Performance Enhancement of MIMO OFDM

H.S.Shwetha
M.Tech, Digital Communication
Siddaganga Institute of Technology
Tumakuru, India

R.N.Sathisha
Department of Telecommunication
Siddaganga Institute of Technology
Tumakuru, India

ABSTRACT
With the emergence of forthcoming broadband wireless communication, the MIMO OFDM has been recognized as one of the most promising techniques to support high information rate and spectral efficiency. This paper presents MIMO OFDM system with convolution coding technique. Here, OFDM with 64 QAM modulation is combined with Orthogonal Space Time Block Coding (OSTBC) - a MIMO technique providing diversity gain with multiple transmitter and receiver antennas. Using Matlab/Simulink, the performance of MIMO OFDM is compared for different code rates in convolution coding by varying the number of transmitter and receiver antennas like 2x2, 3x3 and 4x4 and their effects on Bit Error Rate(BER) is examined.

Keywords
MIMO-OFDM, 64 QAM modulation, OSTBC, convolution coding, Matlab/Simulink, BER.

1. INTRODUCTION
The major issue faced by the wireless communication systems is to provide a high information rate with good quality of service. Moreover, bandwidth is limited and transmitted information is subjected to multipath fading and also interference from other users. Thus, there is a need to increase spectral efficiency and to improve link reliability [1]. MIMO OFDM technology seems to meet these demands by providing increased spectral efficiency through orthogonal frequency division multiplexing and improved link reliability due to antenna diversity. There is also a significant improvement in performance, achieved in terms of lower bit error rate (BER).

OFDM is a simple and efficient way of achieving multi-carrier modulation by employing orthogonal sub-carriers and use the DFT pair (more precisely, fast Fourier transform (FFT) and its inverse) for implementation. The samples of the overall signal to be transmitted over N sub-carriers can be obtained using the N-point inverse DFT (IDFT) or inverse FFT (IFFT) of the data sequence of the N sub-carriers. At the receiver the DFT (or FFT) is applied, and the standard receiver algorithms are used [2].The cyclic prefix is added to remove possible interference between two consecutive OFDM symbols. The transmission of OFDM symbols with the use of MIMO achieves higher data rates, wider coverage and increased reliability-all without the using additional frequency spectrum.

2. MIMO OFDM SYSTEM

2.1 OFDM System
Orthogonal Frequency Division Multiplexing (OFDM) is implemented using discrete Fourier transform and inverse DFT. The bandwidth is divided into a number of sub- carriers and each one is modulated by a low rate data stream [2]. However, OFDM uses the spectrum efficiently by spacing the sub-channels close together. This is achieved by making all the sub-carriers orthogonal to each another, preventing interference between these closely spaced sub-carriers. The Fig. 1 shows the block diagram of OFDM system.

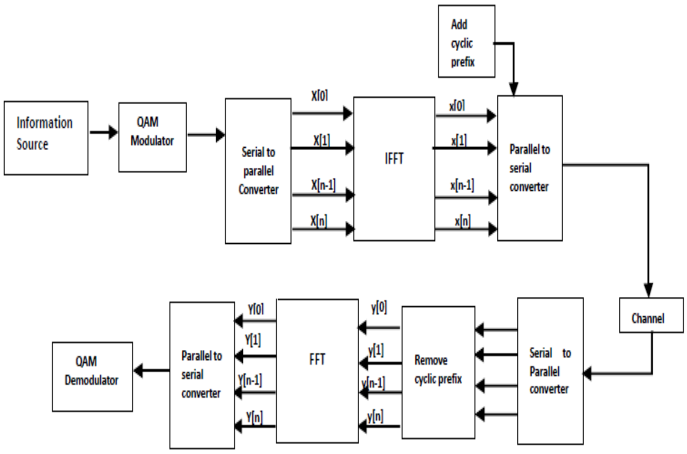

Fig. 1: Block Diagram of OFDM system

The reason that the information transmitted on the subcarriers can be separated at the receiver is the orthogonality relation giving OFDM its name as shown in Fig.2. By using an IDFT for modulation, the spacing of the subcarriers is implicitly chosen in such a way that, at the frequencies where the received signals are evaluated, all other signals are zero.

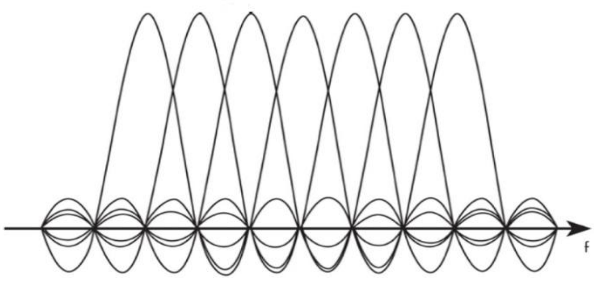

Fig. 2: Overlapping Subcarriers of OFDM

2.2 MIMO System
MIMO systems consists of transmitter, the channel, and the receiver. Here, N_t denotes the number of transmitter antennas and N_r denotes the number of receiver antennas. Fig. 3 depicts the MIMO system [3].

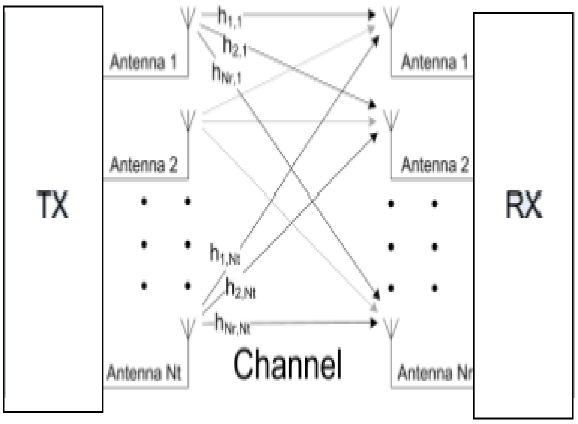

Fig. 3: MIMO System Model

The multiple inputs are located at the output of the transmitter (the input to the channel), and the multiple outputs are located at the input of the receiver (the output of the channel). The channel with N_r outputs and N_t inputs is denoted by N_r x N_t matrix given by (1):

$$H = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,Nt} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,Nt} \\ \vdots & \vdots & \ddots & \vdots \\ h_{Nr,1} & h_{Nr,2} & \cdots & h_{Nr,Nt} \end{pmatrix} \quad (1)$$

where each entry $h_{i,j}$ denotes the channel attenuation and phase shift (transfer function) between the j^{th} transmitter and the i^{th} receiver. The MIMO signal model is described by (2):

$$\vec{r} = H\vec{s} + \vec{n} \qquad (2)$$

where $\vec{r}$ is the received vector of size N_r x 1, H is the channel matrix of size N_r x N_t , $\vec{s}$ is the transmitted vector of size N_tx1 and $\vec{n}$ is the noise vector of size N_r x 1.

2.2.1 Space Time Block Coding (STBC)

Space-Time Block Coding (STBC) is a MIMO transmit strategy which exploits transmit diversity and high reliability. The STBC can be viewed as repetition codes over space and time, simultaneously transmitting the multiple copies of same data over different antennas and at different times [4]. This redundancy results in higher chance of being able to use one or more of the received copies of the data to correctly decode the received signal [5].

The simplest form of space-time block codes was invented by Alamouti. He proposed technique for two transmitter antennas and one receiver antenna. Alamouti's code uses a complex orthogonal design and satisfies the condition for complex orthogonality in both space and time dimensions. The code matrix is given by (2) [5]:

$$C_2 = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad (2)$$

Due to the orthogonality of the code matrix, the Alamouti code has fast Maximum Liklihood (ML) decoding property which allows simple single-symbol ML detection.

A general class of space time block codes called as orthogonal space time block coding (OSTBC) can be used to construct the code matrix for more than two antenna system. The Orthogonal Space Time Block Code (OSTBC) for the 3 transmit antennas and rate ½ is given by (3) [5]:

$$C_3 = \begin{bmatrix} s_1 & s_2 & s_3 \\ -s_2 & s_1 & -s_4 \\ -s_3 & s_4 & s_1 \\ -s_4 & -s_3 & s_2 \\ s_1^* & s_2^* & s_3^* \\ -s_2^* & s_1^* & -s_4^* \\ -s_3^* & s_4^* & s_1^* \\ -s_4^* & -s_3^* & s_2^* \end{bmatrix} \quad (3)$$

For a higher code rate of ¾ is given by (4) [5]:

$$C_3 = \begin{bmatrix} s_1 & s_2 & \frac{s_3}{\sqrt{2}} \\ -s_2^* & s_1^* & \frac{s_3}{\sqrt{2}} \\ \frac{s_3^*}{\sqrt{2}} & \frac{s_3^*}{\sqrt{2}} & \frac{-s_1 - s_1^* + s_2 - s_2^*}{2} \\ \frac{s_3^*}{\sqrt{2}} & \frac{-s_3^*}{\sqrt{2}} & \frac{s_2 + s_2^* + s_1 - s_1^*}{2} \end{bmatrix} \quad (4)$$

For the 4 transmiet antennas and rate ½ is given by (5) [5]:

$$C_4 = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \\ -s_2 & s_1 & -s_4 & s_3 \\ -s_3 & s_4 & s_1 & -s_2 \\ -s_4 & -s_3 & s_2 & s_1 \\ s_1^* & s_2^* & s_3^* & s_4^* \\ -s_2^* & s_1^* & -s_4^* & s_3^* \\ -s_3^* & s_4^* & s_1^* & -s_2^* \\ -s_4^* & -s_3^* & s_2^* & s_1^* \end{bmatrix} \quad (5)$$

For code rate of ¾ is given by (6) [5]:

$$C_4 = \begin{bmatrix} s_1 & s_2 & \frac{s_3}{\sqrt{2}} & \frac{s_3}{\sqrt{2}} \\ -s_2^* & s_1^* & \frac{s_3}{\sqrt{2}} & \frac{-s_3}{\sqrt{2}} \\ \frac{s_3^*}{\sqrt{2}} & \frac{-s_3^*}{\sqrt{2}} & \frac{-s_1 - s_1^* + s_2 - s_2^*}{2} & \frac{-s_2 - s_2^* + s_1 - s_1^*}{2} \\ \frac{s_3^*}{\sqrt{2}} & \frac{-s_3^*}{\sqrt{2}} & \frac{s_2 + s_2^* + s_1 - s_1^*}{2} & \frac{s_1 + s_1^* + s_2 - s_2^*}{2} \end{bmatrix} \quad (6)$$

g in orthogonal STBCs is that maximum likelihood decoding can be achieved at the receiver with only linear processing.

2.3 MIMO OFDM Systems

MIMO OFDM combines the OFDM with MIMO providing significant performance improvement in terms of many parameters like data transmission rate, smaller bit error rate (BER), and increased reliability. MIMO is known to increase the capacity and provide diversity and OFDM can combat the effects due to multipath fading and provides spectral efficiency suitable for high data rate applications. Because of low bit rate and insertion of cyclic prefix, OFDM has a very strong capacity to overcome multi path interference. So that allows single frequency networks to be used for broadband OFDM systems, which rely on multiple antennas.

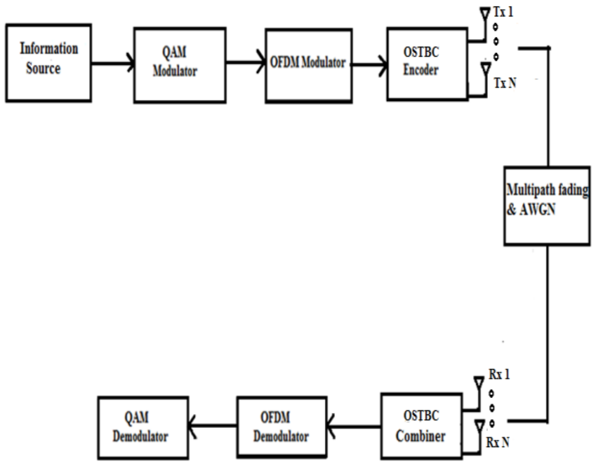

Fig. 4: Block Diagram of MIMO OFDM

The Fig. 4 shows the block diagram of MIMO OFDM system [6]. Setting multiple antennas both in transmitter and receiver can provide space diversity. Data input is modulated through OFDM processing, which include QAM mapping, IFFT and cyclic prefix insertion. Then the signal will be sent to the wireless channel by the antennas. Finally, in the receiver, the original data will be attained through an opposite signal processing as the transmitter [7], [8]. This MIMO OFDM system model provides a significant decrease in bit error rate.

3. SIMULINK MODEL OF MIMO OFDM

The Simulink model of MIMO OFDM is as shown in Fig. 5. The performance of the system can be enhanced by the inclusion of the error correction coding [9]. The main reason to apply error correction coding in a wireless system is to reduce the probability of bit error. The channel coding provides coding gain i.e. a reduction in Eb/No for a given bit error rate. The channel coding technique used is convolution coding with the Viterbi decoding at the receiver.

The information sequence is generated using Bernoulli binary generator that generates random binary numbers. The forward error correction includes convolution coding, puncturing and interleaving. The Convolutional encoder block encodes the binary input sequence k to produce a binary output code word n (n>k). The convolution encoder with a coding gain of ½ is used. To reduce the decoding complexity of high rate convolution codes i.e. (n-1)/n, the selected coded bits are removed. The Puncture block is used to create variable code rates by removing the selected bits and retaining others depending on the puncture vector used. To improve the performance of the coding in fading channels, coding is combined with the interleaving to overcome the effects of burst errors.

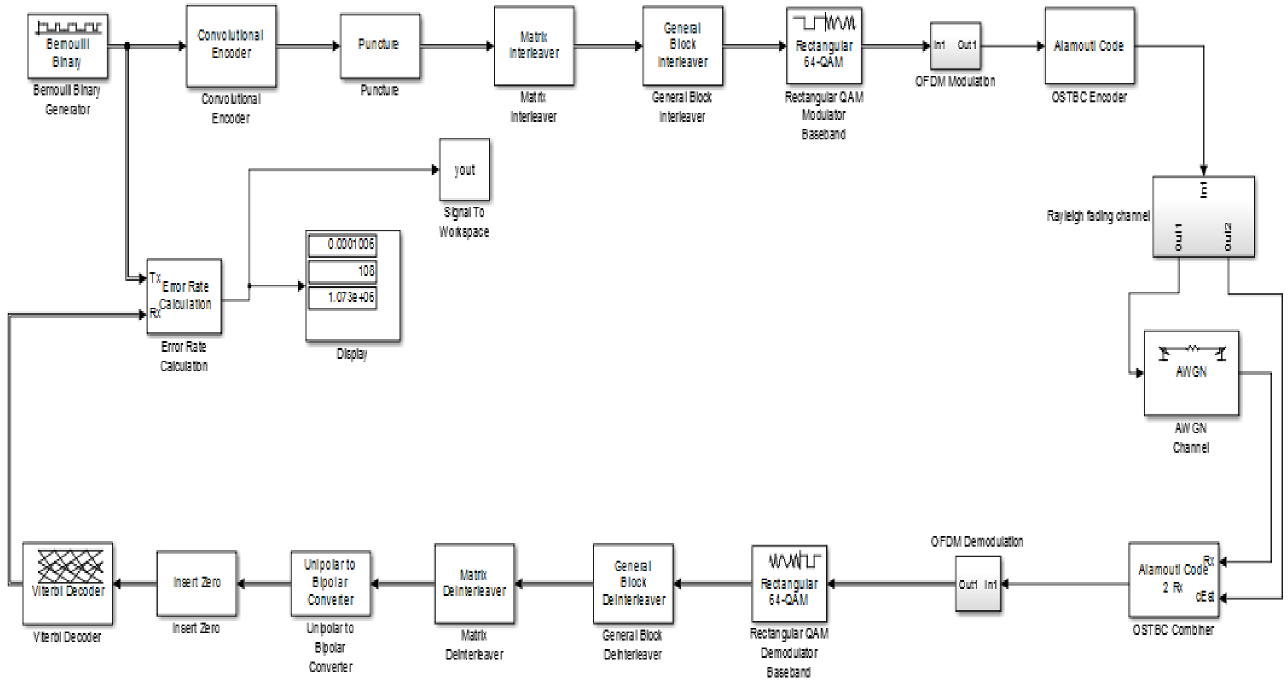

Fig. 5: Simulink Model of MIMO OFDM with convolution coding

The interleaving is performed by matrix interleaver and general block interleaver. The matrix interleaver accepts the input row-wise and gives output bits column-wise. Then the general block interleaver will re-arrange the bits without repeating or eliminating them. The 64 QAM modulator maps the input bits to symbols. The output is OFDM modulated and transmitted over multiple antennas using Orthogonal Space Time Coding (OSTBC) technique. The transmitted signal is passed through Rayleigh multipath channel and AWGN channel. At the receiver, multiple copies of transmitted data is combined and decoded. The OSTBC Combiner block combines the input from receiver antennas and the channel estimate is used to obtain the information about the symbols that were encoded using an OSTBC. After demodulation, de-interleaving, de- puncturing and Viterbi decoding, the transmission error rate calculation is used to evaluate the bit error rate of the system.

4. RESULTS

Table 1: Simulink model parameters

Parameters	
Channel bandwidth	20MHz
Symbol duration	4µs
Modulation	64 QAM
IFFT size	64
Number of subcarriers	48 data subcarriers+4 pilot symbols=52
Cyclic Prefix	16
Diversity order	2x2, 3x3, 4x4

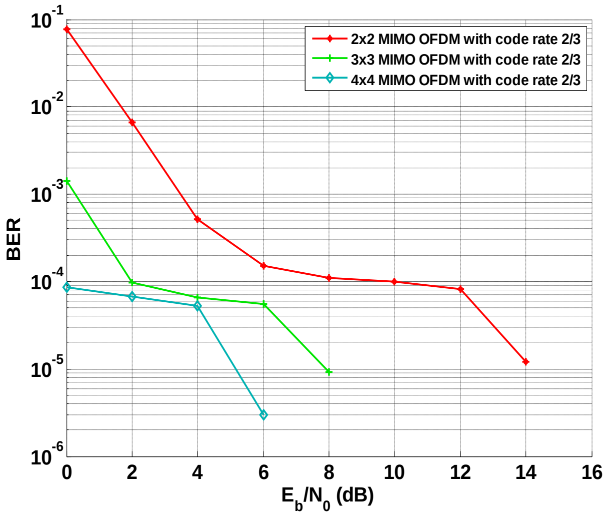

Fig. 6: BER plot of 2x2, 3x3, 4x4 64-qam MIMO OFDM with code rate 2/3 convolution coding

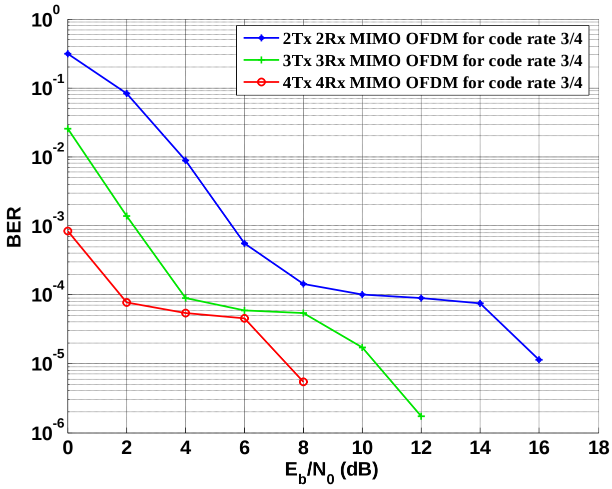

Fig. 7: BER plot of 2x2, 3x3, 4x4 64-qam MIMO OFDM with code rate 3/4 convolution coding

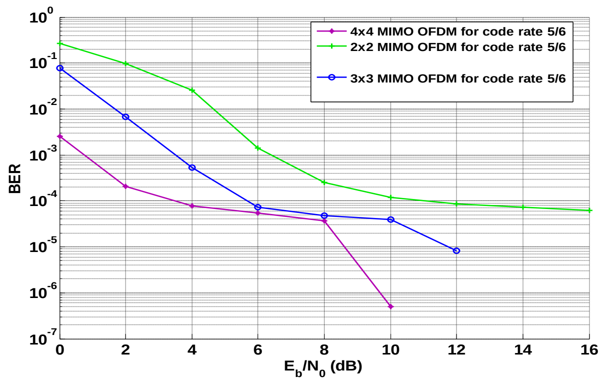

Fig. 8: BER plot of 2x2, 3x3, 4x4 64-qam MIMO OFDM with code rate 5/6 convolution coding

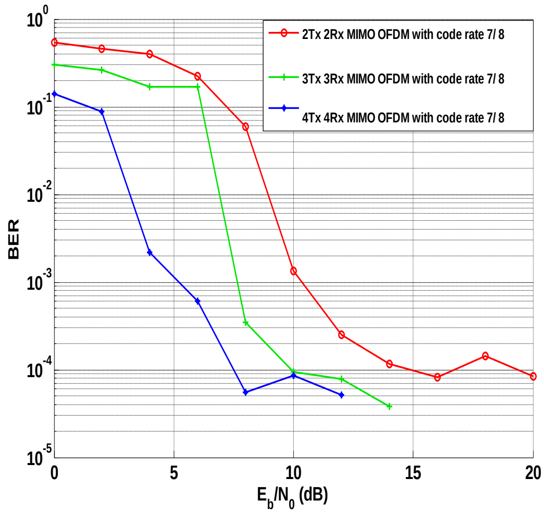

Fig. 9: BER plot of 2x2, 3x3, 4x4 64-qam MIMO OFDM with code rate 7/8 convolution coding

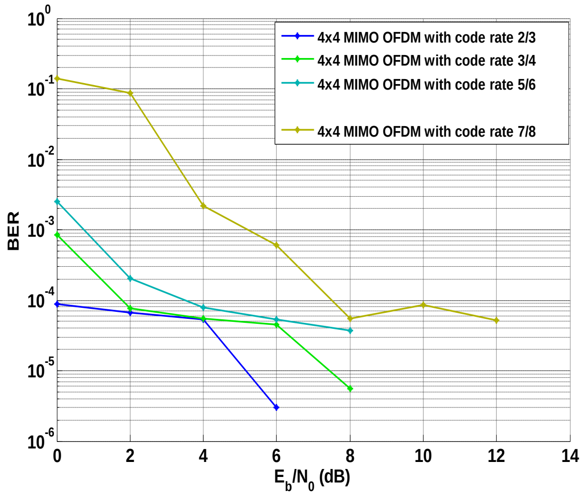

Fig. 10: Comparison of different code rates in 4x4 64 qam MIMO OFDM

The Fig. 6-9 shows the BER plot of MIMO OFDM with convolution coding obtained by varying the code rates. It is seen that 4x4 MIMO OFDM provides the best performance for different code rates. And as the code rate is increased, the Eb/No for a given BER increases. The Table 2 shows the Eb/No value required to achieve a BER of 10^{-5}.

Table 2: Eb/No for different code rate MIMO OFDM

No. of transmitter antenna x No. of receiver antennas	Eb/No (dB) for MIMO OFDM with 2/3 convolution coding	Eb/No (dB) for MIMO OFDM with 2/3 convolution coding	Eb/No (dB) for MIMO OFDM with 2/3 convolution coding	Eb/No (dB) for MIMO OFDM with 2/3 convolution coding
2x2	12	4	16	20
3x3	6	8	10	14
4x4	4	6	8	10

From the Table 2 it is seen that, 4x4 MIMO OFDM requires a lower Eb/No to achieve a low BER. Furthur, from the Fig. 10 it is evident that 4x4 MIMO OFDM with code rate 2/3 convolution coding gives the best performance.

5. CONCLUSION & FUTURE WORK

The MIMO OFDM system with convolution coding was analyzed for different code rates and by varying the number of transmit and receive antennas. The results show that a lower code rate with higher transmit and receive diversity enhanced the system performance providing a lower BER (10^{-6}) at low Eb/No (dB).

The present work was carried out using convolution coding as a channel coding technique in MIMO-OFDM system. So, the work can be extended by using other channel coding techniques like turbo coding, LDPC coding.

6. REFERENCES

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