Performance of Least Square Based Channel Estimation for High Order Modulation QAM-OFDM-MIMO in the Presence of Multipath Fading Channel

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Abstract- **As the communication system evolving and enhancing, the need for high speed and reliable communication system is crucial. With the combination of multiple-input multiple-output (MIMO) communication system along orthogonal frequency division multiplexing (OFDM), a reliable high rate communication system can be achieved. The MIMO OFDM system with 2X2, 3x3, and 4x4 antenna configurations will use 256, 512 and 1024 QAM modulation level in the presence of multipath Rayleigh and Additive White Gaussian Noise (AWGN) channel. The performance evaluation of the system is determined in term of Bit Error Rate (BER) and Signal Energy to Noise Power Ratio (Eb/No). The MIMO OFDM system with Least Square channel estimation will be designed and simulated using MATLAB where the results will then be analyzed. From the results obtained, it can be said that as the QAM level increased the BER will increase too. Besides that, the performance of the system will improves as the number of transmit and receive antennas increase.**

Keywords-MIMO-OFDM; M-QAM; Least Square;

I. INTRODUCTION

Wireless communication system has been through many changes and improvement since the first wireless communication invention by Alexander Graham Bell and Charles Sumner Tainter in 1880. It is widely used over the world and has great impact in our daily life. The need for high communication speed caused the technology keep evolving and advancing. MIMO-OFDM is a new wireless communication technology that has gained more attention for its capability of high rate transmission and its robustness against Multi-path fading and other channel impairments [1, 2].

Least Square (LS) channel estimation is used at the receiver to remove the fading effect caused by the Rayleigh multipath channel. The LS method is chosen because it is less complicated and simple compared to other methods [1, 3], but it is more sensitive to channel noise [3]. M-ary quadrature amplitude modulation (QAM) is an attractive technique to achieve high rate transmission without increasing the bandwidth since it is spectrally efficient [1, 4]. Many of modern wireless communications standards has been using Quadrature amplitude modulation in their system[5]. Quadrature Amplitude Modulation (QAM) schemes like 16-QAM and 64-QAM are used in typical wireless digital communications and 256-QAM, 512-QAM, 1024-QAM are used in Wifi [1, 5].

In order to achieve high transmission data rate, the system use high order QAM level. High order QAM level has high data rate but less resilient to noise [1, 6, 7]. To overcome the noise problem in high order QAM level, high antenna configuration is used as BER decreases with the increases of number of transmit and receive antenna [6, 8, 9]. The antenna configurations used are 2x2, 3x3, and 4x4 in the presence of Rayleigh and AWGN channel.

A. MIMO SYSTEM

MIMO are receiving more attention as it provides many advantages for communication system by exploiting the multi path channel between transmitter and receiver. Spatial diversity in MIMO helps to reduce the fading effect. Besides that, the capacity also increased over single-antenna-to-single-antenna communication (SISO) [10].

MIMO uses multiple antennas at the transmitter and receiver in a communication system and it can increases the transmission rate by using the multi-path propagation. The spectrum efficiency in wireless transmission can be enhanced by the use of multipath channel between transmitter and receiver [11]. In MIMO systems, a transmitter sends multiple streams by multiple transmit antennas. The transmit streams go through a matrix channel which consists of all N_tN_r paths between the N_t transmit antennas at the transmitter and N_r receive antennas at the receiver. Then, the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information [9].

The number of receiver antenna has to be equal to or larger than the number of transmitter antennas to remove the mutual interference when the signals from different antennas interfere with each other [12].

The relation between transmitted and received signal in MIMO is modeled as

$$y = Hx + n \tag{1}$$

Where x is the transmitted signal, y is the received signal, H is the MIMO channel matrix and n is the noise vector.

The channel of the mimo system can be expressed by a matrix

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \dots & h_{1,N_T} \\ h_{2,1} & h_{2,2} & \dots & h_{2,N_T} \\ \vdots & \vdots & \dots & \vdots \\ h_{N_R,1} & h_{N_R,2} & \dots & h_{N_R,N_T} \end{bmatrix}$$

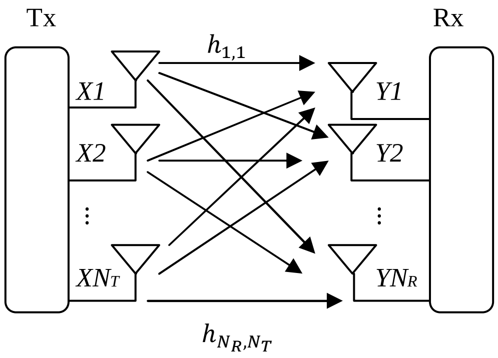

Figure 1. MIMO system structure

Figure 1 shows the system structure of MIMO system. As the number transmit and receive antennas increase, the number of MIMO channels also increase by *NtNr*.

B. OFDM SYSTEM

OFDM is a multi-carrier modulation technology [11, 13, 14]. Modulation by an orthogonal sub-carrier is easily implemented by the inverse fast Fourier transform (IFFT) operation. Firstly, a serial high rate data stream is converted to parallel low rate data stream which are modulated by an orthogonal sub-carrier and transmitted in N sub-channels [11, 13]. As a result, the symbol period will increase. Inter symbol interference can be eliminated if a signal is sent over multiple low-rate carriers instead of a single high-rate carrier. Moreover, the receiver will less complex when the frequency selective channel becomes flat channel.

The N-point FFT is defined as

$$\mathrm{FFT}\{x[n]\} = \sum_{k=0}^{n} x[n]e^{-jk\frac{2\pi}{N}n} \quad k = 0,1,\dots N-1 \quad (2)$$

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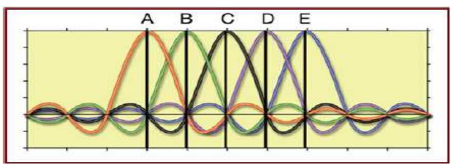


Figure 2. OFDM signal spectrum[13]

Figure 2 shows the signal spectrum of OFDM signal. It can be seen that each signal is overlapping with each other but interfering is not occurs as the signal is orthogonal to each other. Thus it will increase the spectrum efficiency.

C. MIMO-OFDM SYSTEM

MIMO-OFDM has been widely use in many wireless standards such as WiMAX and 4G mobile wireless systems. MIMO-OFDM system can compensate for the lacks of MIMO systems and give play to the advantage of OFDM system [15]. High capacity and high data rate can be achieved by combining MIMO and OFDM system. [14].

Diversity method and spatial multiplexing are the ways to improve the MIMO signaling in wireless communication systems [16]. By exploiting the multiple paths between transmit and receive antenna, diversity method could improve the system performance of the communication system in terms of BER. [15]. While in spatial multiplexing method, increased number of antennas will provide a linear increased in capacity gain with the use of multiple antennas at transmitter and receiver. [7].

Figure 3 shows the MIMO-OFDM system with least square channel estimation. Constellation data mapping is done in QAM modulator and then the serial data stream is modulated by OFDM modulator to become parallel data stream which are orthogonal with each other. The sets of data are transmitted with multiple antennas through multipath Rayleigh and AWGN channel. At receiver, the signal data is demodulated by OFDM demodulator and is applied with least square channel estimation to get rid of the fading effect. Then QAM demapper converts the data stream to original data.

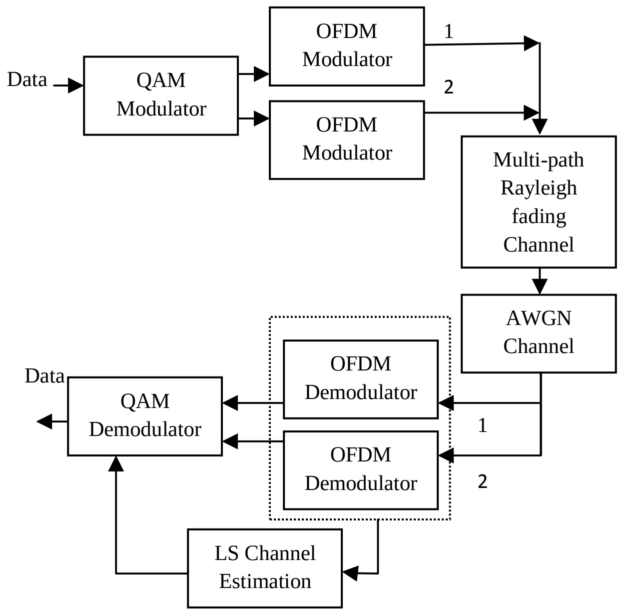


Figure 3. 2x2 MIMO-OFDM System Structure

D. QUADRATURE AMPLITUDE MODULATION

QAM is a modulation technique that consists of two carriers whose amplitudes are out of phase (in quadrature) with each other. It can be expressed as

$$s(t) = A_I cos2\pi f_c t + A_Q sin2\pi f_c t \quad , 0 \leq t < T \qquad (4)$$

Where A_I and A_Q are the carrier's amplitude, f_c is the carrier frequency and T is the time period. Bits per symbol transmit for M-QAM level can be determined by $M=2^N$ where M is the QAM level and N is the bits per symbol. For example, 256 QAM level has 8 bits per symbol. Higher bits per symbol sent will increase the probability of bits error. Figure 4 shows the modulation and demodulation of square M-QAM. At the modulator, the data bit stream is split into the in phase (I) and quadrature (Q) bit streams. The I and Q components together are mapped to complex symbols using Gray coding. The demodulator splits the complex symbols into I and Q components and puts them into a decision device (demapper), where they are demodulated independently against their respective decision boundaries [1].

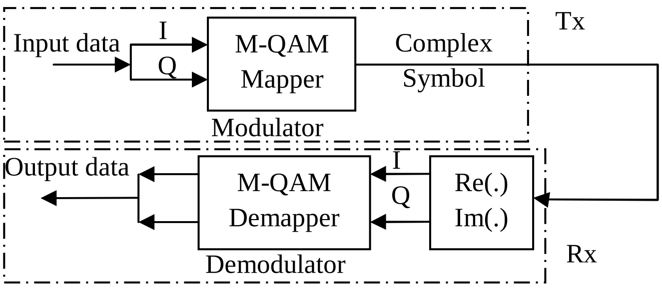


Figure 4. M-QAM modulation and demodulation

E. LEAST SQUARE CHANNEL ESTIMATION

The received signal through noisy channel is distorted. To recover the transmitted data, the channel effect must be estimated and compensated in the receiver. The goal of the channel least square estimator is to minimize the square distance between the received signal and the original signal [17]. LS has been used widely for its simplicity.

The LS channel estimation H_{LS} can be written for each subcarrier as,

$$H_{LS}[k] = \frac{Y[k]}{X[k]}, \ k = 0,1,2, \ldots, N-1 \qquad (5)$$

II. METHODOLOGY

The MIMO-OFDM system is simulated in Matlab version 8.3.

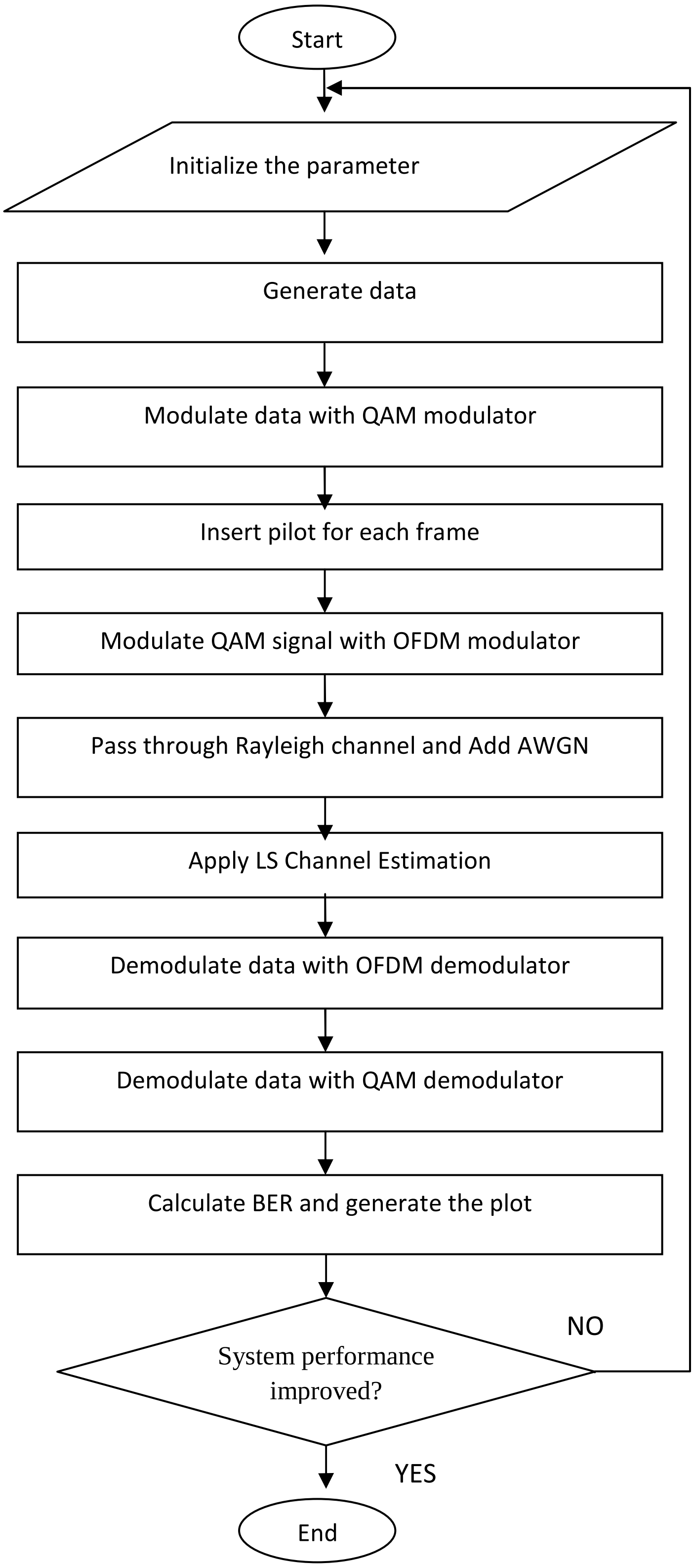


Figure 5. MIMO-OFDM System Flowchart

Figure 5 above shows the simulation process of MIMO-OFDM system with LS channel estimation. First of all, the system object for the simulation process is initialized. This processes including defining the function of QAM modulator, QAM demodulator, OFDM modulator and demodulator. Besides that, all the setting parameters and values are declared at this process such as the QAM level and the number of antenna.

The next process is to generate random data to be transmitted for each sub-carrier and antennas. Then, the data will be modulated by the QAM modulator for each QAM level. The next process is to modulate the data using OFDM modulator where the signal is orthogonal to each other. After that, the data is transmitted through multipath Rayleigh channel and AWGN is added in the process. Distorted signal then is estimated using LS channel estimation to remove the fading effect. OFDM demodulator and QAM demodulator demodulates the signal to original data. Then, the BER is calculated and the graph of BER versus Eb/No for MQAM level with various antennas configurations is plotted.

TABLE I. PARAMATER OF MIMO-OFDM SYSTEM

Parameter	Value
Antenna Configuration	2x2,3x3,4x4
QAM level	256,512,1024
FFT length	128
Frame length	100
Cyclic Prefix	16
Channel Estimation	Least Square

Table 1 shows the parameters that are used in the simulation. The parameters are based on the WLAN standard.

III. RESULTS AND DISCUSSION

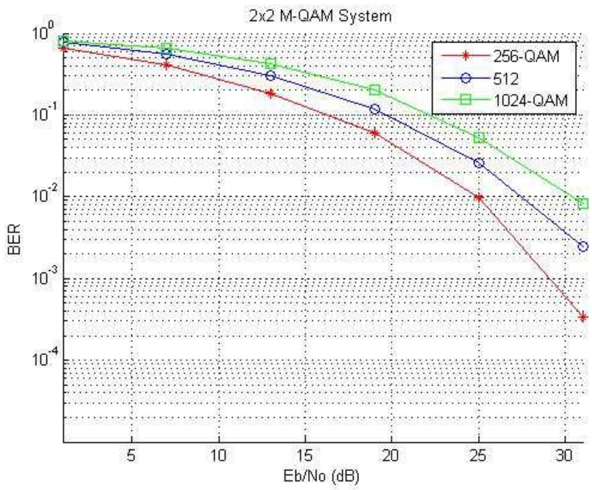


Figure 6. BER vs Eb/No of MIMO-OFDM system with 2x2 antenna configuration

Figure 6 shows the BER versus Eb/No for 256 QAM, 512 QAM and 1024 QAM with 2x2 antenna configurations. BER for 256 QAM is lower than BER for 512QAM and 1024QAM for the same Eb/No. At Eb/No equal to 25dB, the BER for 256 QAM is 10^{-2}. While BER for 512 QAM and 1024 QAM are $29x10^{-2}$ and $5x10^{-2}$ respectively.

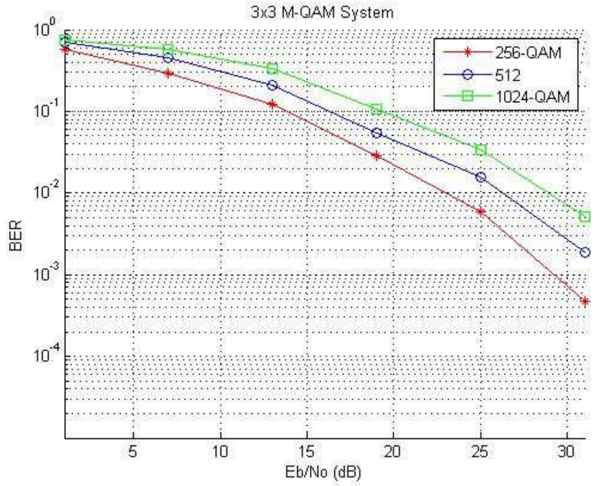


Figure 7. BER vs Eb/No of MIMO-OFDM system with 3x3 with antenna configuration

Figure 7 shows the BER versus Eb/No for 256 QAM, 512 QAM and 1024 QAM with 3x3 antenna configurations. BER for 512 QAM is higher than BER for 256 QAM but lower than 1024 QAM for the same Eb/No. At Eb/No equal to 25dB, the BER for 512 QAM is $18x10^{-2}$. While BER for 256 QAM and 1024 QAM are $6x10^{-3}$ and $35x10^{-2}$ respectively.

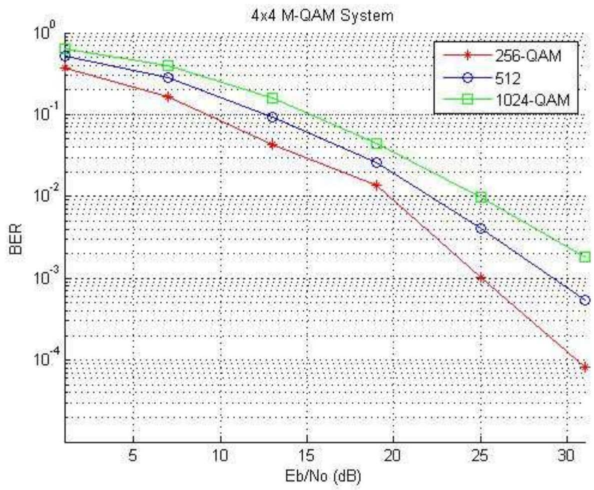


Figure 8. BER vs Eb/No of MIMO-OFDM system with 4x4 antenna configuration

Figure 8 shows the BER versus Eb/No for 256 QAM, 512 QAM and 1024 QAM with 4x4 antenna configurations. BER for 1024 QAM is higher than BER for 256 QAM and 512 QAM for the same Eb/No. At Eb/No equal to 25dB, the BER for 1024 QAM is 10^{-2}. While BER for 256 QAM and 512 QAM are 10^{-3} and $45x10^{-3}$ respectively.

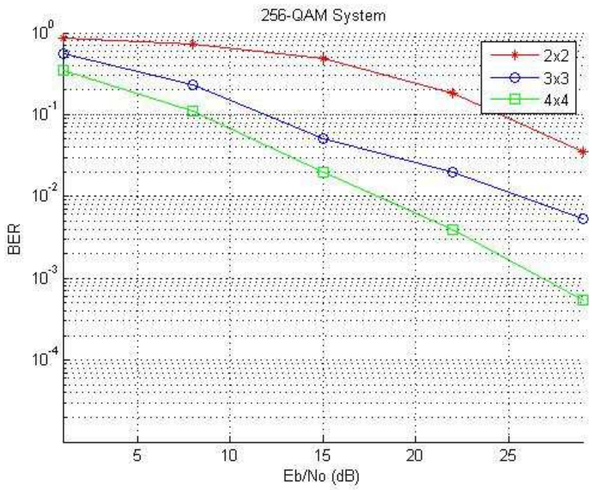


Figure 9. BER vs Eb/No of MIMO-OFDM system for 256 QAM with 2x2,3x3 and 4x4 antenna configuration

Based on Figure 9, the BER for 4x4 antennas is better than 2x2 and 3x3 antennas. At Eb/No equal to 15dB, BER for 4x4 antennas is $2x10^{-2}$ while it increases with 3x3 and 2x2 which the BER are $5x10^{-2}$ and $5x10^{-1}$ respectively.

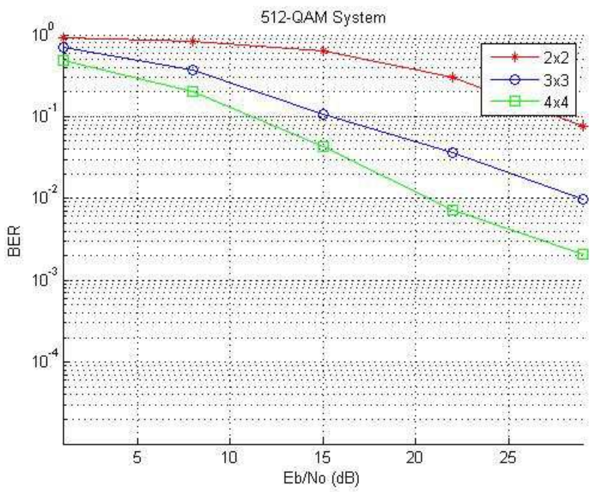
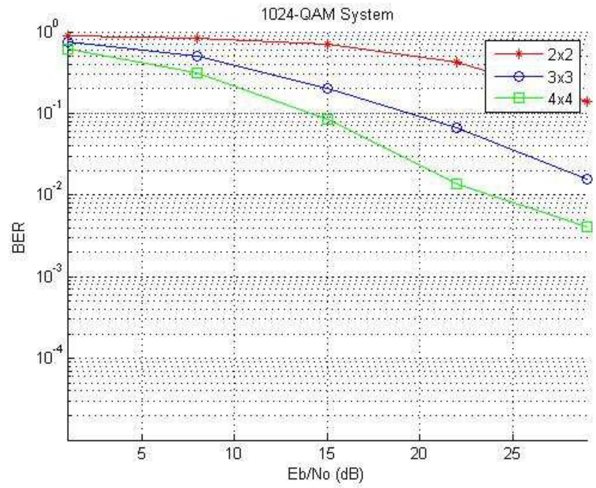


Figure 10. BER vs Eb/No of MIMO-OFDM system for 512 QAM with 2x2, 3x3 and 4x4 antenna configuration

Figure 10 shows the BER vs Eb/No for 512 QAM with 2x2, 3x3 and 4x4 antennas. As expected, the BER for 4x4 antennas is better compared to 3x3 and 2x2 antennas. At Eb/No equal to 15dB, the BER for 4x4 antennas is $4.5x10^{-2}$. It increases to 10^{-1} and $6x10^{-1}$ for 3x3 and 2x2 antennas with the same value of Eb/No.



Figgure 11. BER vs Eb/No of MIMO-OFDM system with 2x2, 3x3, and 4x4 antenna configuration

In figure 11, the BER for 1024 QAM with 4x4 antennas is still showing lower BER than 3x3 and 2x2 antennas. However, the BER is increased compared to 256 QAM and 512 QAM. The graph shows that the BER for 4x4 antennas are $9x10^{-2}$, $2x10^{-1}$ and $7x10^{-1}$ for 3x3 and 2x2 antennas respectively with Eb/No equal to 15dB.

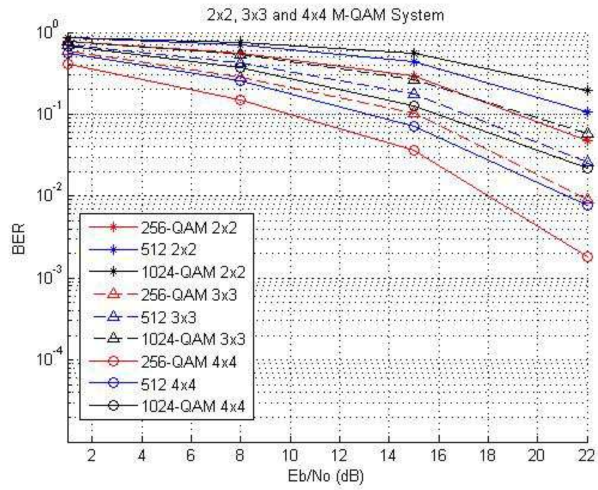


Figure 12. BER vs Eb/No of MIMO-OFDM system for M-QAM with 2x2, 3x3, 4x4 antenna configuration

Figure 12 shows the BER vs Eb/No for 256 QAM, 512 QAM and 1024 QAM for 2x2, 3x3 and 4x4 antenna configuration. It can be seen that the BER for 256 QAM with 4x4 antennas produce the best performance compare to others. In the mean time, 1024 QAM with 2x2 antennas indicates the lowest performance of BER.

TABLE II. BER AT EB/NO = 25DB FOR MIMO-OFDM SYSTEM

	Bit Error Rate		
M-QAM	***2x2***	***3x3***	***4x4***
256	0.01	0.006	0.001
512	0.029	0.018	0.0045
1024	0.05	0.035	0.01

Based on Table II, the performance of the system clearly degraded when the QAM level increases. At Eb/No equal to 25dB, 1024 QAM has the lower BER for 4x4 antenna configurations which is 10^{-2} compared to 2x2 and 3x3 antennas where the BER are $5x10^{-2}$ and $35x10^{-2}$. For 512 QAM with 4x4 antenna configurations, the BER is $45x10^{-3}$ and increased to $18x10^{-2}$ for 3x3 antennas and then $29x10^{-2}$ for 2x2 antenna configurations. Lastly, for 256 QAM with 4x4 antennas, the BER is 10^{-3}. The BER increased to $6x10^{-3}$ and 10^{-2} for 3x3 and 2x2 antenna configurations respectively.

High QAM level means high bits per symbol is transmitted. For example, in 256 QAM, 8 bits per symbol is transmitted while in 32QAM, only 5 bits per symbol is transmitted. Therefore, the probability of errors also increased. However, the performance of high order QAM is improved with 4x4 antenna configuration compared to 2x2 and 3x3 antennas. The diversity scheme provided by MIMO help to reduced the BER. Data transmitted by multiple transmit antennas and distorted by noise. Then multiple distorted data is picked up by multiple receive antennas and being compared. The best decoded data will be the output.

IV. CONCLUSION

In this paper, the MIMO-OFDM system is estimated by using LS technique due to its simplicity. Besides that, the system is modulated with 256, 512, and 1024 QAM level for their high data rate characteristics in transmission. With high data rate, high order QAM is prone to noise. To reduce the BER caused by noise, the system is using MIMO antenna which are 2x2, 3x3 and 4x4. Greater number of transmit and receive antenna has improved the system performance where the BER decreases. Another technique to use high order QAM without increasing the BER is with high Eb/No by increasing the signal energy or reducing the noise or both.

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VI. RECOMMENDATION

System performance can further be improved by using another channel estimation such as Minimum Mean Square Error and Maximum Likelihood channel estimation. In exchange, the complexity of the system will increase. Besides that, the system also can implement STBC or SFBC to get better performance.

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