximizing the information rate.

Space-Time Block Coding (STBC) is a MIMO transmit strategy which exploits transmit diversity and high reliability. STBCs can be divided into two main classes, namely, Orthogonal Space-Time Block Codes (OSTBCs) and Non-Orthogonal Space-Time Block Codes (NOSTBCs) [4]. The Quasi-Orthogonal Space-Time Block Codes (QSTBCs) belong to class of NOSTBCs and have been an intensive area of research. The OSTBCs achieve full diversity with low decoding complexity, but at the price of some loss in data rate [5].

Full data rate is achievable in connection with full diversity only in the case of two transmit antennas in case of complex-valued symbol transmission. For more than two transmit antennas full data rate can be achieved with QSTBCs with a small loss of the diversity gain. However, it has been shown that QSTBCs perform even better than OSTBCs in the SNR range of practical interest (up to 20 dB) that makes this class of STBCs an attractive area of research [6]. In the analysis of STBCs it is usually assumed that the channel state information (CSI) is known perfectly at the receiver but not at the transmitter. On the other hand, CSI can be made available at the transmitter. In some cases CSI is limited to the channel statistics whereas the actual CSI is unknown. In fact, the transmitter should exploit any channel information available. This knowledge, whether partial or complete, can be advantageously exploited to adapt the transmission strategy in order to optimize the system performance. Full channel knowledge at the transmitter implies that the instantaneous channel transfer matrix H is known at the transmitter [7].

SYSTEM AND CHANNEL MODEL

Let us consider a point-to-point MIMO system with n_t transmit and n_r receive antennas. Let $h_{i,j}$ be a complex number corresponding to the channel gain between transmit antenna j and receive antenna i. If at a certain time instant the complex signals $\{s_1, s_2, \cdot \cdot \cdot ,s_{nt} \}$ are transmitted via n_t transmit antennas, the received signal at antenna i can be expressed as [8]:

$$y_i = h_{i,j}s + n_i \quad (1)$$

where n_i is a noise term usually the AWGN present in channel. Combining all receive signals in a vector, y can be easily expressed in matrix form as:

$$Y=HS+n \quad (2)$$

y is the $n_r \times 1$ receive symbol vector, H is the $n_r \times n_t$ MIMO channel transfer matrix,

$$H = \begin{bmatrix} h_{1,1} & \cdots & h_{1,nt} \\ \vdots & \ddots & \vdots \\ h_{nr,1} & \cdots & h_{nr,nt} \end{bmatrix} \quad (3)$$

s is the $n_t \times 1$ transmit symbol vector and n is the $n_r \times 1$ additive noise vector. Note that the system model implicitly assumes a flat fading MIMO channel, i.e., channel coefficients are constant during the transmission of several symbols.

Flat fading, or frequency non-selective fading, applies by definition to systems where the bandwidth of the transmitted signal is much smaller than the coherence bandwidth of the channel. All the frequency components of the transmitted signal undergo the same attenuation and phase shift propagation through the channel [9-11].

Orthogonal Space-Time Block Codes (OSTBCs)

Historically, the Alamouti code is the first STBC that provides full diversity at full data rate for two transmit antennas [4]. The pioneering work of Alamouti has been a basis to create OSTBCs for more than two transmit antennas. First of all, Tarokh studied the error performance associated with unitary signal matrices [5]. Sometime later, Ganesan at al. streamlined the derivations of many of the results associated with OSTBC and established an important link to the theory of the orthogonal and amicable orthogonal designs [6].

It has been shown how simple decoding which can separately recover transmit symbols, is possible using an orthogonal design. However, in [5] it is proved that a complex orthogonal design of STBCs which provides full diversity and full transmission rate is not possible for more than two transmit antennas. In [12-16] so called Quasi Orthogonal Space-Time Block Codes (QSTBC) have been introduced as a new family of STBCs. These codes achieve full data rate at the expense of a slightly reduced diversity. Using quasi-orthogonal design, pairs of transmitted symbols can be decoded independently and the loss of diversity in QSTBC is due to some coupling term between the estimated symbols.

Quasi-Orthogonal Space–Time Block Code (QO-STBC)

All QSTBCs are extensions of the Alamouti (2 × 2) matrix defined in [4] to a (4 × 4) code matrix and are designed following the Alamoutisation rules:

Design Rule for Alamoutisation [17]:

1. Each row and each column contains all elements of s. This rule ensures symmetry of the code behavior and an equal distribution of all symbols in a code word.

2. Any element in a code word may occur with a positive or negative sign.

3. The conjugate complex operation of symbols is only allowed on entire rows of the (4 × 4) block matrix. This rule is required for holding quasi-orthogonality and low decoding complexity.

4. The code matrix is divided into groups where the columns of the code matrix are not orthogonal to each other, but columns of different groups are orthogonal to each other.

These constraints make QSTBCs more attractive for wireless communication than other non-orthogonal STBCs especially due to the low complexity of the decoding algorithm. QOSTBC codes used in ths paper for four antennas can be derived from famous Alamouti codes as follows:

$$S_1 = \begin{bmatrix} A_{12} & A_{34} \\ -A_{34}^* & A_{12}^* \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & -x_3 & -x_2 & x_1 \end{bmatrix}$$

… (4)

This limitation of the conventional QO-STBC scheme of having high decoding complexity is mainly due to interference terms in the detection matrix. Hence a scheme to achieve full transmit diversity without increasing the decoding complexity is by shifting the balance of transmit power [12].

Transmit Power Imbalance Scheme

To mitigate detection error due to interference terms, shifting the amplitudes of transmitted symbol is one of the solution. If the initial

amplitude of symbols is decomposed into its real and imaginary part as: $x_i = x_i^R + j\ x_i^I$; where, x_i^R is the real part and x_i^I is the imaginary part of transmitted symbol [12]. Let us consider following replacement

$$X_i = a_1 * x_i^R + j\ a_2 * x_i^I \quad (5)$$

Where a_1 and a_2 are constants chosen in order to reduce the interference term. The values of a_1 and a_2 are such that they satisfy the following equation:

$$a_1^2 + a_2^2 = 1 \qquad (6)$$

This method can be shown by a figure below in Fig.1. [12] :

Fig 2. BER performance of power   imbalance and conventional sceheme for four transmit antennas over a Rayleigh channel.
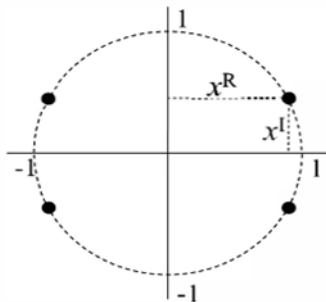

Fig.1: Signal constellation for proposed amplitude shifting for QPSK.

The results imply that the imbalance of IQ component or amplitudes of symbols could yield better BER performance with respect to the original QOSTBC.
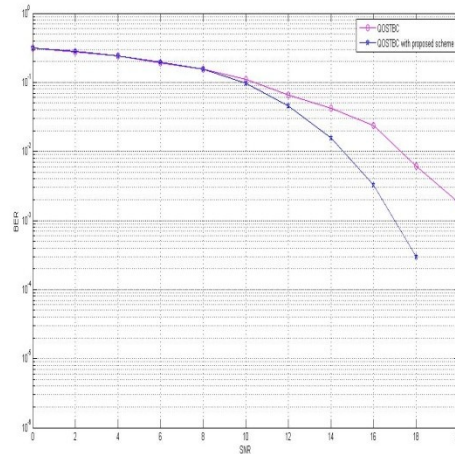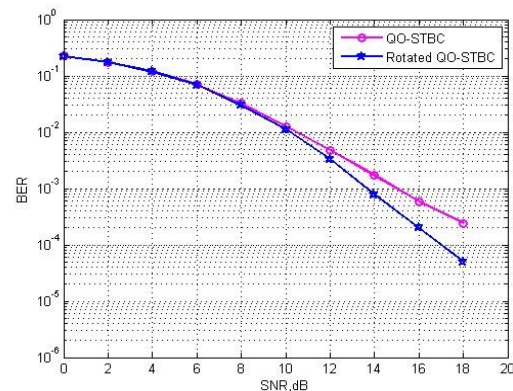

Fig.3. Comparison of bit error rate for rotate and non rotated QOSTBC

ROTATED CONSTELLATION:

Although QO-STBC can achieve higher code rates than O-STBC, it generally does not provide full transmit diversity directly. It is easy to show that minimum rank of the difference matrix $D(C^i, C^j)$ is two for QO-STBC explained in this section for regular symmetric constellations like BPSK, QPSK, 8-PSK etc. The maximum diversity of four is impossible in this case if all the symbols are taken from same constellation. To provide full diversity, different constellations for different

transmitted symbols are used. Let in above explained QO-STBC, $\tilde{s}_3$ and $\tilde{s}_4$ are rotated version of s_3 and s_4 respectively, so replace s_3 and s_4 by $\tilde{s}_3$ and $\tilde{s}_4$ respectively in the QO-STBC code. The resulting code is very robust since it provides full diversity; rate one and pairwise decoding with good performance. Let the desired QO-STBC code is C which is of Jafarkhani type, is given by

$$C = \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ -c_2^* & c_1^* & -c_4^* & c_3^* \\ -c_3^* & -c_4^* & c_1^* & c_2^* \\ c_4 & -c_3 & -c_2 & c_1 \end{bmatrix} \qquad (7)$$

An error occurs if the decoder mistakenly decides that transmitted code is C^2 in place of C^1, where C^1 and C^2 is given as

$$C^1 = \begin{bmatrix} c^1_1 & c^1_2 & c^1_3 & c^1_4 \\ -c^{1*}_2 & c^{1*}_1 & -c^{1*}_4 & c^{1*}_3 \\ -c^{1*}_3 & -c^{1*}_4 & c^{1*}_1 & c^{1*}_2 \\ c^1_4 & -c^1_3 & -c^1_2 & c^1_1 \end{bmatrix}$$

$$C^2 = \begin{bmatrix} c^2_1 & c^2_2 & c^2_3 & c^2_4 \\ -c^{2*}_2 & c^{2*}_1 & -c^{2*}_4 & c^{2*}_3 \\ -c^{2*}_3 & -c^{2*}_4 & c^{2*}_1 & c^{2*}_2 \\ c^2_4 & -c^2_3 & -c^2_2 & c^2_1 \end{bmatrix}$$

For examining the decoding error probability of C, A is an important parameter which is expressed as $A(C^1,C^2) = (C^2-C^1)^H (C^2-C^1)$. The expression of A given by [12]:

$$A = \begin{bmatrix} \alpha & 0 & 0 & \beta \\ 0 & \alpha & -\beta & 0 \\ 0 & -\beta & \alpha & 0 \\ \beta & 0 & 0 & \alpha \end{bmatrix} \qquad (8)$$
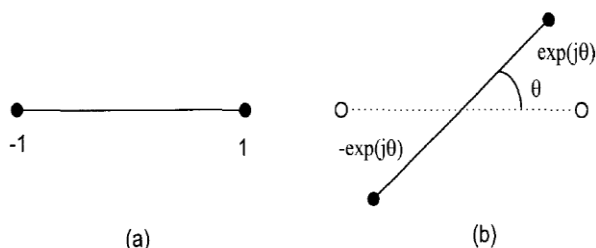

(a)   (b)

Fig.4. Constellation rotation for BPSK constellation set($d_{min} = 2$)

Besides giving full diversity, constellation rotation also provide an extra degree of freedom to maximize the minimum determinant value to achieve maximum coding gain for the QO-STBC. The C code after appropriate CR, denoted as C_CR, is able to achieve full diversity, which is given by [7]

$$C\_CR = \begin{bmatrix} c_1 & c_2 & c_3 e^{j\theta} & c_4 e^{j\theta} \\ -c_2^* & c_1^* & -(c_4 e^{j\theta})^* & (c_3 e^{j\theta})^* \\ -(c_3 e^{j\theta})^* & -(c_4 e^{j\theta})^* & c_1^* & c_2^* \\ c_4 e^{j\theta} & -c_3 e^{j\theta} & -c_2 & c_1 \end{bmatrix}$$

…(9)

where the factor $e^{j\theta}$ denotes constellation rotation angle for the symbols c_3 and c_4. It can be seen that both C and C_CR perform same at low SNR region. However, as the SNR increases, the performance of C loses out, as it is not able to achieve full transmit diversity and hence its BER slope is smaller than the rotated version. On the other hand, C_CR, which employs constellation rotation, performs consistently better than C because C_CR achieves full transmit diversity. This can be seen in the simulation result been shown in fig.4. Due to the use of constellation rotation, the decoding complexity

Because of the use of constellation rotation the decoding complexity of the QO-STBC increases.

In this, half of the symbols are taken from the original constellation and the other half from the rotated constellation and this would improve the performance of the rotated QO-STBC codes.

CONCLUSION:

In this paper, a theoretical background for OSTBC and QSTBC codes is provided. We have reviewed two schemes to achieve full

transmit diversity without increasing the decoder complexity. One is the shifting the balance of transmit power and another is choosing half of the symbols from rotated constellations. Power imbalance scheme is simple and easy to implement, however, the BER performance tend to improve by applying both these schemes individually, whem compared to the conventional QOSTBC scheme.

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