Institute of Advanced Engineering and Science

International Journal of Information & Network Security (IJINS)
Vol.2, No.6, December 2013, pp. 482~491
ISSN: 2089-3299

Performance Comparison of Space Time Block Coding with Code Rate ½ and ¾ for Turbo Coded Multiple Input Multiple Output System

M.M.Kamruzzaman
Key Lab of Information Coding & Transmission, Southwest Jiaotong University, Chengdu, Sichuan, China.

Article Info

Article history:

Received Oct 15th, 2013
Revised Nov 20th, 2013
Accepted Dec 26th, 2013

Keyword:

MIMO
Space Time Block Code
Turbo Code
Rayleigh fading
Wireless communication.

ABSTRACT

This paper compares the performance of Space Time Block Coding with code rate ½ and ¾ for a Turbo Coded Multiple Input Multiple Output (MIMO) system and uncoded MIMO system. Turbo encoder encodes the input information bits and sends to a QPSK or 16 QAM or 64 QAM modulator. Modulated symbols are mapped by STBC. Outputs of STBC split into n streams which are simultaneously transmitted using n transmit antennas. The Rayleigh fading effected received signal at receiver is a linear superposition of the transmitted signals. It is observed that there is around 7-11 db coding gain for using code rate ½ compared to code rate ¾ of a TC coded MIMO system and there is around 8-10 db coding gain for using code rate ½ compared to code rate ¾ of a uncoded MIMO system.

Corresponding Author:

M.M.Kamruzzaman
Key Lab of Information Coding & Transmission,
Southwest Jiaotong University,
Chengdu, Sichuan, China.
E-mail: m.m.kamruzzaman@gmail.com

1. INTRODUCTION

Space Time Block Coding is one of the simplest and most widely used diversity schemes were proposed by Alamouti in 1998, although he did not use the term “Space Time Block Code” [1]. It was designed for a two transmit antenna system. Tarokh et al. further extended the Alamouti’s transmit diversity scheme to an arbitrary number of transmit antennas. This new generalized coding scheme is known as Space Time Block Code (STBC) [2-7].

The code rate of an STBC is the ratio of total number of symbols to the number of time slots which reflects the bandwidth efficiency. In order to improve the bandwidth efficiency, it is desired to construct a code with rate as high as possible. In [2], Tarokh et al. proposed STBC with code rate of ½ and ¾ for 3 and 4 transmit antennas. In our previous paper [8, 9], we investigated the performance of Turbo Coded (TC) Multiple Input and Multiple Output (MIMO) system using STBC with code rate ¾ . This paper shows the performance of TC coded MIMO system using STBC with code rate ½ and compare with code rate ¾ . A combination of the STBC and the TC has been widely studied [10-32] but performance comparison with code rate ½ and ¾ for turbo coded STBC system has not been studied.

The rest of the paper is organized as follows. In section II, we present the system model with encoding and decoding techniques and channel characteristics. The simulation results are presented in section III, and section VI contains the conclusions.

2. SYTEM MODEL

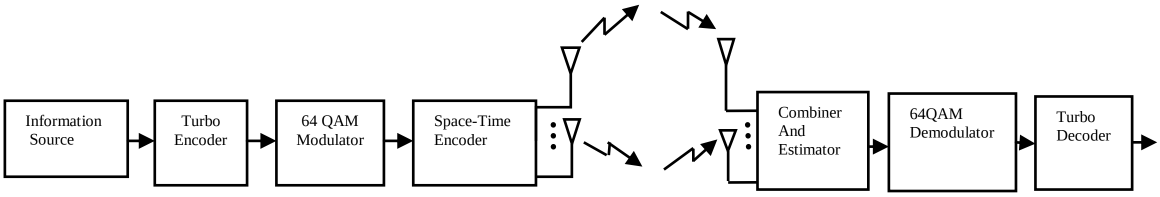

Figure 1. System block diagram

The system considered in this paper consists of n transmit and m receive antennas. Turbo encoder is used for TC coded MIMO system whereas Turbo encoder is not used for uncoded MIMO system. Data can be modulated by a QPSK or 16 QAM or 64 QAM modulator and the modulated symbols are mapped using STBC before transmission according to number of transmit antennas as shown in fig. 1. Encoding and Decoding techniques are discussed in more detail below.

2.1. Encoding

At the transmitter, the turbo encoder gets the input bits sequence u having length of N bits. The turbo encoder consists of at least two recursive systematic convolutional (RSC) encoders and an interleaver [33-35]. The RSC encoders are concatenated in parallel via interleaver as shown in fig. 2. So the input bits sequence u are encoded by first RSC encoder and generates a redundancy sequence based on the non-interleaved bit sequence of u whereas the second RSC encoder generates a redundancy sequence based on the interleaved bit sequence of u . The output bit sequence c of turbo encoder is obtained by multiplexing the information bits of u and the punctured redundancy generated by the RSC encoders. If the input symbol is of length N and output symbol size is R, then the encoder is of code rate r_c=N/R. The RSC code, interleaver size, encoding frame length and the puncturing rules affect error performance considerably; no

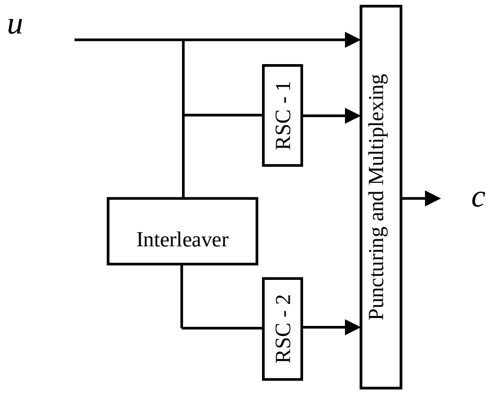

Figure 2. Structure of Turbo Encoder

Table 1. The Encoding and Transmission Sequence for Three Transmit Antennas of Tarokh with Code Rate ½ .

Time slot	Antenna		
	Antenna-I	Antenna-II	Antenna-III
Time slot-I	x_1	x_2	x_3
Time slot-II	$-x_2$	x_1	$-x_4$
Time slot-III	$-x_3$	x_4	x_1
Time slot-IV	$-x_4$	$-x_3$	x_2
Time slot-V	x_1^*	x_2^*	x_3^*
Time slot-VI	$-x_2^*$	x_1^*	$-x_4^*$
Time slot-VII	$-x_3^*$	x_4^*	x_1^*
Time slot-VIII	$-x_4^*$	$-x_3^*$	x_2^*

attempt was made to optimize their design of turbo code. The QPSK or 16 QAM or 64 QAM modulator modulates the turbo encoded bits. Space-Time Encoder (STE) encodes the modulated symbols according to number of transmit antennas. STE uses Table I for 3 transmit antennas and Table II for 4 transmit antennas to obtain code rate ½. On the other hand, it uses Table III for 3 transmit antennas and Table IV for 4 transmit antennas to obtain code rate ¾. After encoding, signals s_t^i , i =1, 2, ... n are transmitted simultaneously using n transmit antennas at each time slot t.

Table 2. The Encoding and Transmission Sequence for Four Transmit Antennas of Tarokh with Code Rate ½

Time slot	Antenna			
	Antenna-I	Antenna-II	Antenna-III	Antenna-IV
Time slot-I	x_1	x_2	x_3	x_4
Time slot-II	$-x_2$	x_1	$-x_4$	x_3
Time slot-III	$-x_3$	x_4	x_1	$-x_2$
Time slot-IV	$-x_4$	$-x_3$	x_2	x_1
Time slot-V	x_1^*	x_2^*	x_3^*	x_4^*
Time slot-VI	$-x_2^*$	x_1^*	$-x_4^*$	x_3^*
Time slot-VII	$-x_3^*$	x_4^*	x_1^*	$-x_2^*$
Time slot-VIII	$-x_4^*$	$-x_3^*$	x_2^*	x_1^*

Table 3. The Encoding and Transmission Sequence for Three Transmit Antennas of Tarokh with Code Rate ¾.

Time slot	Antenna		
	Antenna-I	Antenna-II	Antenna-III
Time slot-I	x_1	x_2	$\frac{x_3}{\sqrt{2}}$
Time slot-II	$-x_2^*$	x_1^*	$\frac{x_3}{\sqrt{2}}$
Time slot-III	$\frac{x_3^*}{\sqrt{2}}$	$\frac{x_3^*}{\sqrt{2}}$	$\frac{-x_1-x_1^*+x_2-x_2^*}{2}$
Time slot-IV	$\frac{x_3^*}{\sqrt{2}}$	$-\frac{x_3^*}{\sqrt{2}}$	$\frac{x_2+x_2^*+x_1-x_1^*}{2}$

Table 4. The Encoding and Transmission Sequence for Four Transmit Antennas of Tarokh with Code Rate ¾

Time slot	Antenna			
	Antenna-I	Antenna-II	Antenna-III	Antenna-IV
Time slot-I	x_1	x_2	$\frac{x_3}{\sqrt{2}}$	$\frac{x_3}{\sqrt{2}}$
Time slot-II	$-x_2^*$	x_1^*	$\frac{x_3}{\sqrt{2}}$	$-\frac{x_3}{\sqrt{2}}$
Time slot-III	$\frac{x_3^*}{\sqrt{2}}$	$\frac{x_3^*}{\sqrt{2}}$	$\frac{-x_1-x_1^*+x_2-x_2^*}{2}$	$\frac{-x_1-x_2^*+x_1-x_1^*}{2}$
Time slot-IV	$\frac{x_3^*}{\sqrt{2}}$	$-\frac{x_3^*}{\sqrt{2}}$	$\frac{x_2+x_2^*+x_1-x_1^*}{2}$	$\frac{x_1+x_1^*+x_2-x_2^*}{2}$

2.2. Channel

It is assumed that the channel is flat fading. The path gain from transmit antenna *i* to receive antenna *j* is defined to be $\alpha_{i,j.}$ The path gains are modeled as samples of independent complex Gaussian random variables with variance 0.5 per real dimension and path gains are constant over a frame of length *l* and vary from one frame to another. It is assumed that the noise on each receive antenna is independent from the noise on the other receive antennas and noise samples are independent samples of a zero-mean complex Gaussian random variable with variance *n*/(2SNR) per complex dimension. The average energy of the symbols transmitted from each antenna is normalized to be one.

2.3 Decoding

At time t the signal r_t^j , received at antenna j, is given by

$$r_t^j = \sum_{i=1}^{n} \alpha_{i,j} s_t^i + \eta_t^j \quad (1)$$

Assuming perfect channel state information is available; the receiver computes the decision metric

$$\sum_{t=1}^{l} \sum_{j=1}^{m} \left| r_t^j - \sum_{i=1}^{n} \alpha_{i,j} s_t^i \right|^2 \quad (2)$$

over all code words $s_1^1 s_1^2 \ldots s_1^n s_2^1 s_2^2 \ldots s_2^n \ldots\ldots\ldots\ldots s_l^1 s_l^2 \ldots s_{l1}^n$ and decides in favor of the code word that minimizes the sum.

We use (3), (4), (5) and (6) decision metrics for detecting symbols s_1, s_2, s_3, s_4 respectively which transmitted from three transmit antennas with code rate ½.

$$\left|\left[\sum_{j=1}^{m}\begin{pmatrix} r_1^j\alpha_{1,j}^* + r_2^j\alpha_{2,j}^* + r_3^j\alpha_{3,j}^* + \\ (r_5^j)^*\alpha_{1,j} + (r_6^j)^*\alpha_{2,j} + (r_7^j)^*\alpha_{3,j}\end{pmatrix}\right] - s_1\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \quad (3)$$

$$\left|\left[\sum_{j=1}^{m}\begin{pmatrix} r_1^j\alpha_{2,j}^* + r_2^j\alpha_{1,j}^* + r_4^j\alpha_{3,j}^* + \\ (r_5^j)^*\alpha_{2,j} - (r_6^j)^*\alpha_{1,j} + (r_8^j)^*\alpha_{3,j}\end{pmatrix}\right] - s_2\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_2\right|^2 \quad (4)$$

$$\left|\left[\sum_{j=1}^{m}\begin{pmatrix} r_1^j\alpha_{3,j}^* - r_3^j\alpha_{1,j}^* - r_4^j\alpha_{2,j}^* + \\ (r_5^j)^*\alpha_{3,j} - (r_7^j)^*\alpha_{1,j} - (r_8^j)^*\alpha_{2,j}\end{pmatrix}\right] - s_3\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_3\right|^2 \quad (5)$$

$$\left|\left[\sum_{j=1}^{m}\begin{pmatrix} -r_2^j\alpha_{3,j}^* + r_3^j\alpha_{2,j}^* - r_4^j\alpha_{1,j}^* - \\ (r_6^j)^*\alpha_{3,j} + (r_7^j)^*\alpha_{2,j} - (r_8^j)^*\alpha_{1,j}\end{pmatrix}\right] - s_4\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_4\right|^2 \quad (6)$$

We use (7), (8), (9) and (10) decision metrics for detecting symbols s_1, s_2 , s_3, s_4 respectively which transmitted from four transmit antennas with code rate ½.

$$\left|\left[\sum_{j=1}^{m}\left(\begin{array}{l} r_1^j\alpha_{1,j}^* + r_2^j\alpha_{2,j}^* + r_3^j\alpha_{3,j}^* + r_4^j\alpha_{4,j}^* \\ +\left(r_5^j\right)^*\alpha_{1,j} + \left(r_6^j\right)^*\alpha_{2,j} + \left(r_7^j\right)^*\alpha_{3,j} \\ + r_8^j\alpha_{4,j}^* \end{array}\right)\right] - s_1\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{4}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \quad (7)$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{array}{l} r_1^j\alpha_{2,j}^* - r_2^j\alpha_{1,j}^* - r_3^j\alpha_{1,j}^* + r_4^j\alpha_{3,j}^* \\ +\left(r_5^j\right)^*\alpha_{2,j} - \left(r_6^j\right)^*\alpha_{1,j} - \left(r_7^j\right)^*\alpha_{4,j} \\ +\left(r_8^j\right)^*\alpha_{3,j} \end{array}\right)\right] - s_2\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_2\right|^2 \quad (8)$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{array}{l} r_1^j\alpha_{3,j}^* + r_2^j\alpha_{4,j}^* - r_3^j\alpha_{1,j}^* - r_4^j\alpha_{2,j}^* \\ +\left(r_5^j\right)^*\alpha_{3,j} + r_6^j\alpha_{4,j}^* - \left(r_7^j\right)^*\alpha_{1,j} \\ -\left(r_8^j\right)^*\alpha_{2,j} \end{array}\right)\right] - s_3\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_3\right|^2 \quad (9)$$

$$\left|\left[\sum_{j=1}^{m}\left(\begin{array}{l} -r_1^j\alpha_{4,j}^* - r_2^j\alpha_{3,j}^* + r_3^j\alpha_{2,j}^* - r_4^j\alpha_{1,j}^* \\ -\left(r_5^j\right)^*\alpha_{4,j} - \left(r_6^j\right)^*\alpha_{3,j} + \left(r_7^j\right)^*\alpha_{2,j} \\ -\left(r_8^j\right)^*\alpha_{1,j} \end{array}\right)\right] - s_4\right|^2 + \left(-1+2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_4\right|^2 \quad (10)$$

Furthermore, we use (11), (12) and (13) decision metrics for detecting symbols s_1, s_2 and s_3 respectively which transmitted from three transmit antennas with code rate ¾.

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{1,j}^* + \left(r_2^j\right)^*\alpha_{2,j} + \frac{(r_4^j - r_3^j)\alpha_{3,j}^*}{2} - \frac{(r_3^j + r_4^j)^*\alpha_{3,j}}{2}\right)\right] - s_1\right|^2 + \left(-1+\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \quad (11)$$

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{2,j}^* - \left(r_2^j\right)^*\alpha_{1,j} + \frac{(r_4^j - r_3^j)\alpha_{3,j}^*}{2} - \frac{(-r_3^j + r_4^j)^*\alpha_{3,j}}{2}\right)\right] - s_2\right|^2 + \left(-1+\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_2\right|^2 \quad (12)$$

$$\left|\left[\sum_{j=1}^{m}\left(\frac{\left(r_1^j + r_2^j\right)\alpha_{3,j}^*}{\sqrt{2}} + \frac{\left(r_3^j\right)^*\left(\alpha_{1,j} + \alpha_{2,j}\right)}{\sqrt{2}} + \frac{\left(r_4^j\right)^*\left(\alpha_{1,j} - \alpha_{2,j}\right)}{\sqrt{2}}\right)\right] - s_3\right|^2 + \left(-1+\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)\left|s_3\right|^2 \quad (13)$$

Then, used (14), (15) and (16) decision metrics for detecting symbols s_1, s_2 and s_3 respectively which transmitted from four transmit antennas with code rate ¾.

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{1,j}^* + \left(r_2^j\right)^*\alpha_{2,j} + \frac{(r_4^j - r_3^j)\left(\alpha_{3,j}^* - \alpha_{4,j}^*\right)}{2} - \frac{(r_3^j + r_4^j)^*\left(\alpha_{3,j} - \alpha_{4,j}\right)}{2}\right)\right] - s_1\right|^2 + \left(-1+\sum_{j=1}^{m}\sum_{i=1}^{4}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \quad (14)$$

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{2,j}^* + \left(r_2^j\right)^*\alpha_{1,j} + \frac{(r_4^j + r_3^j)\left(\alpha_{3,j}^* - \alpha_{4,j}^*\right)}{2} + \frac{(-r_3^j + r_4^j)^*\left(\alpha_{3,j} - \alpha_{4,j}\right)}{2}\right)\right] - s_2\right|^2 + \left(-1+\sum_{j=1}^{m}\sum_{i=1}^{4}\left|\alpha_{i,j}\right|^2\right)\left|s_2\right|^2 \quad (15)$$

$$\left\| \left[\sum_{j=1}^{m} \left(\frac{(r_1^j + r_2^j)\alpha_{3,j}^*}{\sqrt{2}} + \frac{(r_1^j - r_2^j)^* \alpha_{4,j}^*}{\sqrt{2}} + \frac{(r_3^j)^* (\alpha_{1,j} + \alpha_{2,j})}{\sqrt{2}} + \frac{(r_4^j)^* (\alpha_{1,j} - \alpha_{2,j})}{\sqrt{2}} \right) \right] - s_3 \right|^2 + \left(-1 + \sum_{j=1}^{m} \sum_{i=1}^{4} |\alpha_{i,j}|^2 \right) |s_3|^2 \quad (16)$$

The detected symbols are demodulated by QPSK or 16 QAM or 64 QAM demodulator and send to turbo decoder to get the output. The decoder consists of two decoders (DEC1 and DEC2 which operate iteratively and pass their decisions to each other after each iteration as shown in Fig. 3. The component decoders are based on a maximum a posteriori (MAP) algorithm or a soft output Viterbi algorithm (SOVA) generating a weighted soft estimate of the input sequence. However researchers used the MAP decoder to decode the Turbo code.

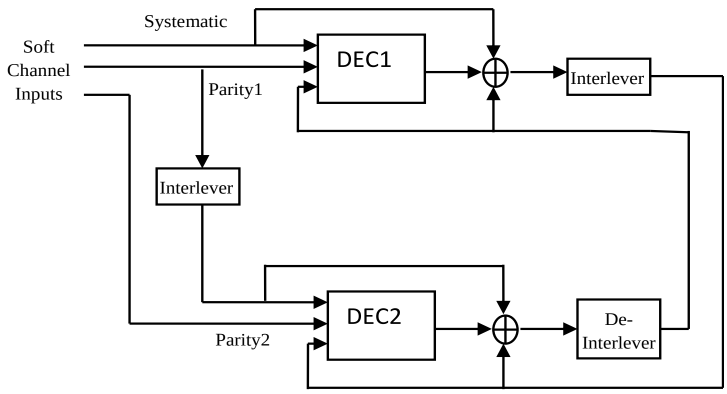

Figure 3 Block diagram of turbo decoder

3. SIMULAION RESULTS

In this section, computer simulation is carried out to show the BER performance. The results are evaluated using code rate ½ and ¾ for several combinations of Tx and Rx antennas with and without Turbo coding. For the uncoded system (without turbo code), researchers used only STBC. For two three and four transmit antennas, researchers used Tarokh's codewith code rate ½ and ¾. Turbo code with frame size= 378, rate= 1/3, encoder generator g = [1 0 1 1; 1 1 0 1; 1 1 1 1] and number of iterations =2 is considered to perform simulation.

Fig. 4 shows the comparison of coded and uncoded MIMO system with code rate ½ and ¾ for 3 Tx and 2 Rx. Coded MIMO system with rate ½ provides 7 db coding gain compared to coded MIMO with code rate ¾ for 3 Tx and 2 Rx. And uncoded MIMO system with rate ½ provides 8 db coding gain compared to uncoded MIMO with code rate ¾ for 3 Tx and 2 Rx.

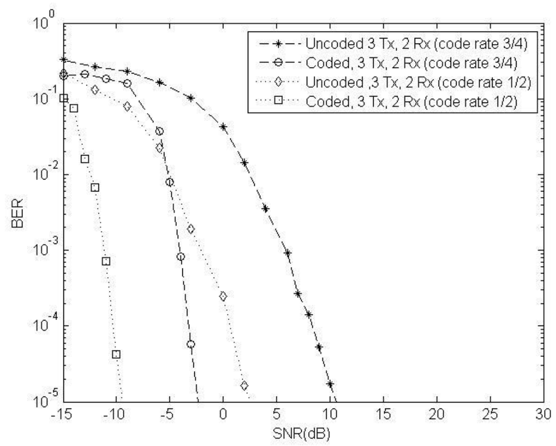

Figure. 4 BER performance comparison with code rate ½ and ¾ for Turbo-MIMO system(3Tx & 2 Rx) and uncoded MIMO system.

Fig. 5 shows the comparison of coded and uncoded MIMO system with code rate ½ and ¾ for 3 Tx and 3 Rx. Coded MIMO system with rate ½ provides 8 db coding gain compared to coded MIMO with code rate ¾ for 3 Tx and 3 Rx. And uncoded MIMO system with rate ½ provides 8 db coding gain compared to uncoded MIMO with code rate ¾ for 3 Tx and 3 Rx

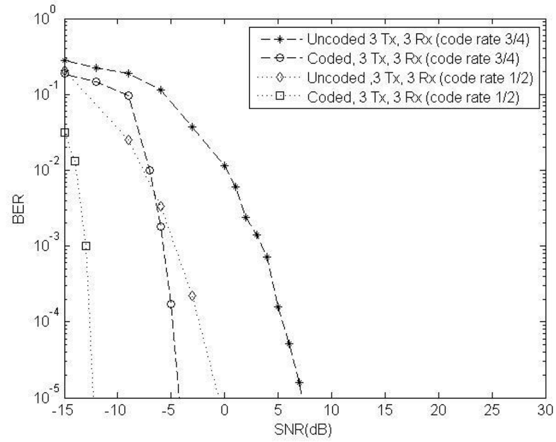

Figure. 5 BER performance comparison with code rate ½ and ¾
for Turbo-MIMO system(3Tx & 3 Rx) and uncoded MIMO

Fig. 6 shows the comparison of coded and uncoded MIMO system with code rate ½ and ¾ for 3 Tx and 4 Rx. Coded MIMO system with rate ½ provides 8 db coding gain compared to coded MIMO with code rate ¾ for 3 Tx and 4 Rx. And uncoded MIMO system with rate ½ provides 8 db coding gain compared to uncoded MIMO with code rate ¾ for 3 Tx and 4 Rx.

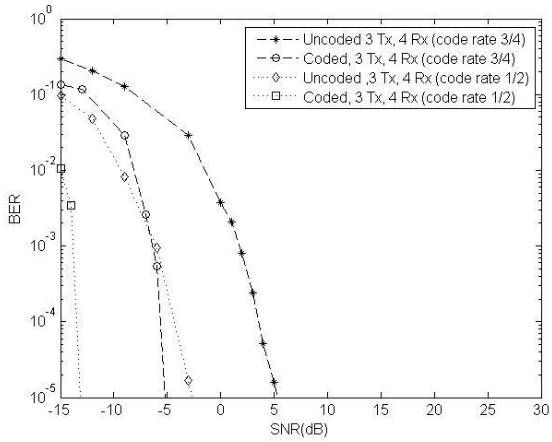

Fig. 6 BER performance comparison with code rate ½ and ¾ for
Turbo-MIMO system(3Tx & 4 Rx) and uncoded MIMO system.

Fig. 7 shows the comparison of coded and uncoded MIMO system with code rate ½ and ¾ for 4 Tx and 2 Rx. Coded MIMO system with rate ½ provides 9 db coding gain compared to coded MIMO with code rate ¾ for 4 Tx and 2 Rx. And uncoded MIMO system with rate ½ provides 10 db coding gain compared to uncoded MIMO with code rate ¾ for 4 Tx and 2 Rx.

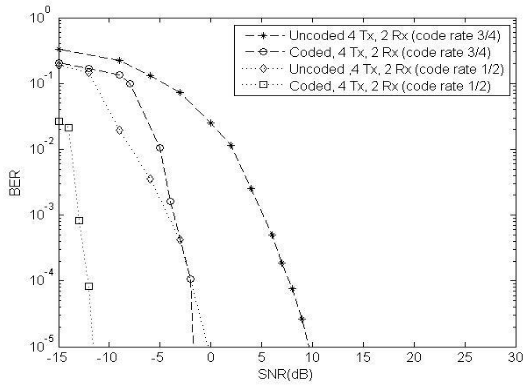

Figure. 7 BER performance comparison with code rate ½ and ¾ for Turbo-MIMO system (4Tx & 2 Rx) and uncoded MIMO

Fig. 8 shows the comparison of coded and uncoded MIMO system with code rate ½ and ¾ for 4 Tx and 3 Rx. Coded MIMO system with rate ½ provides 9 db coding gain compared to coded MIMO with code rate ¾ for 4 Tx and 3 Rx. And uncoded MIMO system with rate ½ provides 9 db coding gain compared to uncoded MIMO with code rate ¾ for 4 Tx and 3 Rx.

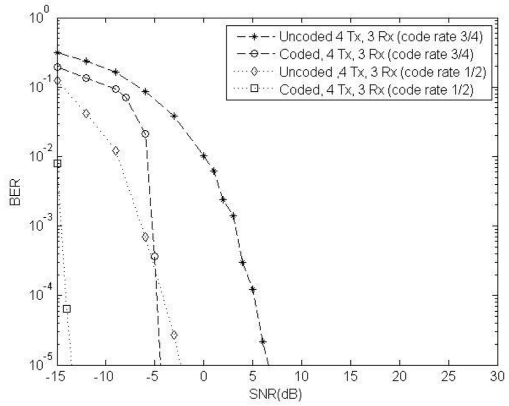

Figure. 8 BER performance comparison with code rate ½ and ¾ for Turbo-MIMO system (4Tx & 3 Rx) and uncoded MIMO

Fig. 9 shows the comparison of coded and uncoded MIMO system with code rate ½ and ¾ for 4 Tx and 4 Rx. Coded MIMO system with rate ½ provides 11 db coding gain compared to coded MIMO with code rate ¾ for 4 Tx and 3 Rx. And uncoded MIMO system with rate ½ provides 10 db coding gain compared to uncoded MIMO with code rate ¾ for 4 Tx and 3 Rx.

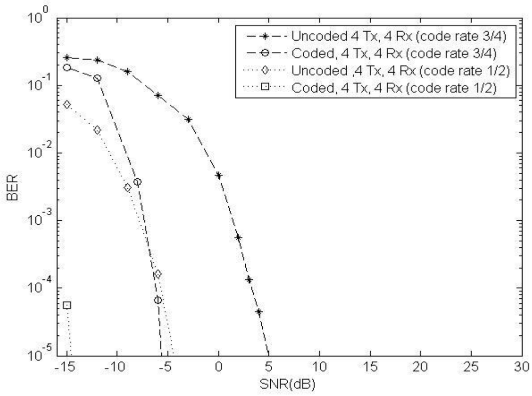

Figure. 9 BER performance comparison with code rate ½ and ¾ for Turbo-MIMO (4Tx & 4 Rx) and uncoded MIMO system.

4. CONCLUSION

From the simulation results, researcher observes that TC coded or uncoded MIMO system with code rate ½ makes a significant difference over TC coded or uncoded MIMO system with code rate ¾ .There is around 7-11 db coding gain for using code rate ½ compared to code rate ¾ of a TC coded MIMO system and there is around 8-10 db coding gain for using code rate ½ compared to code rate ¾ of a uncoded MIMO system.

ACKNOWLEDGEMENTS

The author would like to thank the reviewers for the suggestions which help to improve the quality of this paper. In addition, the authors are also very thankful to Key Lab of Information Coding & Transmission, Southwest Jiaotong University, Chengdu, Sichuan, China for providing resources.

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BIOGRAPHY OF AUTHOR

M. M. Kamruzzaman was born in Bangladesh in 1978. He received B.E. degree in Computer Science and Engineering from Bangalore University, Bangalore, India in 2001, M.S. degree in Computer Science and Engineering from United International University, Dhaka, Bangladesh in 2009. At present he is studying PhD in the department of Information & Communication Engineering at Southwest Jiaotong University, Chengdu, Sichuan, China. After completing B.E, he worked several universities as a faculty. He worked in Islamic Institute of Technology, Bangalore, India and Leading University, Dhaka, Bangladesh. And before studying PhD, he was working as a faculty of Presidency University, Dhaka, Bangladesh. He is a member of TPC of several international conferences and reviewer of few international journals and conferences.

His areas of interest include wireless communications, modern coding theory, Turbo coding, Space Time Coding, Vblast, MIMO, OFDM, Relay, WCDMA and LTE system.