

Performance Investigation of Interleaving and BCH code in MIMO System

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ABSTRACT: The technology of MIMO mitigates the ISI in wireless systems by providing spectral efficiency and high bit rate. Generally, channel fading increases BER, therefore interleaving with channel coding is utilized to enhance the performance of wireless communication. In this study, matrix interleaving along with BCH code is employed to enhance the system performance for different modulation techniques using STBC in MIMO diversity system. The simulation and modeling are applied in MATLAB environment, and the result is compared among the BER performance of Uncoded, BCH code, and BCH code & Interleaving of MIMO system.

KEYWORDS: BCH, STBC, MIMO, Interlever, BER.

I. INTRODUCTION

The main aspects of modern wireless communication systems have the ability to support high data rate transmission and reliability Vo, et al. 2015 [1]. The reliability achieved through transmit and receive messages over error prone channels such as Rayleigh fading channel without or with the least amount of errors occurs Al-Barrak, et al. 2017 [2]. Space Time Block Code (STBC) scheme improves link reliability by using multiple antennas at the receiver and transmitter communication link which called Multi Input Multi Output (MIMO) technology Bhaskar and Kandpal 2017 [3]. STBC works on improving system capacity and spectral efficiency by expanding transmission symbols on both time and space domain Lari et. al. 2017[4], Gupta et. al. 2013 [5].

Furthermore, Forward Error Correction (FEC) technique, known as Bose, Ray-Chaudhuri (BCH) codes employed to minimize bit error rate in wireless fading channel Al-Barrak, et al. 2017 [2], Mohamed, et al. 2017 [6]. BCH encoder at transmitter works on making changes in the structure of information parity by adding redundancy at the end of the transmit data. BCH decoder at the receiver will exploit redundancy to retrieve the original data, although errors may occur in the sequences of receiving data Al-Barrak, et al. 2016 [7].

There are many researchers concentrated on study improvement provided when BCH code used. The important role of BCH codes in applications of the wireless communication system is presented by Ding, et al. 2017 [8] has been shown that BCH code one of the best FEC technique regarding the ability to correct errors. Also, it calculated the minimum distances could be employed as a primitive BCH code. The mathematical calculations for implementing BCH encoder and decoder presented by Azinović, et al. 2016 [9]. The calculations measured for different ability to correct errors and when data symbols transmitted over a noisy wireless channel. Bhattacharyya, et al. 2016 [10] using the BCH coded system make it more resistant to interference and permits to coverage larger distance by using lower power. Al-Barrak, et al. 2016 [7] have shown that using BCH codes in multipath propagation channel with low values to both redundancy and ability to correct error gives better performance with respect to high values. Additional, BCH codes give better performance under the same condition compared with Reed Solomon (RS) codes.

Furthermore, some researches have been shown interesting towards analyzing the performance of various FEC techniques when integrated with MIMO technology. Wadday, et al. 2012 [11] two different coding techniques (Convolutional and Turbo code) adopted to improve performance STBC. The obtained result shows there is a coding gain about (3-4.5 dB and 2.7-3.8 dB) for $BER=10^{-5}$ compared with uncoded model for Convolutional and Turbo code respectively. Evaluated results investigated based on 3x4 and 4x4 MIMO antennas with BPSK and QPSK modulation. Kushwah, et al. 2014 [12] have been investigated performance communication system combine between convolution

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code and MIMO technology. Their results calculated for various modulation schemes in Rayleigh fading channel and show increase in system efficiency through reduced BER.

In the above studies, authors did not take into their consideration the role of interleaving process when utilizing with FEC techniques. Interleaving is a type of signal processing technique used adjacent with coding to minimize the BER Wu 2016 [13]. Interleaving minimizes burst error's effect which may be occurred during transmission by spreading bits sequences in a bit stream Sawarkar et al. 2016[14]. Dagur et al. 2016 [15] used convolutional codes with interleaving for error correction. They analyze proposed system performance of 4x2 MIMO diversity for BPSK, QPSK and QAM modulation techniques with respect to three different schemes (convolution encoder, interleaving, and encoder with interleaving). Obtain result showed that using an encoder with interleaving gives the minimum error rate for both BPSK and QPSK than other schemes. Likewise, Pandayas, et al. 2013 [16], Chaturvedi, et al. 2012 [17] have been analyzed RS codes with interleaving of a MIMO system for QAM modulation. Also, they have been proved that BER reduces when using RS codes with interleaving.

In this paper, BCH codes are used adjacent with interleaver to improve the performance of MIMO communication system. The performance will examine with different levels of modulation in the case of different numbers of receiver/transmitter antennas. Comparisons based on BER values when transmission being over Rayleigh fading channel will be made for three different schemes: Uncoded, BCH code, and BCH code & Interleaving.

II. SYSTEM MODEL

Fig. 1 presents system scheme of the model which has been proposed in this paper.

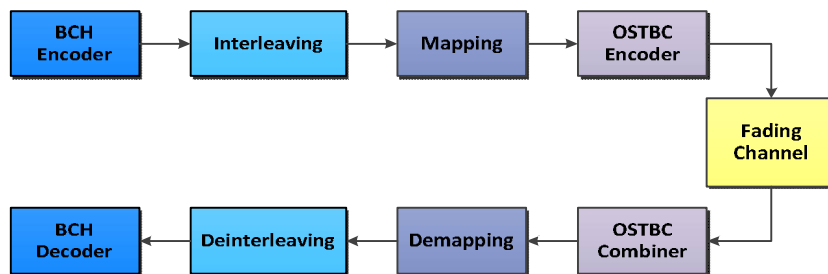


Fig.1. System Model

This system includes message's symbols ($K=11$) which are taking as inputs to the channel coding (BCH Code has codeword $N = 15$ symbols). The symbols will be mapped onto different types of digital modulation and forwarded to the OSTBC encoder, before that, the symbols are handled in interleaver block. OSTBC is the space time coding techniques where information is divided into multistreams that transmitted by N_t antennas simultaneously (N_t used in simulation = 2,3,4). Then, data received by multiple antennas up to 8 antennas. Fig. 2 displays the structure of STBC encoder.

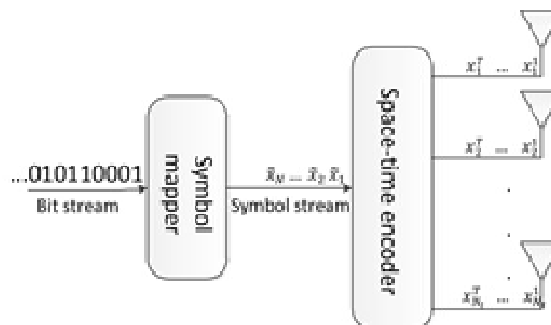


Fig.2. STBC Encoder

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The OSTBC encoder output is a codeword matrix X with $N_t \times T$ dimension, T is the time slot as presented below:

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

Then signals transmit from OSTBC encoder to the fading channel and pass to the receiver part. The channel's matrix can be found using Eq. 2:

$$H = \begin{bmatrix} h_{1.1} & \dots & h_{i.1} \\ \vdots & \ddots & \vdots \\ h_{1.j} & \dots & h_{i.j} \end{bmatrix} \dots \quad (2)$$

Where $h_{i,j}$ represents the path gain from i^{th} transmit to j^{th} receive antennas over the t^{th} time slot. At the receiver part, reverse processors are used to retrieve the required signal. The received signal R expressed:

$$R = \sqrt{\frac{E_x}{N_o}} Hx + z \dots \quad (3)$$

Where z represents noise vector, z presumed to be zero-mean circular symmetric complex Gaussian, E_x represents the energy of transmitted signals and N_o represents the additive noise.

III. BCH CODE

BCH code is a type of error correcting cyclic codes. The parameters of BCH code n , k and t are codeword length, message length, and errors that could be corrected respectively. There is a binary BCH code for positive integers m and t [$m \geq 3$ and $t < 2^{(m-1)}$] with the following properties:

Block length: $n = 2^m - 1$

No. of parity check digits: $n - k \leq mt$

Minimum distance: $d_{min} \geq 2t + 1$

Galois field $GF(2^m)$ specifies the roots of generator of BCH code polynomials. Assume that α is a primitive element and $g(x)$ is the lowest degree of generator polynomial over Galois field. $g(x)$ has the following roots: $\alpha, \alpha^2, \alpha^3, \dots, \alpha^{2t}$. This generator $g(x)$ constructed from the least common multiple (LCM) of minimal polynomial $\phi_i(x)$ as shown in Eq. (4).

$$g(x) = LCM\{\phi_1(x), \phi_2(x), \dots, \phi_{2t}(x)\} \dots \quad (4)$$

A. BCH Encoder

The input message block of length k takes by the encoder to obtain a codeword of length n . BCH encoder will apply the following procedure to get a codeword [9]:

- 1) Shift the message $m(x)$ by $n-k$ positions to the right using the following expression (5):

$$x^{n-k} m(x) \dots \quad (5)$$

Where $m(x)$ can be expressed in Eq. (6) below:

$$m(x) = m_0 + m_1x + m_2x^2 + \dots + m_{k-1}x^{k-1} \dots \quad (6)$$

- 2) Calculate the remainder $r(x)$, which represents parity check, as depicted in Eq. (7):

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$$r(x) = x^{n-k} m(x) \text{ mod } g(x) \dots (7)$$

3) The codeword will obtain by adding the remainder $r(x)$ to the message shift, as shown below:

$$c(x) = r(x) + x^{n-k} m(x) \dots (8)$$

B. BCH Decoder

There are three steps for decoding BCH code [6, 9]:

- 1) Evaluate the syndrome S_i from the received signal by substituting roots $\alpha, \alpha^2, \dots, \alpha^{2t}$ into the received polynomial $R(x)$.

$$S_i = R(\alpha^i) \dots (9)$$

Where received vector is the sum of transmitted codeword $c(x)$ and transmission errors $e(x)$:

$$R(x) = c(x) + e(x) \dots (10)$$

Assume that $e(x)$ has q errors at locations $x^{(j_1)}, x^{(j_2)}, \dots, x^{(j_q)}$, as below:

$$e(x) = x^{j_1} + x^{j_2} + \dots + x^{j_q} \dots (11)$$

Where $0 \leq j_1 < j_2 < \dots < j_q < n$. From (9) and (11) we get the following expression:

$$S_i = \sum_{u=1}^q (\alpha^{j_u})^i \dots (12)$$

For $1 \leq i \leq 2t$, where the components of syndrome are elements in the $GF(2^m)$.

- 2) Determine location $\sigma(x)$ according to syndrome values S_1, S_2, \dots, S_{2t} . There are two methods for finding $\sigma(x)$: Peterson's algorithm and Berlekamp-Massey algorithm.
- 3) Find the number of $\sigma(x)$ $\beta_1, \beta_2, \dots, \beta_q$ by calculating the roots of $\sigma(x)$ and correct the errors in $r(x)$ using the Chien search.

IV. INTERLEAVING

One of the most popular methods to overcome burst errors which is a standard technique in signal processing of communication system. The concept of interleaving includes that the symbols are taken from an input and generate the corresponding symbols at the output in a diverse sequential order.

Different types of interleaver are classified, usually known as block and convolutional. Block interleaver also categories into two kinds; Matrix and Random interleaver. In this study, matrix interleaver will be applied. In matrix approach, writing the input data is arranged as a matrix in rows of memory, and the output is read as columns.

V. SPACE TIME BLOCK CODING

The STBC is one of the techniques which is employed in wireless communication to transmit a number of a replica of symbol streams through multiple antennas to avail the different received versions of the signal to get better reliability of the transmitted signal.

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A) Encoder

In a STBC system, the symbol is encoded in a matrix X; this matrix has $T \times N_t$ dimensions. T represents time slot, and N_t represents the No. of transmit antennas.

Alamouti was improved a complex OSTBC - for two transmitting antennas, x_1, x_2 are encoded with the following codeword matrix of space time Kabir, et al.[18],andChaturvedi, et al. 2012 [19]:

$$X_2 = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \dots \dots \dots (13)$$

The two transmitting antennas will transmit the Alamouti encoded signal over two periods of the symbol. Firstly, the symbols (x_1, x_2) will instantaneously transmit. Secondly, x_1^* and $-x_2^*$ will be sent from second and first antenna respectively.

When $N_T \geq 3$, it is identified that there are not exist a complex space time code which achieves the goals of two design of attaining the maximum coding rate at the same time. Taking into account the below expressions for $N_T = 3$ and $N_T = 4$:

$$X_3 = \begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \end{bmatrix} \dots \dots \dots (14)$$

$$X_4 = \begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & x_3 & -x_2 & x_1 & x_4^* & x_3^* & -x_2^* & x_1^* \end{bmatrix} \dots \dots \dots (15)$$

The code rate of an STBC can be calculated by the following expression:

$$R = \frac{N}{T} \dots \dots \dots (16)$$

Where N and T are the no. of symbols, and the time slot respectively.

B) Decoder

At the receiver part, the variety of examinations depend on the Maximum likelihood (ML) signal detection. ML for Alamouti STBC supposes that channel gains, $h_1(t)$ and $h_2(t)$, are time invariant over two sequential symbol periods, as shown Eq. 17 and Eq. 18:

$$h_1(t) = h_1(t + T_s) = h_1 = |h_1|e^{-j\theta_1} \dots (17)$$

and

$$h_2(t) = h_2(t + T_s) = h_2 = |h_2|e^{-j\theta_2} \dots (18)$$

$|h_i|$ and θ_i represent capacity gain and rotation phase through the two periods, $i = 1, 2$, and y_1, y_2 represent the received signals at time t and $t + T_s$, respectively,

$$y_1 = h_1x_1 + h_2x_2 + z_1 \dots (19)$$

$$y_2 = h_1x_2^* + h_2x_1^* + z_2 \dots (20)$$

z_1 and z_2 represent the additive noise. Taking the complex conjugation of y_2 :

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$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2^* \end{bmatrix} \dots (21)$$

Multiplying both parts of Eq. 21 by the channel matrix Hermitian transpose, will get the following equation:

$$\begin{bmatrix} \tilde{y}_1 \\ \tilde{y}_2 \end{bmatrix} = (|h_1|^2 + |h_2|^2) \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \tilde{z}_1 \\ \tilde{z}_2 \end{bmatrix} \dots (22)$$

The Eq. 22 indicates that x_1 and x_2 determined separately, which decreases the decoding complexity of original ML decoding algorithm from $|C|^2$ to $2|C|$, C denotes a constellation of symbols (x_1, x_2).

$$\tilde{x}_{i,ML} = Q \left(\frac{\tilde{y}_i}{|h_1|^2 + |h_2|^2} \right), \quad i = 1, 2 \dots (23)$$

$Q(\bullet)$ represents a slicing function that defines a transmit symbol of the specified constellation set.

Eq. 24 is denoted the input-output relation of STBC for various codewords and a various number of receiving antennas:

$$\tilde{y}_{eff} = \sqrt{\frac{E_x}{N_t N_o}} \sum_{i=1}^{N_t} |h_i|^2 I_{N_t} x_{eff} + \tilde{z}_{eff} \dots (24)$$

Utilizing the Eq. 24, the ML can be executed

$$\tilde{x}_{i,ML} = Q \left(\frac{\tilde{y}_{eff,i}}{\sqrt{\frac{E_x}{N_t N_o}} \sum_{j=1}^{N_r} |h_j|^2} \right), \quad i = 1, 2, \dots, N_t \dots (25)$$

VI. SIMULATION RESULT

The results of the simulation are executed in MATLAB environment for MIMO systems with three different schemes: Uncoded, BCH code, and BCH code & Interleaving. The simulation parameters implemented in this model are shown in the Table (□):

Table □: Simulation Model Parameters

Parameter	Value
BCH Code Rate	n=15 , k=11
Interleaving	30x30
Channel	Rayleigh Fading Channel
Doppler shift	0.01 Hz
Channel Encoder	1 (2x2 MIMO), ½ (3x3, 4x4, 4x8 MIMO)
Modulation Schemes	BPSK, QPSK, 16QAM
No. of transmitting and receiving antennas	2x2, 3x3, 4x4, 4x8

In this study, different digital modulations have been used (BPSK, QPSK, and 16-QAM) to investigate performance MIMO communication system when using FEC technique (BCH) besides interleaving process over Rayleigh channel. Furthermore, proposed model implemented with different numbers of transmitting and receiving antenna.

In **Fig. 3** the obtained gain of the BPSK modulation for the interleaving & BCH code scheme provides better performance compared with two other schemes which were 2.9 dB for using BCH code and 5.2 dB for the uncoded scheme. The results calculated for the case of using 2x2 MIMO system at BER = 10^{-5} . Table (□) shows the amount of gain for all other cases of MIMO system.

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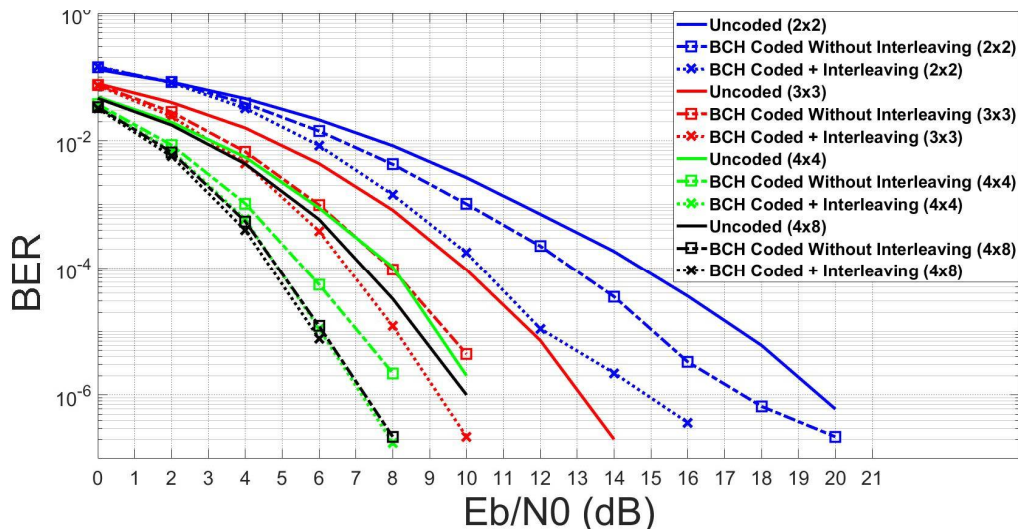


Fig. 3. BER comparison between Uncoded, BCH code, and BCH code & interleaving schemes for BPSK modulation of various cases of MIMO systems.

In the same manner, comparative curves for QPSK modulation presented in Fig. 4. Better performance is recorded for using interleaving & BCH code with gain value 1.45dB and 3.05dB compared with BCH code and uncoded scheme respectively at $BER = 10^{-5}$ and 3x3 MIMO system. From another side, using interleaving & BCH scheme with 4x8 MIMO system has lower BER calculation than other cases of MIMO systems. At $E_b/N_0 = 10$ dB the BER value for 4x8 MIMO is 1×10^{-7} , while it was 1.083×10^{-6} , 3.75×10^{-5} , and 1.125×10^{-3} for 4x4 MIMO, 3x3 MIMO and 2x2 MIMO respectively.

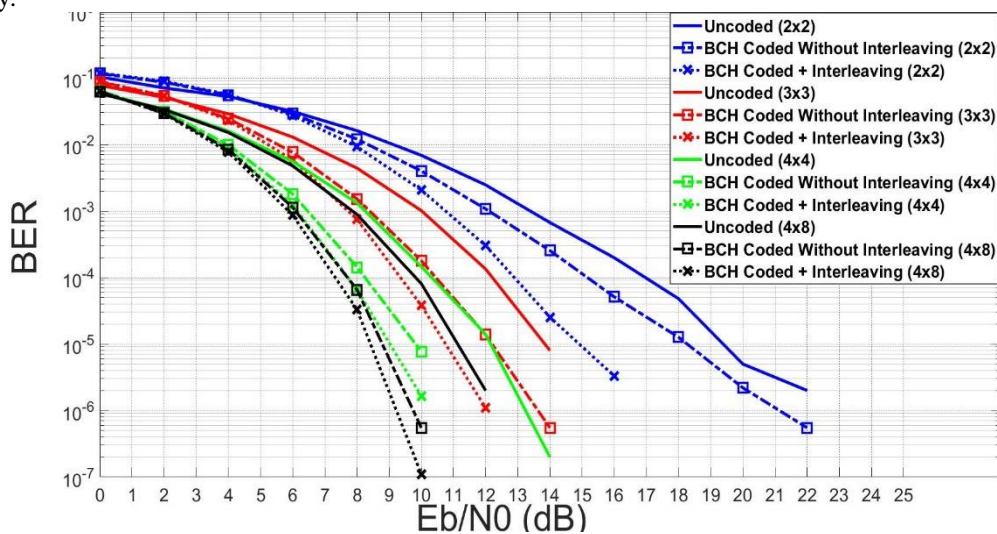


Fig. 4. BER comparison between Uncoded, BCH code, and BCH code & interleaving schemes for QPSK modulation of various cases of MIMO systems.

For 16-QAM modulation, Fig. 5 exhibits that minimum BER values are registered for using interleaving & BCH code. At $BER = 10^{-5}$ and 4x4 MIMO system, the obtain gain from using this scheme is 0.69dB comparing with BCH code and

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3.32dB for the uncoded scheme. Also can be seen that 4x8 MIMO improved system performance with respect to other cases of MIMO system for all values of E_b/N_0 .

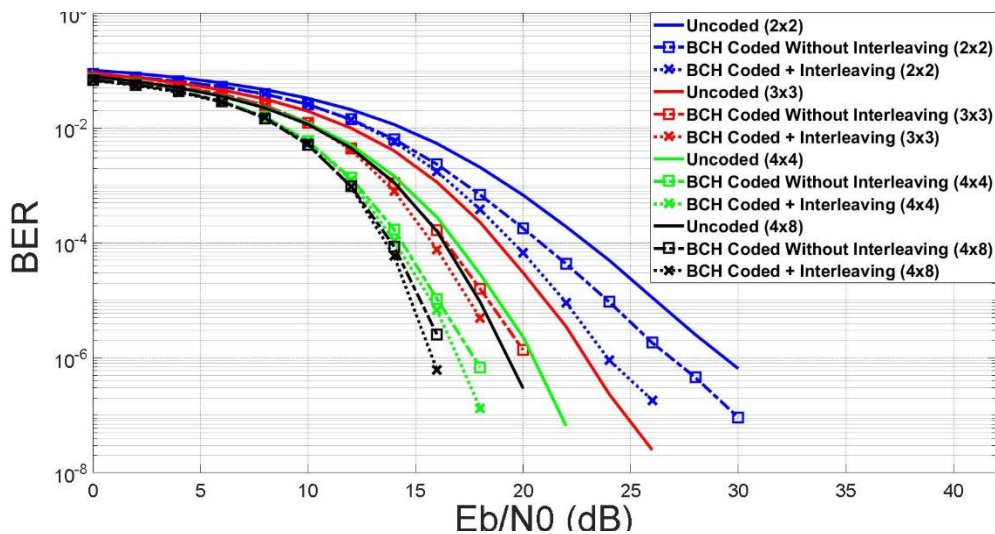


Fig. 5. BER comparison between Uncoded, BCH code, and BCH code & interleaving schemes for 16 QAM modulation of various cases of MIMO system.

From the above results, we can conclude that as a certain BER the SNR value decreases when the number of receiving antenna increased for all kinds of modulations in this paper.

Table 1: Performance comparison of Gain (dB) obtained from using interleaving & BCH code compared with another scheme at $BER = 10^{-5}$

Antennas ($N_t \times N_r$)	Gain (dB) obtained from using interleaving & BCH code compared with another scheme at $BER = 10^{-5}$					
	BPSK		QPSK		16-QAM	
	BCH code	Uncoded	BCH code	Uncoded	BCH code	Uncoded
2x2	2.9	5.2	3.35	4.5	2.1	4.1
3x3	1.4	3.65	1.45	3.05	1.08	3.88
4x4	1	3.15	0.9	3.15	0.4	2.4
4x8	0.3	2.9	0.4	2.7	0.69	3.32

VII. CONCLUSION

In this paper, the simulation executed in MATLAB environment for STBC MIMO systems with three different schemes (Uncoded, BCH code, and BCH code & Interleaving). The various digital modulations have been used (BPSK, QPSK, and 16-QAM) to investigate the performance of MIMO communication system. The purpose of this study is to estimate the power gain of STBC MIMO systems. The results show that using the BCH code & Interleaving gave the best results compare with the Uncoded and BCH code.

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