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Performance Analysis of QOSTBC-OFDM System based on FEC codes

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ABSTRACT
The demands for high data rate are growing. If data rate increases ISI increases which makes the extract the information at the receiver nearly impossible. In order to overcome this problem, OFDM transmission system is used. The performance of OFDM system can be improved using multiple antennas at transmitted and/or received sides to provide diversity via exploiting Space Time Coding technique .However, the challenge which wireless communications system faces is errors due to channel impairments .High Bit Error Rate (BER) will degrade system performance, thus, requiring employing Forward Error Correction (FEC) to minimizing the errors. This research aims to improve MIMO-OFDM systems performance using free interference Quasi Orthogonal Space Time Code (QOSTBC) with FEC. We have investigated and compared the performance of QOSTBC-OFDM under QPSK, 16-QAM modulation using different types of FEC over Rayleigh fading channel in graphical form using MATLAB. FEC used are Reed Solomon code (RS), Convolutional code (CC) and concatenated RS-CC code. By comparing these coding techniques, we find that CC improves system performance better than RS due to RS corrects burst errors while CC corrects random errors .Also, we find that concatenated RS-CC codes have different characteristic in terms of treating the errors. Where CC is good for correcting random errors that occur due to noisy channel and RS can combat burst errors caused by CC decoder. Therefore, it improves system performance better than single coding scheme.

KEYWORDS: MIMO, OFDM, QOSTBC, AWGN, Rayleigh, RS, CC, QPSK, 16QAM

INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a very popular modulation technique used in high speed wireless communications due to its high data rate transmission ability with high bandwidth qualifications. OFDM enables robust multiple access method to conflict the impairment of wireless channels, particularly of multipath fading, delay spread and Doppler shifts. [1]. In an OFDM system the available bandwidth is partitioned into many narrowband sub-channels, that are orthogonal together, thus, OFDM is a multicarrier transmission technique; each carrier being modulated by a low data rate takes part of the transmission bandwidth [2].

Multiple-input multiple-output (MIMO) wireless systems consist of an antenna arrays at the transmitter and /or receiver. MIMO systems open a new dimension in reliable wireless communications that can upgrade the system performance significantly. The concept behind MIMO is that, the transmit antennas at one side and the receiver antennas at the other side are connected and combined in a manner such that the quality of the system (Bit Error Rate (BER) or data rate) improved [3]. Different transmission schemes have been suggested that use the MIMO channel in several ways, for instance, spatial multiplexing, space-time coding or beam forming [4].

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Space-time coding (STC) is a technique that guarantees extremely improved performance in wireless communications by utilizing multiple antennas at the transmitter and receiver. STC is implemented in both space and time domains. STC are broadly used in cellular communications and wireless local area networks (WLAN) [5].The orthogonal STBC (OSTBC) is that it exploits full power transmission for orthogonal codes so long as the transmitter diversity order is no more than two. For more than two transmit diversity, it has been shown that full rate power is not possible. Meanwhile, it is possible to deploy the STBC technology in way that full rate power transmission can be achieved. In such case, the codes are rather formed in a special orthogonal way. This is usually discussed as the quasi-orthogonal STBC. The QOSTBC offers the advantage of improved channel capacity and also improved BER statistics for a multi-antenna transmission [6].

The combination of OFDM and MIMO conveys a significant performance enhancement in terms of many parameters, including; data rate, minimized BER, and increased reliability. MIMO-OFDM technology achieves important considerations for the evaluation of 4G wireless communication systems [7].

Coding techniques is utilized for giving reliable information over the transmission channel. In coding techniques, the number of symbols in the source message is increased in order to simplify two essential goals at the receiver first, is error detection and the other is error correction to minimize the effect of noise and interferences in receiver side. In digital communications systems, coding techniques is a widely used term mostly indicating to the forward error correction (FEC). The main feature of FEC is that retransmission of data can often be averted [8]. In the paper, Reed-Solomon (RS) code, Convolutional code (CC) and concatenation RS-CC with interleaver are used to improve the performance of MIMO-OFDM system under multipath fading channels like AWGN in conjunction with Rayleigh fading channel

System Model:

The modeling of the MIMO-OFDM is as shown in the figure 1. The system performance in terms of BER is analyzed in MATLAB. In this model, at the transmitter side, the incoming bit stream is encoded via some channel coding techniques namely RS, CC and concatenated RS-CC. After encoding, the bits are interleaved to minimize burst errors. These bits are now mapped into a number of data symbols using modulation scheme QPSK and 16-QAM. The data from the modulator are then applied to QOSTBC encoder as 3x1 Dama QOSTBC and 4x1 Dama QOSTBC.

The output symbols from each transmitted antenna are transformed from serial to parallel and afterward distributed over the sub-channels. At this point, the DC carrier and Pilot Carriers are generated. The DC index is set to zero in order to decouple the data from the carrier. Pilot generator is produced using BPSK modulator. Then, 28 nulls in the upper indexes and 27 nulls in the lower indexes are added to the original 192 indexes to provide frequency guard bands. The total symbols are feed to an IFFT to bring the signal into the time domain, in order to generate an OFDM signal. Then cyclic prefix with length 32 is added to produce the required format. Finally, data are reshaped from parallel to serial form and transmitted over Rayleigh channel.

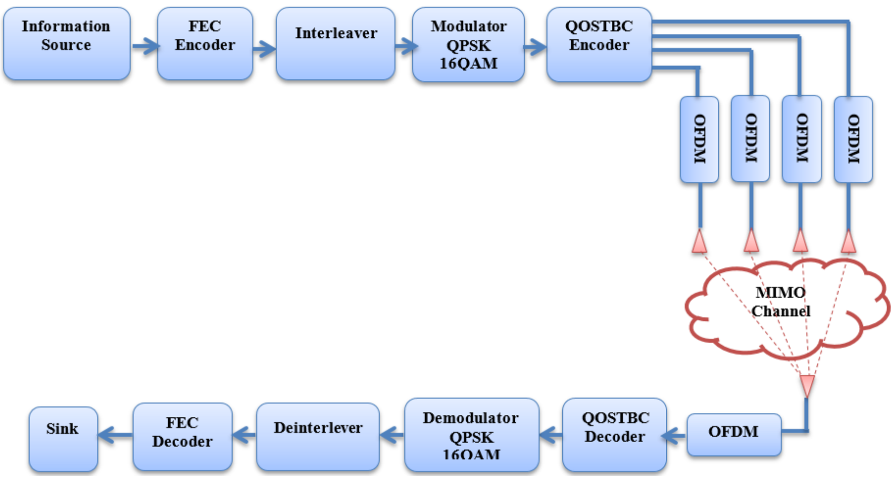


Fig. 1: System model of proposed QOSTBC-MMO-OFDM

At the receiver side, the received signal from the channel is converted from serial to parallel, and the following characteristics are removed; cyclic prefix, DC carrier and pilots. The data is then fed to FFT and decoding of STBC is achieved by applying MRC. The incoming symbols are de-mapped into bits using QPSK or 16-QAM demodulators. The sequences now are bits, thus using de-interleaving to recover the original data sequence. The incoming bit stream from the de-interleaver is decoded to extract the original transmitted data using (Berlekamp–Massey decoding algorithms for RS, Viterbi algorithms for CC, both algorithms for concatenated RS-CC). Finally, to calculate the BER for each SNR, the received and transmitted bits are compared and estimating the ratio of bits in errors to the total transmission bits. The details regarding the sub-blocks are as explained below:

I-Reed Solomon Code:

The Reed Solomon codes (RS) are the very effective non-binary block codes that used in digital communications. RS code work with symbols that consist of many bits. RS codes are utilized when burst error occurs because of correction capability of these codes is achieved on the symbol level. A given RS code is denoted by *(n, k)* code. The parameter *n* refers to the codeword length in terms of the number of symbols. The parameter *k* refers to the number of message symbols in the codeword. The number of parity check symbols added is *(n-k)*. The error-correcting capability of the code is *t= (n-k)/2*. The minimum distance of RS code is *(n-k+1)* [9].

II-Convolutional code:

Convolutional code (CC) was first introduced by Elias in 1955 as stand by to block codes. CC contain memory, the outputs of convolutional encoder at any instant depend on input bits and previous input bits. This is differing with block codes that don't have memory [10]. Encoding of CC can be accomplished by using shift registers. The block diagram of convolution encoder is illustrates in figure (2) below

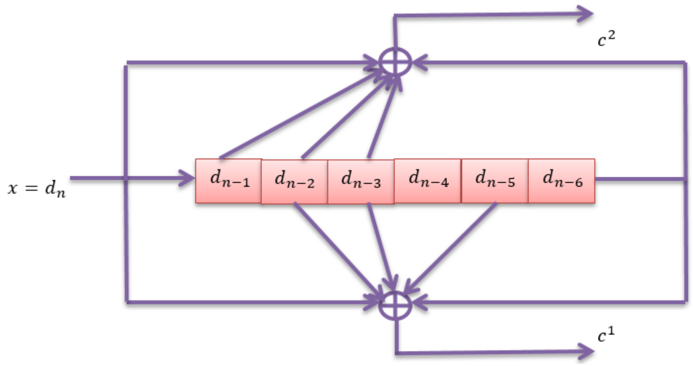


Fig. 2: Convolution encoder with constraint length K =7 and bit rate R =1/2

Where *C* is number of output bits, x is number of input bits entering at a time, *m* is number of stages of shift register, *L* is number of bits in a message sequence, *j* is number of modulo 2 adders, Constraint Length is $K = (m + 1)$ digits and Bit Rate is $R = x / c$.

III-Concatenated Code:

Concatenation of code is very helpful method that leads to the construction of highly efficient code by utilizing two or more codes of relatively small size and complexity. In this work, we use serial concatenated two codes, one non-binary code (RS) and one binary code (CC).The non-binary code is connect to the information source (outer code) and the binary code (inner code) is connected directly to the transmission channel.

IV-Interleaver:

Interleaving data is a widely applied technique in digital communications system and date storage. An interleaver takes a specified sequence of data and exchanges their positions, arranging them in a different time order. The essential objective of an interleaver is to randomize the information succession. At the point when utilized against burst errors, interleaver are prepared to transform error patterns that contain long serial sequences of erroneous data into a random error pattern, thus distributing errors amongst many code vectors. Burst errors are characteristic the wireless channel. In general, data interleaver can be categorized into block, convolutional, random, and linear interleaver [11], [12].

V-Symbol Mapping and De-Mapping:

After encoder, bit stream was mapped (modulated), converting bits into complex symbols. At the receiving end, vice-versa de-mapping (demodulation) technique was used to recover bits. Under this study, Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) based symbol mapping/de-mapping schemes were used. [13].

VI-Orthogonal frequency division multiplexing:

Orthogonal frequency division multiplexing **(**OFDM) belongs to a group of transmission techniques called multicarrier modulation, which depend on the idea of partitioning a single high data rate into many parallel lower data rate and modulating every stream on separate carriers often called subcarriers [8]. OFDM is appealing techniques for wireless high-rate information transmission with high bandwidth efficiency because of minimizing impact over frequency selective fading channels .OFDM have a point of interest in that modulation and demodulation can be done by utilizing the Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) operations, which are computationally productive. Other important advantages are robustness to channel fading, immunity to impulse interference, and capability of handling strong multipath fading [1]. In OFDM system, the number of sub-carriers is not bounded by the spectral bandwidth only, but also by the IFFT size, that determine the complexity of the system. The higher IFFT size lead to more complex OFDM system, thus a higher number of sub-carriers can be used and higher data transmission rate done. The changing in modulation types can vary the data rate and Bit Error Rate (BER) [13]. The way to OFDM is keeping up orthogonality of the carriers. If the inner product of two signals is zero over a symbol period, then these two signals are said to be orthogonal to each other. Also, when two signals with frequencies that are integer multiples of a common frequency can fulfill this criterion. OFDM system performance can be improved by adding to transmitting signal the following parameters: pilot signal is used in channel estimation in wireless channels and cyclic prefix (CP) to reduce the effect of Inter Symbol Interference (ISI) in OFDM signal [14], [15].

VII-Quasi Orthogonal Space Time Block Code (QOSTBC):

In complex orthogonal design, cannot get full rate and full diversity STBC for more than two antennas. Quasi-orthogonal design provides full rate and partial diversity. Full rate is very important for low SNR and high BER, whereas full diversity is the right choice for high SNR and low BER [16].

In Quasi-orthogonal structure, the columns of the encoding matrix are partitioned into groups. The columns inside each group are not orthogonal to each other but those from various groups are orthogonal to each other. By utilizing quasi-orthogonal design, pairs of transmitted symbols can be decoded independently. The diversity in QOSTBC is loss due to some coupling terms between the estimated symbols. The block structure is used x_A , x_B and the resulting known as extended Alamouti QOSTBC, for four transmit antennas:

$$x_A = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \quad (1a)$$

$$x_B = \begin{bmatrix} x_3 & x_4 \\ -x_4^* & x_3^* \end{bmatrix} \quad (1b)$$

$$x_{ABBA} = \begin{bmatrix} x_A & x_B \\ x_B & x_A \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ x_3 & x_4 & x_1 & x_2 \\ -x_4^* & x_3^* & -x_2^* & x_1^* \end{bmatrix} \quad (2)$$

The channel matrix $h = [h_1 \; h_2 \; h_3 \; h_4]^T$, noise and interference are added at the receiver, assuming the transmission matrix is x_{ABBA} and one receiver antenna, then the received signals for four time instants is

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ x_3 & x_4 & x_1 & x_2 \\ -x_4^* & x_3^* & -x_2^* & x_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \quad (3)$$

We can rewrite equation (3) to find (EVCM) as:

$$\begin{bmatrix} y_1 \\ y_2^* \\ y_3 \\ y_4^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \\ n_3 \\ n_4^* \end{bmatrix} \quad (4)$$

Hence

$$H_{v4} = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix}$$

By applying MRC to find the receiver symbols

$$H_{v4}^H . y = H_v^H . H_{v4} . x_{ABBA} + H_{v4}^H . n$$
$$= D_4 \, x_{ABBA} + H_{v4}^H . n$$

The detection matrix $D_4 = H_{v4}^H . H_{v4}$ is used to decode the received signal. For the OSTBC design the detection matrix is diagonal, this enables the use of simple linear decoding, but in the QOSTBC design the detection matrix is non-orthogonal, as shown in equation(5)

$$D_4 = H_{v4}^H . H_{v4} = \begin{bmatrix} \alpha & 0 & \beta & 0 \\ 0 & \alpha & 0 & \beta \\ \beta & 0 & \alpha & 0 \\ 0 & \beta & 0 & \alpha \end{bmatrix} \quad (5)$$

Where

α : represent the channel gains

β : represent the interference from the neighboring signals

$$\alpha = |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \quad (6a)$$

$$\beta = h_1 h_3^* + h_2 h_4^* + h_1^* h_3 + h_2^* h_4 \quad (6b)$$

The interference part β in the detection matrix D_4 will degrade system performance; furthermore, complex decoding schemes required to detect and estimate received signals.

Similarly, for three transmitted antennas, the transmission matrix can be derived by discarding the last column of equation (2) thus:

$$X_3 = \begin{bmatrix} x_1 & x_2 & x_3 \\ -x_2^* & x_1^* & -x_4^* \\ x_3 & x_4 & x_1 \\ -x_4^* & x_3^* & -x_2^* \end{bmatrix} \quad (7)$$

By using the same procedure for four transmitted antenna, we can find the detection matrix of three transmit antenna as follow:

$$D_3 = H_{v3}^H . H_{v3} = \begin{bmatrix} \alpha & 0 & \beta & 0 \\ 0 & \alpha & 0 & \beta \\ \beta & 0 & \alpha & 0 \\ 0 & \beta & 0 & \alpha \end{bmatrix}$$

Where EVCM defined as:

$$H_{v3} = \begin{bmatrix} h_1 & h_2 & h_3 & 0 \\ h_2^* & -h_1^* & 0 & -h_3^* \\ h_3 & 0 & h_1 & h_2 \\ 0 & -h_3^* & h_2^* & -h_1^* \end{bmatrix} \quad (8)$$

The channel gain and interference part are:

$$\alpha = |h_1|^2 + |h_2|^2 + |h_3|^2 \quad (9a)$$

$$\beta = h_1 h_3^* + h_1^* h_3 \quad (9b)$$

The detection matrix D_4 of the QOSTBC can be reformed by eigenvalue feature as:

$$D_4 . V - V . D = 0 \quad , \; D = \gamma I \quad (10)$$

Where γ is the eigenvalue operator, the solution of equation (10) produces eigenvalues matrix D and eigenvectors matrix V of detection matrixD_4, so that to fulfill the $D_4 . V = V . D$ as follows

$$D = \begin{bmatrix} \alpha+\beta & 0 & 0 & 0 \\ 0 & \alpha+\beta & 0 & 0 \\ 0 & 0 & \alpha-\beta & 0 \\ 0 & 0 & 0 & \alpha-\beta \end{bmatrix} \quad (11)$$

$$V = \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \quad (12)$$

The new channel matrix can be defined as:

$$H_4 = H_{v4} . V = \begin{bmatrix} h_1 + h_3 & h_2 + h_4 & h_3 - h_1 & h_4 - h_2 \\ h_2^* + h_4^* & -h_1^* - h_3^* & h_4^* - h_2^* & h_1^* - h_3^* \\ h_1 + h_3 & h_2 + h_4 & h_1 - h_3 & h_2 - h_4 \\ h_2^* + h_4^* & -h_1^* - h_3^* & h_2^* - h_4^* & h_3^* - h_1^* \end{bmatrix} \quad (13)$$

$H_4^H . H_4$ is diagonal matrix which can provide simple linear decoding, because of the channel matrix characteristic is orthogonal. The encoding matrix X_{new} can be derived according to the channel matrix H_4, as following

$$x_{new} = \begin{bmatrix} x_1 - x_3 & x_2 - x_4 & x_3 + x_1 & x_4 + x_2 \\ x_4^* - x_2^* & x_1^* - x_3^* & -x_4^* - x_2^* & x_1^* + x_3^* \\ x_1 + x_3 & x_2 + x_4 & x_1 - x_3 & x_2 - x_4 \\ -x_2^* - x_4^* & x_1^* + x_3^* & x_4^* - x_2^* & -x_3^* + x_1^* \end{bmatrix} \quad (14)$$

Another simplest method to find x_{new} by using equations ($1a$,$1b$) as follow:

$$x_{new} = \begin{bmatrix} x_A - x_B & x_A + x_B \\ x_A + x_B & x_A - x_B \end{bmatrix} \quad (15)$$

The relationship (14) is called Dama QOSTBC. In a similar way, we can derive the detection matrix for three transmitted antennas using identical procedure above to discard the interference part. The resultant new channel matrix and QOSTBC encoding matrix be given as in following [17].

$$H_3 = H_{v3}.V = \begin{bmatrix} h_1 + h_3 & h_2 & h_3 - h_1 & -h_2 \\ h_2^* & -h_1^* - h_3^* & -h_2^* & h_1^* - h_3^* \\ h_1 + h_3 & h_2 & h_1 - h_3 & h_2 \\ h_2^* & -h_1^* - h_3^* & h_2^* & h_3^* - h_1^* \end{bmatrix} \quad (16)$$

And

$$x_{3new} = \begin{bmatrix} x_1 - x_3 & x_2 - x_4 & x_3 + x_1 \\ x_4^* - x_2^* & x_1^* - x_3^* & -x_4^* - x_2^* \\ x_1 + x_3 & x_2 + x_4 & x_1 - x_3 \\ -x_2^* - x_4^* & x_1^* + x_3^* & x_4^* - x_2^* \end{bmatrix} \quad (17)$$

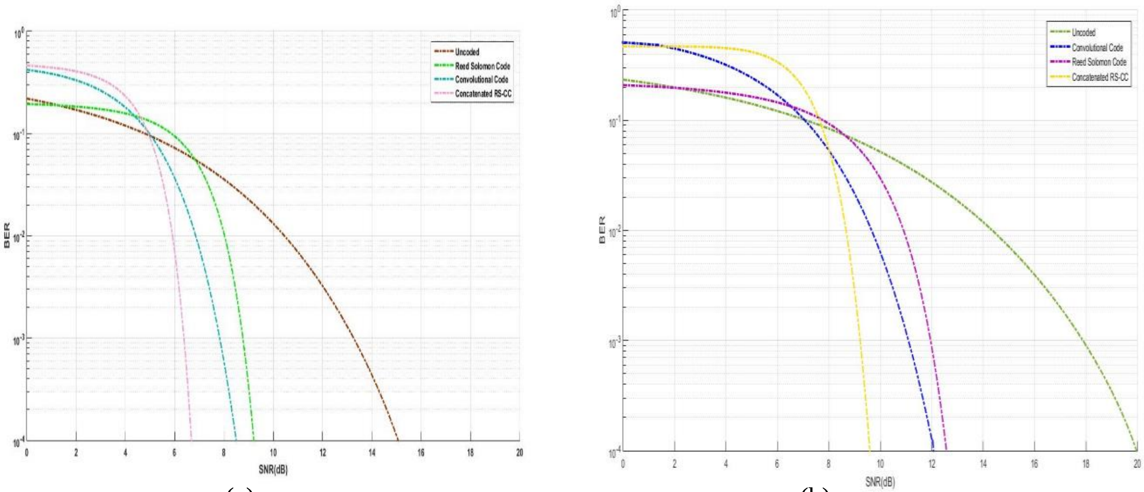
RESULTS AND DISCUSSIONS

The MIMO-OFDM model is simulated for different digital modulation schemes (QPSK, 16-QAM) under Rayleigh channel with the help of MATLAB. The performance parameter in terms of BER of MIMO-OFDM systems is determined and compared with different channel coding technique. The simulation parameters used for simulation is given in Table 1.

Table 1: Simulation Parameters

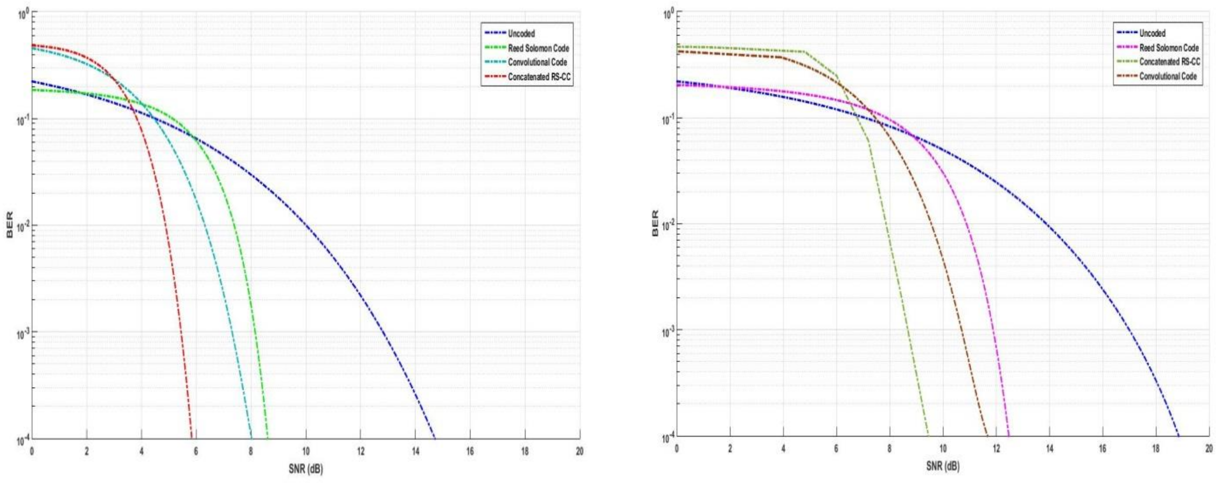
Parameters	Values
IFFT/FFT Size	256
Number of active sub-carriers	192
Cyclic prefix length	32
Number of guard bands	28 high ,27 low
Number of pilots	8
DC null	1
Modulation schemes	QPSK ,16 QAM
Channel model	Rayleigh fading channel
Channel Coding	CC with constraint length = 7 , rate=1/2 and Interleaving
	RS (63, 31) code over GF (2^6) and interleaver
	concatenated (RS-CC) and interleaver
Space Time Coding type	Dama QOSTBC
Antennas transmitted Power	Equally
Receiver detection schemes	MRC

Figures 3 and 4 presents a comparison of all proposed systems with uncoded QOSTBC-OFDM system, it is clear that the system with CC gives better performance than RS, because CC deals with bits due to random errors, whereas, RS deals with burst errors. Also, concatenated RS-CC can be utilized to minimize the overall errors when compared with single coding scheme, thus it gives a better performance.



(a) (b)

Fig. 3: BER Performance Comparison of 3x1 Dama QOSTBC–OFDM using RS, CC and concatenated (RS-CC) code (a) for QPSK ,(b) for 16-QAM



(a) (b)

Fig. 4: BER Performance Comparison of 4x1 Dama QOSTBC–OFDM using RS, CC and concatenated (RS-CC) code (a) for QPSK ,(b) for 16-QAM

Also, for more details about our results, tables 2 and 3 shows that BER is decreased according to FEC types and number of transmitted antennas.

Table 2: 3x1 Dama QOSTBC-OFDM system performance compared with coded system

Modulation used	BER	SNR for uncoded system (dB)	SNR for Proposed System (dB)		
			RS	CC	RS-CC
QPSK	10^{-4}	15	9.199	8.484	6.669
16-QAM	10^{-4}	19. 92	12.56	12.08	9.541

Table 3: 4x1 Dama QOSTBC-OFDM system performance compared with coded system

Modulation used	BER	SNR for uncoded system (dB)	SNR for Proposed System (dB)		
			RS	CC	RS-CC
QPSK	10^{-4}	14.71	8.61	8	5.818
16-QAM	10^{-4}	18.79	12.34	11.6	9.12

Conclusion:

The results presented in this paper compared the performance of STBC-MIMO-OFDM systems in terms of BER versus SNR using different FEC codes. Simulations conducted via two types of STBC, three types of FEC codes and two types of modulation schemes, using MATLAB. It can be concluded that the overall system with FEC performed much better than the system without FEC in terms of the criteria mentioned above. The BER performance of all systems investigated with CC outperforms RS, because CC deals with random bits in error, whereas RS deals with symbols in error. The simulation results confirmed the outperformance of the concatenated codes when compared with individual codes, this is due to its deals with both random bit errors and burst bit errors. Furthermore, we concluded that system performance of QPSK modulation was better than 16-QAM modulation because of the spacing of the constellation points. When using QPSK modulation, each two bits makes one modulated symbol thus, the total four types of modulated symbols. When using 16-QAM modulations, each four bits now makes one modulated symbol and the total sixteen types of modulated symbols. With reference to spectral efficiency, 16-QAM has 4 bit/sec/Hz whereas QPSK has 2 bit/sec/Hz, hence 16-QAM better than QPSK.

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