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On the performance of code word diversity based quasi orthogonal space time block codes in multiple-input-multiple-output systems

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Article Info

ABSTRACT

In the recent past, a lot of researches have been put into designing a Multiple-Input-Multiple-Output (MIMO) system to provide multimedia services with higher quality and at higher data rate. On par with these requirements, a novel Quasi Orthogonal Space Time Block Code (QOSTBC) scheme based on code word diversity is proposed, which is a multi-dimensional approach, in this paper. The term code word diversity is coined, since the information symbols were spread across many code words in addition to traditional time and spatial spreading, without increasing transmission power and bandwidth. The receiver with perfect channel state information estimates the transmitted symbols with less probability of error, as more number of samples is available to estimate given number of symbols due to the extra diversity due to code words. The simulation results show a significant improvement in the Bit Error Rate (BER) performance of the proposed scheme when compared with the conventional schemes.

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1. INTRODUCTION

Higher data rate and reliability are the demands of the modern day applications and are met by Multiple-Input-Multiple-Output (MIMO) technique. Exhaustive research was carried out in the past and still it is a field of interest. MIMO systems have become the field of attraction in recent times, as they support high speed applications without demanding extra communication resources like power and bandwidth [1, 2]. Space-Time Block Coding (STBC) is a scheme developed for MIMO systems to provide higher diversity gain and coding gain [3]. The subcarrier power allocation algorithms to meet the requirements of next generation wireless technology are proposed in [4-6]. In [7], a multipath diversity scheme in conjunction with OFDM is proposed to improve the BER performance of a MIMO system. Orthogonal Space Time Block Code (OSTBC) is a kind of STBC, having faster Maximum Likelihood (ML) decoding ability due to its orthogonal property [8], however, suffers a drawback of ability to offer full rate only for two antennas, for complex constellations [9] and [10]. QOSTBC has gained the attention as an alternative to overcome this drawback with a compromise in orthogonality, which in turn compromises with diversity order and decoding complexity [11]. To improve Bit Error Rate (BER) performance of QOSTBC, optimum constellation rotation is proposed in [12]. In [13], a receive antenna selection scheme without feedback requirement for exploiting the advantages of MIMO is proposed. Cooperative diversity schemes for exploiting advantages of MIMO are proposed in [14-20]. In contrast to the open loop QOSTBCs mentioned above, several closed loop QOSTBC schemes

are presented in [21-24] for better performance. The drawbacks of these schemes are higher cost and complexity due to the feedback. In [25, 26], the channel state information is computed at the receiver and fed back to the transmitter via single bit of information. Based on the feedback, the transmitter selects one of its two code words for transmission, which suits better for the present channel conditions. In [27], a scheme that selects best code word for a given channel condition is presented. All these works are based on the truth that the channels respond differently for different spatial locations (i.e. spatial diversity), at different instances of time (i.e. temporal diversity), for different frequencies (i.e. frequency diversity) and for different polarizations (i.e. polarization diversity).

Similarly, the channels respond differently for different QOSTBC code words, for one code word, the performance may be good at one instant of time and the same may yield a poor performance later. A multidimensional approach for space-time coding is proposed in [28], which combined spatial and temporal diversity with spatial multiplexing. The three dimensional tensor coding considered transmitting antenna, time and data stream as its dimensions. In [29], the authors have proposed Multiple Khatri-Rao Space-Time (MKRST) code for improving the performance of MIMO systems by providing additional diversity either in time or space. In [30], the authors have proposed Double Orthogonal Vandermonde constrained Alternating Least Square (DOVALS) algorithm to utilize the orthogonal structures in the factored matrices. From the literature, it is understood that increasing the number of received signals without increasing the frequency, time and power requirement is still an open problem. It is also clear that the full potential of diversity is not fully exploited. The idea of the proposed work is that all the code words that are transmitted will not suffer the same channel impairments and with a hope that at least one will be received in good condition, similar to the concepts of time, space and frequency diversity. But, the proposed work makes use of code word diversity, in addition to space and time diversity for improving the BER performance of the system. To the best of our knowledge, this is the first work on multidimensional approach for code word diversity with QOSTBC. The proposed work makes use of code word diversity in addition to the space and time diversity. The proposed work transmits multiple code words simultaneously with the same power and bandwidth, without requiring feedback. Thus, the performance of the proposed work is better than the conventional schemes, thanks to the extra code word diversity.

The main contribution of the proposed scheme is the increase in the number of received signals by increasing the number of code words for a fixed number of symbols to be estimated. The following are the notations used in this paper. The superscripts $(.)^{*}, (.)^{T}$ and $(.)^{H}$ denotes complex conjugate, transpose and transconjugate (i.e. Hermitian transpose) respectively. Extraction of diagonal elements from a matrix is denoted by $diag(.)$. The Moore Penrose pseudo inverse of a matrix and Frobenius norm are denoted by $(.)^{\dagger}$ and $\|.\|_{F}$ respectively. The rest of the paper is organized as follows. System model is described in section 2. Performance analysis is presented in section 3. Results and discussions are presented in section 4. Finally, section 5 concludes the paper.

2.   SYSTEM MODEL

We have considered quasi-static, flat fading Rayleigh channel which remains constant during transmission of one block and changes for next. The transmitter of the proposed system consists of a Code word-Space-Time (CST) encoder, which spreads the complex information symbols from the symbol mapper, across three dimensions i.e. in space, time and code words. There are A transmitting antennas at the transmitter, which simultaneously transmits C QOSTBC code words in N time slots. The receiver consists of K antennas, which adds one more dimension and hence the received signal is a four dimensional signal. With the perfect channel state information at the receiver, the Code word-Space-Time decoder estimates the transmitted symbols. The block diagram of the transmitter and receiver of proposed code word diversity based QOSTBC scheme is given in Figure 1 and Figure 2.
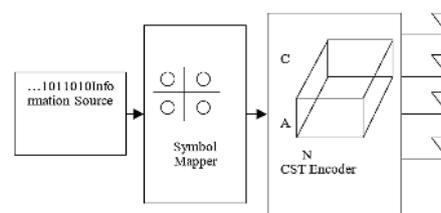

Figure 1. Transmitter of the proposed code word diversity based QOSTBC scheme
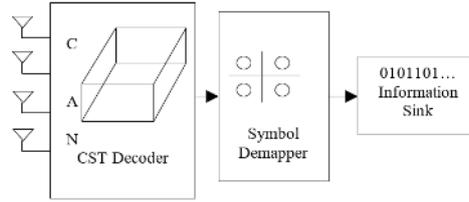
Figure 2. Receiver of the proposed code word diversity based QOSTBC scheme

The incoming bit stream (i.e. 2N bits per block) is mapped onto a complex constellation like QAM or QPSK and a symbol sequence S of length N is obtained and is given by (1) as

$$S = [s_1, s_2, ..., s_N] \in \mathcal{C}^{1 \times N} \tag{1}$$

These information symbols are spread across time, space and code words (3-D) by multiplying with a 3-dimensional information spreading matrix W and is given by (2) as

$$W = e^{j2\pi anc|ANC} \in \mathcal{C}^{A \times N \times C} \tag{2}$$

where A is the number of transmitting antennas, N is the number of time slots required for transmitting a code word, C is the number of code words that are simultaneously transmitted. The information spread matrix G is obtained by element wise product of W in (2) and S in (1) along the dimension N and is given by (3)

$$G_{AC}^N = W_{AC}^N S^{A \times N \times C} \tag{3}$$

The information spread matrix G is transmitted through A transmit antennas in N successive time slots. The transmitted signal X is obtained by element wise product of G and H along the dimension N and is given by (4) as

$$X_{AC}^N = G_{AC}^N H_{ACK}^N \tag{4}$$

where $H \in \mathcal{C}^{A \times N \times C \times K}$ is the channel matrix whose entries are independent and identically distributed with zero mean and unit variance. The received signal R is given by (5) as

$$R = X + Z \in \mathcal{C}^{A \times N \times C \times K} \tag{5}$$

where the noise $Z \in \mathcal{C}^{A \times N \times C \times K}$, whose entries are independent samples of a circularly symmetric complex Gaussian random variable with zero mean and unit variance. The symbols are decoded at the receiver by making use of matrix unfolding as follows. The unfolding is done across the plane C. For better understanding about the unfolding of a matrix, [25] can be referred. The unfolded received signal $R_{unfolded}$ and the unfolded spreading matrix is $W_{unfolded}$ given by (6) as

$$R_{unfolded} = \begin{bmatrix} R_{..1} \\ \vdots \\ R_{..c} \end{bmatrix} \text{ and }$$

$$W_{unfolded} = \begin{bmatrix} W_{..1} \\ \vdots \\ W_{..c} \end{bmatrix} \in \mathcal{C}^{ACK \times N} \tag{6}$$

The unfolded channel $H_{unfolded}$ matrix is given by (7) as

$$R_{unfolded} = \begin{bmatrix} H_{..1} \\ \vdots \\ H_{..c} \end{bmatrix} \in \mathcal{C}^{ACK \times N} \tag{7}$$

The unfolded received signal $X_{unfolded}$ is represented by (8) as

$$X_{unfolded} = G_{unfolded} .* H_{unfolded} \tag{8}$$

$$=[W_{unfolded} .* S] .* H_{unfolded} \tag{9}$$

$$= [W_{unfolded} .* H_{unfolded}] .* S \tag{10}$$

The transmitted symbols $\hat{S}$ can be estimated at the receiver using (10) and it is given by (11) as

$$\hat{S}=diag[[W_{unfolded} .* H_{unfolded}]^{\dagger} .* X_{unfolded}] \tag{11}$$

From (11), it can be understood that a blind joint symbol and channel estimation is possible using Alternate Least Square (ALS) technique.

3.   PERFORMANCE ANALYSIS

In this section, we have analyzed the performance of the proposed scheme and presented the equation for maximum diversity gain. In general, the Pair wise Error Probability (PEP) of the Maximum Likelihood (ML) estimator of the code word matrix is used as a measure of performance. The equation for the maximum diversity gain can be derived from PEP. The PEP of the ML estimator is as follows.

$$P(S \rightarrow \hat{S}|H) = Q \left(\|X - X\|_F / 2\sqrt{N_o/2}\right) \tag{12}$$

Due to space constraints, we skip the intermediate steps and present the final result of the derivation for maximum diversity gain d_{max} in (13) as

$$d_{max} = A \times C \times K \times N \tag{13}$$

The performance comparison between the conventional schemes and the proposed scheme is presented in Table 1.

Table 1 Comparison of diversity gain and code rate of the proposed code word diversity based QOSTBC with conventional schemes

Scheme	Diversity gain	Code rate
Zhu Chen code [25]	Full diversity $(M \times N)$	Full rate (Unity)
Gerard code [28]	Full diversity $(K \times P \times J \times min(M, R))$	< Full rate $\left(\dfrac{P}{R}\right)$
Proposed code word diversity	Full diversity $(A \times C \times K \times N)$	Full rate (Unity)

4.   RESULTS AND DISCUSSIONS

In this section, we have evaluated the error performance of the proposed code word diversity scheme in a quasi static flat fading channel by means of Monte Carlo simulations. The receiver is assumed to have perfect channel state information. The simulation parameters are shown in Table 2. Figure 3 compares the proposed code word diversity scheme with conventional unrotated QOSTBC, rotated QOSTBC, Zhu Chen code [25], Gerard code [28], MKRST [29] and DOVALS [30]. We adopt QPSK constellation for simulating the BER over SNR. The BER for paper [21] is evaluated for a block length of four (P=4), spreading length of one (J=1), with two transmitting (M=2) and two receiving antennas (K=2). For simulating paper [25], unrotated QOSTBC and rotated QOSTBC, we have considered four transmitting antennas and one receiving antenna as mentioned in the original papers. For simulating the proposed code word diversity scheme, we have assumed four transmitting antennas (A=4) for transmitting three code words (C=3) simultaneously and one receiving antenna (K=1). From the Figure 3, it is observed that BER of all the schemes decreases with increase in SNR. It is also clear that the proposed scheme outperforms the schemes of [25] and [28], due to spreading across code words in addition to time and space. The proposed scheme achieves a SNR gain of 6.7 dB at the BER of 10^{-5} over [25] and around 2 dB over [28]. The proposed scheme achieves a SNR gain of 2 dB at the BER of 10^{-5} over [29] and around 1.4 dB over [30].

In Figure 4, we show the effect of number of code words on the BER performance of the proposed code word diversity scheme. From the figure, it is observed that BER of all the schemes decreases with increase in SNR. For a given number of receive antenna, the BER decreases with increase in number of code words. Also, for a given number of code words, the BER decreases with increase in number of receive antenna. We found that the proposed scheme with $C=3$, $K=3$ outperforms proposed scheme with other values of C and K, due to increase in number of samples for estimating the same number of symbols, but at the cost of increase in computational complexity. The effect of constellation size on the BER performance of the proposed scheme is investigated for various values of M, with single receive antenna.

Table 2. Simulation parameters

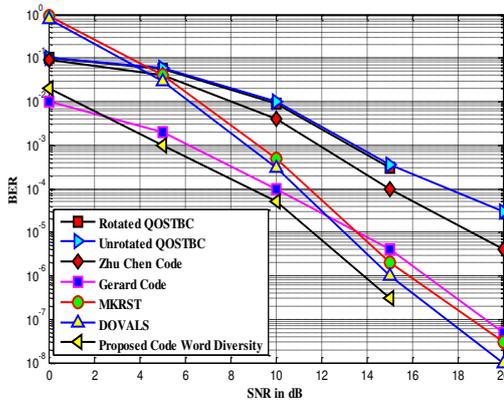| Parameter	Value
Modulation	QAM and QPSK
Noise	AWGN
Channel	quasi static flat fading
Number of receive antennas	1, 2, 3 and 4
Number of receive antennas	1, 2, 3 and 4

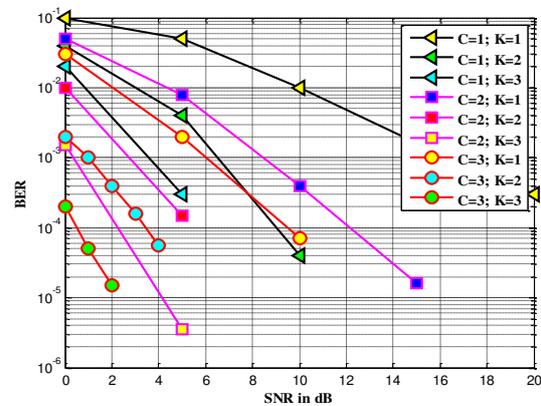Figure 3. Comparison of BER performance of proposed code word diversity based QOSTBC with conventional schemes

Figure 4. Influence of the number of code words C and number of receive antennas K on the BER performance of the proposed code word diversity based QOSTBC

Figure 5 depicts the influence of 128-QAM on BER with $C = 1, 2$ and 3. It is observed that the BER performance of the proposed scheme with 128-QAM improves with increase in SNR for all the C values considered. At a SNR of 10 dB, the BER values for $C = 1, 2$ and 3 are 9×10^{-2}, 4×10^{-2} and 2.8×10^{-2} respectively. From the figure, it is evident that the BER performance of a MIMO system improves with code word diversity (i.e. $C = 2$ and $C = 3$) when compared to the scheme without code word diversity (i.e. $C = 1$).

Figure 6 shows the impact of 64-QAM on BER with $C = 1, 2$ and 3. It is observed that the BER performance of the proposed scheme with 64-QAM improves with increase in SNR for all the C values considered. At a SNR of 10 dB, the BER values for $C = 1, 2$ and 3 are 7×10^{-2}, 2.8×10^{-2} and 2×10^{-2} respectively. From the figure, it is evident that the BER performance of a MIMO system improves with code word diversity (i.e. $C = 2$ and $C = 3$) when compared to the scheme without code word diversity (i.e. $C = 1$). On comparing Figure 5 and Figure 6, it is observed that the BER for $C=3$ with 128-QAM is 2.8×10^{-2} at 10 dB, whereas it is 2×10^{-2} for $C=3$ with 64-QAM. Therefore, it is clear that the BER performance of the proposed scheme improves with reduction in constellation size.

Figure 7 illustrates the effect of 16-QAM on BER with $C = 1, 2$ and 3. It is observed that the BER performance of the proposed scheme with 16-QAM improves with increase in SNR for all the C values considered. At a SNR of 10 dB, the BER values for $C = 1, 2$ and 3 are 5×10^{-2}, 1×10^{-2} and 3.5×10^{-3} respectively. From the figure, it is evident that the BER performance of a MIMO system improves with code word diversity (i.e. $C = 2$ and $C = 3$) when compared to the scheme without code word diversity (i.e. $C = 1$). On comparing Figure 6 and Figure 7, it is observed that the BER for $C=3$ with 64-QAM is 20×10^{-3} at 10 dB, whereas it is 3.5×10^{-3} for $C=3$ with 16-QAM. Therefore, it is clear that the BER performance of the proposed scheme improves with reduction in constellation size.

Figure 8 depicts the influence of 4-QAM on BER with C = 1, 2 and 3. It is observed that the BER performance of the proposed scheme with 4-QAM improves with increase in SNR for all the C values considered. At a SNR of 10 dB, the BER values for C = 1, 2 and 3 are 1×10^{-2}, 2.5×10^{-4} and 4×10^{-5} respectively. From the figure, it is evident that the BER performance of a MIMO system improves with code word diversity (i.e. C = 2 and C = 3) when compared to the scheme without code word diversity (i.e. C = 1). On comparing Figure 7 and Figure 8, it is observed that the BER for C=3 with 4-QAM is 3.5×10^{-5} at 10 dB, whereas it is 4×10^{-5} for C=3 with 16-QAM. Therefore, it is clear that the BER performance of the proposed scheme improves with reduction in constellation size. From the figures, it is clear that the BER performance of the proposed scheme degrades with increase in constellation size for given number of code words. Also it is observed that the BER performance improves with increase in number of code words for a given constellation size. From the figures it is clear that larger number of code words with smaller constellation size would be beneficial.
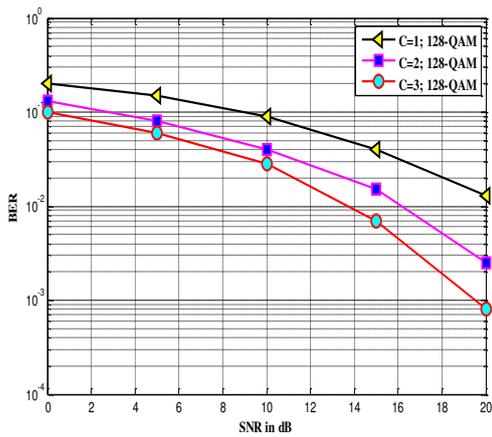

Figure 5. Influence of 128-QAM on the BER performance of the proposed code word diversity based QOSTBC for various values of C
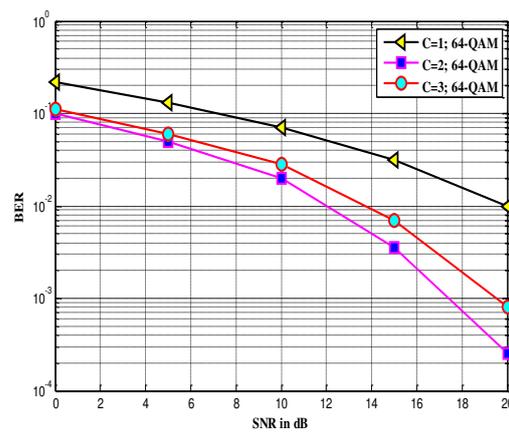

Figure 6. Influence of 64-QAM on the BER performance of the proposed code word diversity based QOSTBC for various values of C
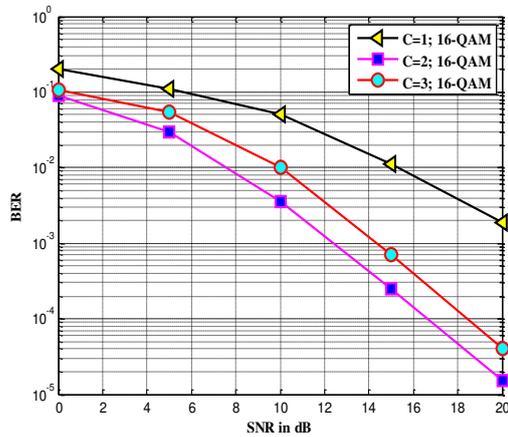

Figure 7. Influence of 16-QAM on the BER performance of the proposed code word diversity based QOSTBC for various values of C
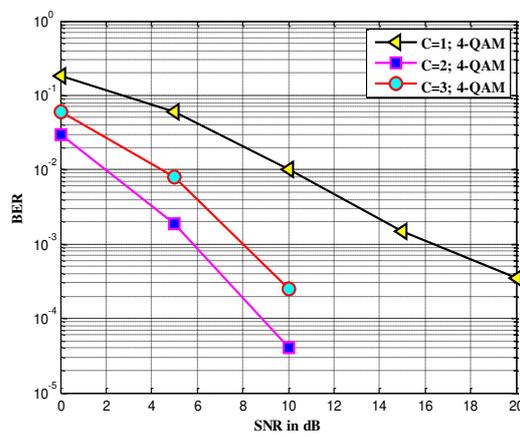

Figure 8 Influence of 4-QAM on the BER performance of the proposed codeword diversity based QOSTBC for various values of C

5. CONCLUSION

We have presented a novel code word diversity scheme for QOSTBC in this paper. From the simulated results, it is evident that the addition of code word diversity to the conventional space and time diversity, achieves a SNR gain of 6.7 dB at the BER of 10^{-5} over Zhu Chen code and around 2 dB over Gerard code and MKRST scheme, and around 1.4 dB over DOVALS scheme without increasing transmission power and bandwidth. The BER performance of the proposed code improves with increase in the number of code words,

across which the information symbols are spread, at the cost of increase in computational complexity. In future, the proposed work can be extended by considering frequency diversity as quasi orthogonal space-time-frequency code along with code word diversity. Also the performance of the proposed work can be improved by incorporating error correcting codes such as turbo and low density parity check codes.

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