Performance Analysis of MIMO-OFDM Using Convolution Codes with QAM Modulation

I Gede Puja Astawa, Yoedy Moegiharto, Ahmad Zainudin, Imam Dui Agus Salim, Nur Annisa Anggraeni

Abstract**—**Performance of Orthogonal Frequency Division Multiplexing (OFDM) system can be improved by adding channel coding (error correction code) to detect and correct errors that occur during data transmission. One can use the convolution code. This paper present performance of OFDM using Space Time Block Codes (STBC) diversity technique use QAM modulation with code rate ½. The evaluation is done by analyzing the value of Bit Error Rate (BER) vs. Energy per Bit to Noise Power Spectral Density Ratio (Eb/No). This scheme is conducted 256 subcarrier transmits Rayleigh multipath channel in OFDM system. To achieve a BER of 10^{-3} is required 10dB SNR in SISO-OFDM scheme. For 2x2 MIMO-OFDM scheme requires 10 dB to achieve a BER of 10^{-3}. For 4x4 MIMO-OFDM scheme requires 5 dB while adding convolution in a 4x4 MIMO-OFDM can improve performance up to 0 dB to achieve the same BER. This proves the existence of saving power by 3 dB of 4x4 MIMO-OFDM system without coding, power saving 7dB of 2x2 MIMO-OFDM and significant power savings from SISO-OFDM system

Keywords**—**Convolution code, OFDM, MIMO, QAM, BER.

I. Introduction

THE multipath fading effect is one of the main features of the wireless communication systems. Antenna diversity is an instrument that is effective enough to reduce the effects of multipath fading. The use of multiple antennas at the transmitter and receiver is expected to result in improved quality of the broadband communication services. This technique is known as Multiple Input Multiple Output (MIMO), discovered by Alamouti who previously discovered a scheme by using two antenna senders with one receiving antenna. This is able to provide the same diversity with a single antenna transmitter and two receiver antennas [1]. This technique can be integrated with the multicarrier modulation OFDM.

OFDM [2] is a transmitting data technique with a carrier signal (multi-carrier) by 256 point Fast Fourier Transform (FFT) [3] according to the standardization of Worldwide Interoperability for Microwave Access (WiMAX) which are arranged in parallel and overlapping with each other. The distance between subcarrier is arranged in such a way that is orthogonal (at the time one of the carriers has a maximum level, the other one is in zero level), so it can save bandwidth channel communication systems up to 50%. The orthogonality properties can be enforced from frequency selective fading channels into a frequency flat fading channel, so the resistance of transmission can be improved. The technique has been widely applied in WiMAX (IEEE 802.16d) aiming to answer the need ofNon Line-of-Sight (NLOS) communication. This MIMO-OFDM system employs convolutional code of rate ½ in encoder side with multipath fading channel. Algorithm is used in the decoder side to produce a low error probability that functions as BER with the number of bits having fewer errors.

II. System Modeling

System modeling is shown Fig. 1. The information is bits of data encoded with convolution into bit codeword, and then mapped by the QAM mapper. Through OFDM multicarrier modulator, the mapper result is converted into an OFDM symbol which transmits over multi antenna with Space-Time Coding scheme. The signal passed through a channel that is affected by the presence of noise Additive White Gaussian Noise (AWGN) and Rayleigh fading. The received signal is detected by using the Maximum Likelihood Detector (MLD) in STBC decoder. Then, the signal is processed by the OFDM demodulator and mapped again with QAM demapper. The QAM demapper output is a single bit encoded again using The Viterbi Algorithm to gain the information bits.

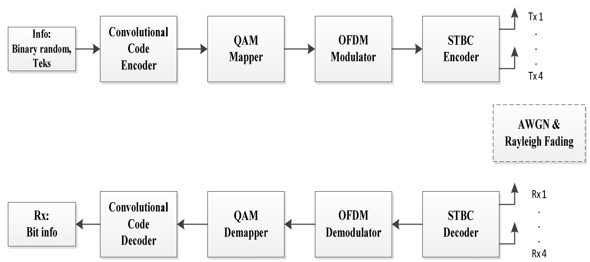

Fig. 1 The simulation block diagram system

A. Convolution Code Encoder

Encoding process begins with the generation of 600000 random binary bits. For text data type, the first step is decimal to binary conversion. Then it is encoded by convolutional code of rate ½. The convolution encoder structure is (2,1,2) with generator upper polynomial matrix [4], [1 1 1] and under polynomial matrix, [1 0 1]. The output of this block is codeword with length 1200000 bits. Through QAM mapper block codeword is mapped into signal with the possibility of phase and amplitude formed. QAM modulator produces symbols in which each symbol represents 2 bits input according to the constellation diagram QAM.

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B. OFDM Modulator

The main principle of OFDM is the high-speed distribution of a data stream into a number of low-speed data streams, then, sent through subcarrier simultaneously. Row of data are converted into information in the form of parallel. The original bit rate R is transmitted into a parallel path R/N, where N refers to number of 256subcarriers (equal to the number of parallel paths) of which each datum is modulated by subcarrier with FFT size 256 using the IFFT to form OFDM symbols. Equation (1) [5] shows the IFFT process that allows the allocation of OFDM symbols in the form of time. The output of the IFFT OFDM symbols forms a mutually orthogonal in time domain.

$$x(n) = \sum_{n=0}^{N-1} x(k) \sin\left(\frac{2\pi kn}{N}\right) - j \sum_{n=0}^{N-1} x(k) \cos\left(\frac{2\pi kn}{N}\right) \quad (1)$$

where x (n) is the IFFT output signal, x (k) is the transmitted signal at the k-th and N is the number of subcarriers. OFDM symbol is formed after the next process is added with cyclic prefix 50% of the total subcarrier channel that serves as a guard to avoid Inter Symbol Interference (ISI). After the addition of the cyclic prefix represented in Equation 2, the data are converted back to serial form that can be transmitted from the channel parallel to serial converter.

$$T_{total} = T + T_g \quad (2)$$

where T is the OFDM symbol length without cyclic prefix, Tg is the length of cyclic prefix and the OFDM symbol T_{total} is the overall length.

C. OSTBC Encoding

Space Time Block Code is a technique used in wireless communications to transmit a copy of a data stream in a number of antennas and utilizes a variety of data received to improve the reliability of data transfer. STBC was first introduced by Alamouti [1] showing the same performance of simple scheme MRC diversity. Alamouti's scheme is very useful because it is easy and economical. STBC techniques apply spatial diversity (multiple antenna transmitters and receivers) and time diversity techniques (sending replica conjugate signals) in the time series. Alamoutih as made the basic foundation of OSTBC developed to be used for more than two transmitting antennas.

$$C^H C = \sum_{n=1}^{N} |C_n|^2 \, \mathrm{I} \quad (3)$$

Based on (3), transmitting C is orthogonal to each other, H is the Hermitian transpose, whereas I is the identity matrix nx n. This means that in each block, the signal sequence of every two transmit antennas are orthogonal [6]. This technique allows us to achieve diversity and send it at the same time. This also allows the receiver to separate the signals transmitted from different antennas and a simple ML decoding to be used. Matrixs for two transmiting antennas in Alamouti STBC code [1] is shown in (4)

$$x_2 = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1 \end{bmatrix} \quad (4)$$

OSTBC matrix of four transmitting antennas with ½ rate code is shown in (5) [6].

$$X_{4,1/2} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ -x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{bmatrix} \quad (5)$$

Note: x_1 is the first signal transmitted on the first antenna 1 time slot, and so on. Conjugation x_1 * is a first signal transmitted from the first antenna 1 time slot and so on.

D.OSTBC Decoding

The STBC signal decoding process is a process called Maximum Ratio Combining (MRC), of which the estimated receiving signals are obtained. Hence, these signals are used as the input of the next block diagram of OFDM demodulator. Signal data are received by 2 or 4 antenna receivers in OSTBC schemes of which$r_t{}^j$ is a signal at time t at the j-th antenna, shown by (6) [2].

$$r_t{}^j = \sum_{i=1}^{n_T} \left(x_t^i h_{i,j} + n_t{}^j \right) \quad (6)$$

$r_t{}^j$is the signal received by the antenna at the receiver-j at time t; $x_t^i$is the signal transmitted by the transmitter to the antenna-i at time t;$h_{i,j}$is the channel coefficient and $n_t{}^j$ is the channel accepted coefficient.

Equations (7) and (8) show the decoding of each STBC signal for two transmitter antennas.

Decoding the signal s_1 :

$$\tilde{x}_1 = \sum_{j=1}^{n_R} \left(r_1{}^j h^*{}_{j,1} + r_2{}^j h^*{}_{j,2} + r_3{}^j h^*{}_{j,3} + \left(r_5{}^j\right)^* h_{j,1} + \left(r_6{}^j\right)^* h_{j,2} + \left(r_7{}^j\right)^* h_{j,3} \right) \quad (7)$$

Decoding signal s_2 :

$$\tilde{x}_2 = \sum_{j=1}^{n_R} \left(r_1{}^j h^*{}_{j,2} - r_2{}^j h^*{}_{j,1} + r_4{}^j h^*{}_{j,3} + \left(r_5{}^j\right)^* h_{j,2} - \left(r_6{}^j\right)^* h_{j,1} + \left(r_8{}^j\right)^* h_{j,3} \right) \quad (8)$$

Equations (9)-(12) represent the equations decoding X_4^c to seek each with 4 antenna OSTBC signal transmitter.

Decoding signal s_2:

$$\tilde{x}_1 = \sum_{j=1}^{n_R} \left(r_1{}^j h^*{}_{j,1} + r_2{}^j h^*{}_{j,2} + r_3{}^j h^*{}_{j,3} + \left(r_5{}^j\right)^* h_{j,1} + \left(r_6{}^j\right)^* h_{j,2} + \left(r_7{}^j\right)^* h_{j,3} + \left(r_8{}^j\right)^* h_{j,4} \right) \quad (9)$$

Decoding signal s_2:

$$\tilde{x}_2 = \sum_{j=1}^{n_R} \left(r_1{}^j h^*{}_{j,2} - r_2{}^j h^*{}_{j,1} - r_3{}^j h^*{}_{j,4} + r_4{}^j h^*{}_{j,3} + (r_5{}^j)^* h_{j,2} - (r_6{}^j)^* h_{j,1} - (r_7{}^j)^* h_{j,4} \right) + (r_8{}^j)^* h_{j,3} \quad (10)$$

Decoding signal s_3:

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:7, No:12, 2013

$$\tilde{x}_3 = \sum_{j=1}^{n_R}\left(r_1{}^j h^*{}_{j,3} + r_2{}^j h^*{}_{j,4} - r_3{}^j h^*{}_{j,1} - r_4{}^j h^*{}_{j,2} + \left(r_5{}^j\right)^* h_{j,3} + \left(r_6{}^j\right)^* h_{j,4} - \left(r_7{}^j\right)^* h_{j,1} - \left(r_8{}^j\right)^* h_{j,2}\right) \quad (11)$$

Decoding signal s_4:

$$\tilde{x}_4 = \sum_{j=1}^{n_R}\left(-r_1{}^j h^*{}_{j,4} - r_2{}^j h^*{}_{j,3} + r_3{}^j h^*{}_{j,2} - r_4{}^j h^*{}_{j,1} - (r_5{}^j)^* h_{j,4} + (r_6{}^j)^* h_{j,3} - (r_7{}^j)^* h_{j,2} - (r_8{}^j)^* h_{j,1}\right) \quad (12)$$

E. OFDM Demodulator

OFDM decomposes a signal using Fast Fourier Transform (FFT). Its function is to obtain a signal in the back frequency domain. The FFT process can be represented by (13) [5]. This process is also done in the disposal of cyclic prefix.

$$x(k) = \sum_{n=0}^{N-1} x(n) \sin\left(\frac{2\pi kn}{N}\right) + j \sum_{n=0}^{N-1} x(n) \cos\left(\frac{2\pi kn}{N}\right) \quad (13)$$

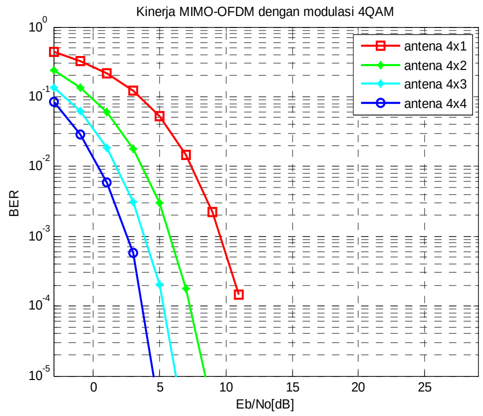
where x (n) is the signal at time n; N is the number of subcarriers (subcarrier = 256); k is the frequency index of N; n is the index of time that produces x (k) that is the value of the frequency spectrum atk .

F. Convolution Decoding

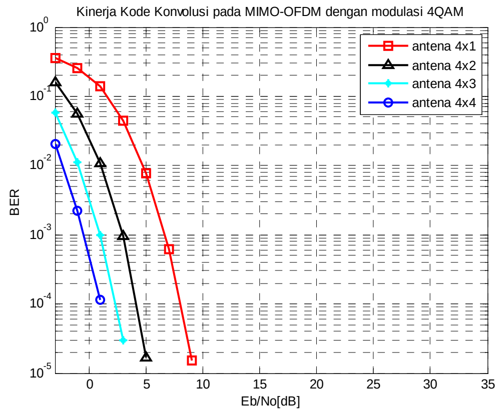
It starts with the initialization of the starting point S0 with value 0. The next process, a set of codes sent (r) first is taken as much as 2 bits. Then the set of codes is compared with sets of all trajectories exiting from the starting point. Next, a value equal to the value of the different sets of trajectories is given to a set of acceptable ones. Then the value of the node that is now achievable determined. The value of the node is obtained by summing up the values achieved origin node with the value of the track. If the set of r has not been exhausted, the next retrieved set of 2 bits is taken again, then the above process repeated. If one node is reached more than one direction, the track that produces the minimum value of the node must remain. Then a track that is considered correct is created. The trajectory assumed to be true is the path that produces the minimum node. Having made the correct trajectory, coding process is considered complete. The process takes 2 bits of data to generate 1 bit output. Determination of output and next state bits is based on the table which has been created. For simplicity, the initial state trellis starts from state 00. According to the table, when the state is 00, input 0 is given to produce output 00 that leads to state 00. When the input 1 is given, the resulting output will be in state 11 that goes to state 01 .To determine which path is used, the output results of the process are compared with the state first 2 bits of data from the system to see the amount of error. This process runs continuously on every state until the end of the data bit system. The amount of errors in each state is accumulated. And the chosen path is the path that has the smallest number of errors (according to the principles Hamming distance). So this process will give output results. The result of decoding data is the output data of the system that has been compared with the bits of info that are sent to the unknown BER system.

III. Results

In this section the results of testing the system are displayed in the form of BER curves based on the method previously described. Tests are performed on an OSTBC-OFDM system with 4 transmitting antennas and 1 to 4 receiving antennas. Where the number of subcarriers is equal to the FFT size being used that is equal to 256 subcarriers and the modulation is QAM. Convolution codes have rate ½.The channel used for the transmission of data contains noise AWGN and Rayleigh fading.



(a)



(b)

Fig. 2 Performance comparison chart Convolution Code OSTBC-OFDM Systems in Rayleigh channel (a) System without Convolution, and (b) System with Convolution

In Fig. 2 (a) system with 4x4 scheme requires Eb/No to achieve a BER of 10^{-3} 3dB. With a 4x3 antenna configuration, the system can achieve 10-3 BER with Eb / No of 4dB.For a 4x2 antenna configuration, the OSTBC-OFDM systems is applied without requiring convolution code Eb/No of 6dB in order to achieve the same BER. And when the system has the configuration 4x1, it has a poor performance compared with the three systems with antenna configuration 4x2, 4x3, 4x4. This system requires Eb/No 10dB to achieve BER of 10^{-3}.The system with a 4x1 antenna configuration is said to be the worst if it is implemented because it requires a great power and it affects the cost of implementation of the system.

In Fig. 2 (b), it can be observed that by using convolution code, 4x4 antenna transmission scheme is able to achieve dB at 10^{-3} BER performance almost 0dB SNR; with a 4x3 antenna configuration achieves the required BER of 10^{-3} dB SNR by 1dB. Then the 4x2 antenna configuration is capable of achieving performance dB at 10^{-3} BER and SNR 4dB to 6dB SNR. For 4x1, configuration achieves a BER of 10-3 dB. The system processed using QAM modulation symbols to represent the mean 1 by 2 bits. The system with a 4x4 antenna configuration scheme has better performance 1dB (value SNR).The system with a 4x3 antenna configuration is 3dB better than the system with 4x2 configuration. And OSTBC-OFDM system is 6dB better with convolution code with 4x1 antenna configuration.

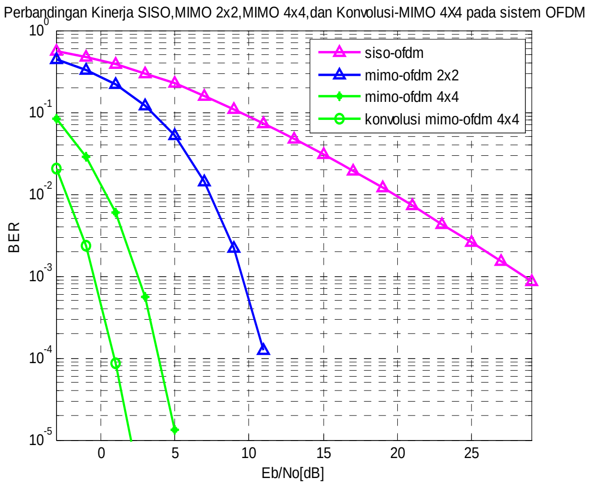


Fig. 3 Performance comparison between SISO-OFDM system, a 2x2 MIMO-OFDM, MIMO-OFDM and 4x4 Convolution Code in the 4x4 MIMO-OFDM modulation 4-QAM

In this section a comparison test is conducted on a pure OFDM system that has been added with STBC 2x2, 4x4 MIMO and 4x4 MIMO with convolution. The system is generated by modulating QAM, FFT size using 256 - FFT and convolution code rate ½. Based on Fig. 3, the OFDM 2x2 MIMO requires SNR of 9dB to achieve a BER of 10^{-3}. 4x4 MIMO-OFDM systems need a 3dB SNR to achieve a BER of 10^{-3}. And the convolution coding in MIMO-OFDM systems 4x4 requires almost 0 dB SNR to achieve a BER of 10^{-3}. So by adding convolution code, the MIMO-OFDM system with 4x4 convolution code can improve the system performance better 3dB of MIMO-OFDM with 4x4 antenna configuration than without convolution code. In addition, the application of the antenna in the dimensional configuration changes in the sender and receiver, the resulting performance is also better. The configuration of 4x4 MIMO-OFDM antenna has 7dB better performance than antenna 2x2 MIMO-OFDM systems with code convolution.

A comparison between a MIMO-OFDM system without Convolution Code and a system using Convolution Codes is discussed. The remaining problem faced in this research is the computation which is lack of enough memory; therefore, the data generated are limited. For further research, a new method is hopefully found to reduce the complexity of systems in testing large data such as multimedia.

IV. Conclusion

Performance testing with rate ½ convolution code has been done by applying the OSTBC-OFDM systems to reduce errors in data transmission. The application of convolution code can improve the performance of the OFDM system up to 3dB gain of 2 dB for dB at 10^{-3}BER value in Rayleigh channels. The applied performance of changing dimension for antenna configuration both the transmitter and the receiver is fairly good. On the configuration of OSTBC-OFDM, 4x4 antenna has better performance than STBC-OFDM 7dB 2x2 antenna.

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