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DESIGN AND PERFORMANCE ANALYSIS OF MIMO-OFDM FOR WLAN STANDARD

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ABSTRACT

A combination of multiple-input multiple-output (MIMO) signal processing with orthogonal frequencydivision multiplexing (OFDM) is regarded as a promising solution for enhancing the performance of next generation wireless local area network (WLAN) systems.Because of the rapid growth of Digital Communication in recent years, the need for high speed data transmission is increased. Orthogonal frequency division multiplexing (OFDM) technique is suitable for high speed communication and it utilizes the bandwidth efficiently [1]. MIMO-OFDM is a combination of OFDM and MIMO (Multiple Input Multiple Output) techniques suitable for design of multi-user system and robust against channel impairments. In this paper we have implemented MIMO-OFDM for WLAN (IEEE802.11a) standard. This paper compares bit error rate (BER) performance of Simulink based MIMO-OFDM model for different modulation technique. Here we have used BPSK, QPSK and M-QAM modulation techniques.

KEYWORDS: OFDM, Wireless LAN, M-QAM, SNR, MIMO-OFDM

INTRODUCTION

For modern wireless communication high data rate is a most important parameter. The principles of orthogonal frequency division multiplexing (OFDM) modulation have been in existence for several decades. These techniques are extensively used now in modern communications systems. Some of the applications of OFDM are Wireless networking, data transmission over the phone line, digital radio and television. OFDM is one of the applications of a parallel-data-transmission scheme, which reduces the influence of multipath fading and makes complex equalizers unnecessary [1]. One of the main reasons to use OFDM is to increase robustness against frequency-selective fading or narrowband interference.

Multiple Input Multiple Output (MIMO) is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power [2]. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) or to achieve a diversity gain that improves the link reliability (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication.

The combination of MIMO signal processing with OFDM [3] is regarded as a promising solution for enhancing the data rates of wireless communication systems operating in frequency selective fading environments. To realize this extension of OFDM with MIMO, a number of changes are required in the baseband signal processing. An overview is given of the necessary changes including time and frequency synchronization, channel estimation, synchronization tracking, and MIMO detection. The OFDM based wireless local area network (WLAN) standard IEEE 802.11a is considered but the results are applicable more generally. This model is used to simulate the bit error rate (BER) and packet error rate (PER) performance of several single user MIMO configurations applying different modulation techniques.

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

OFDM is a special multi-carrier transmission technology in which high-speed serial data are converted into N channel parallel data and certain frequency band is divided into N orthogonal sub-channels. N way different sub-carriers are used to modulate the N-channel data separately, and then transmit the sub-carrier parallel [1]. The traditional frequency division multiplexing method needs a lot of filters in receiver and transmitter for the spectrum of each subcarrier is non overlapping and the sub-carrier must maintain sufficient frequency separation to reduce the mutual interference between the sub-carrier. So the system complexity and cost increase greatly and the frequency utilization is reduced. The OFDM system uses digital signal processing technology. Digital signal processing algorithm is adopted in the process of sub-carrier generation and reception and then the structure of the system is simplified greatly. Meanwhile, in order to improve frequency spectrum utilization, each sub-carrier spectrum which meet the orthogonally throughout the symbol period to ensure the receiving end recover the signal without distortion is overlapped [3]. The OFDM signal spectrum as shown in Figure 1. OFDM is the concept of multicarrier where the different carriers are orthogonal to each other. Orthogonal in this respect means that the signals are totally independent. It is achieved by ensuring that the carriers are placed exactly at the nulls in the modulation spectra of each other. OFDM distributes the data of a large number of carriers that are spaced apart at precise frequencies. This spacing provides orthogonality.

The orthogonality requires that the sub-carrier spacing is

$$\Delta f = \frac{k}{T_U} \text{ Hertz} \tag{1}$$

where T_U seconds is the useful symbol duration (the receiver side window size), and k is a positive integer, typically equal to 1. Therefore, with N sub-carriers, the total pass band bandwidth will be $B \approx N \cdot \Delta f$ (Hz). Two key points of an OFDM system are the Inverse Discrete Fourier Transform (IDFT) at the transmitter side and the Discrete Fourier Transform (DFT) at the receiver side. By these the robustness of the sent data over a fading multipath channel is preserved.

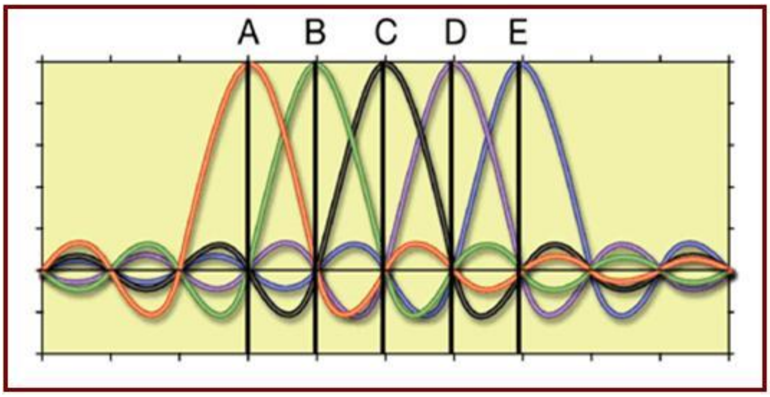

Figure 1: OFDM Signal Spectrum

OFDM techniques are quickly becoming a popular method for advanced communication networks. Advances in VLSI technology have made it possible to efficiently implement an FFT block in hardware.

The N-point FFT is defined as

$$FFT\{x[n]\} = X[k] = \sum_{n=0}^{N-1} x[n] e^{-jk\frac{2\pi}{N}n} \qquad k = 0,1,\ldots,N-1 \tag{2}$$

The N-point IFFT is defined as

$$IFFT\{X[k]\} = x[n] = \sum_{k=0}^{N-1} X[k] e^{jk\frac{2\pi}{N}n} \qquad n = 0,1,\ldots,N-1 \tag{3}$$

$$w = \frac{2\pi}{N}k \tag{4}$$

X[k] is the component of the spectrum due to frequency

$$F = k\frac{F_s}{N} \tag{5}$$

Where N is the size of the FFT which indicates the number of subchannels, F_s is the sampling frequency and W is the bandwidth in the OFDM system. One can think of the above expression as complex data symbols mapped to complex OFDM symbols, which make up the data symbols being sent on different subchannels. In this way the available spectrum is divided into several subchannels which are narrowband and therefore experience almost flat fading during transmission. The use of FFT technique makes OFDM computationally more fast and efficient too. Cyclic prefix is used to reduce the inter symbol interference (ISI) as well as inter channel interference (ICI) which is introduced by the multipath channel.

MIMO-OFDM MODEL

Consider a MIMO OFDM system with Nt transmit (TX) and Nr receive (RX) antennas. When the MIMO technique of spatial multiplexing is applied, encoding can be done either jointly over the multiple transmitter branches or per branch. The latter option is chosen as the encoding scheme in this paper and is called per-antenna-coding (PAC). A transmitter scheme in which PAC is applied to MIMO OFDM is shown in Figure 2. Basically, the MIMO OFDM transmitter consists of Nt OFDM transmitters, among which the incoming bits are multiplexed and then each branch in parallel performs encoding, interleaving, QAM mapping, and point inverse discrete Fourier transformation (IDFT) and adds a cyclic prefix (CP) before the final TX signal is upconverted to radio frequency (RF) and transmitted [2]. For reliable detection, it is typically necessary that the receiver knows the wireless communication channel and keeps track of phase and amplitude drifts. To enable estimation of the wireless communication channel, the transmitter occasionally sends known training symbols. In WLANs, a preamble which includes channel training sequences is added to every packet. Moreover to track the phase drift, pilot symbols are inserted into every MIMO OFDM data symbol on predefined subcarriers [4].

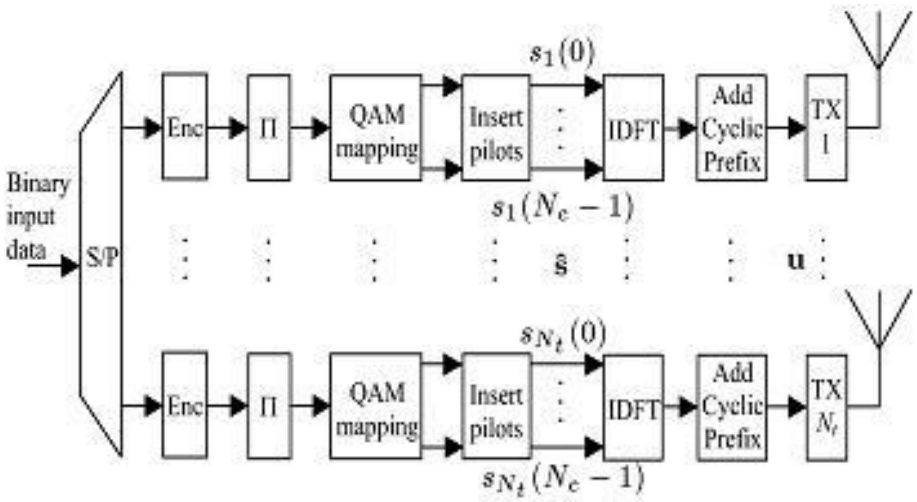

Figure 2: Block Diagram of MIMO-OFDM Transmitter

The MIMO-OFDM receiver system is as shown in Figure 3. The receiver first must estimate and correct for the frequency offset and the symbol timing, e.g., by using the training symbols in the preamble [2]. Subsequently, the CP is removed and the point discrete Fourier transformation (DFT) is performed per receiver branch. Since the MIMO algorithms that are proposed in this paper are single carrieralgorithms, MIMO detection has to be done per OFDM subcarrier. Therefore, the received signals of subcarrier are routed to the i^{th} MIMO detector to recover the Nt data signals transmitted on that subcarrier. Next, the symbols per TX stream are combined and finally demapping, deinterleaving and decoding are performed for the Nt parallel streams and the resulting data are combined to obtain the binary output data.

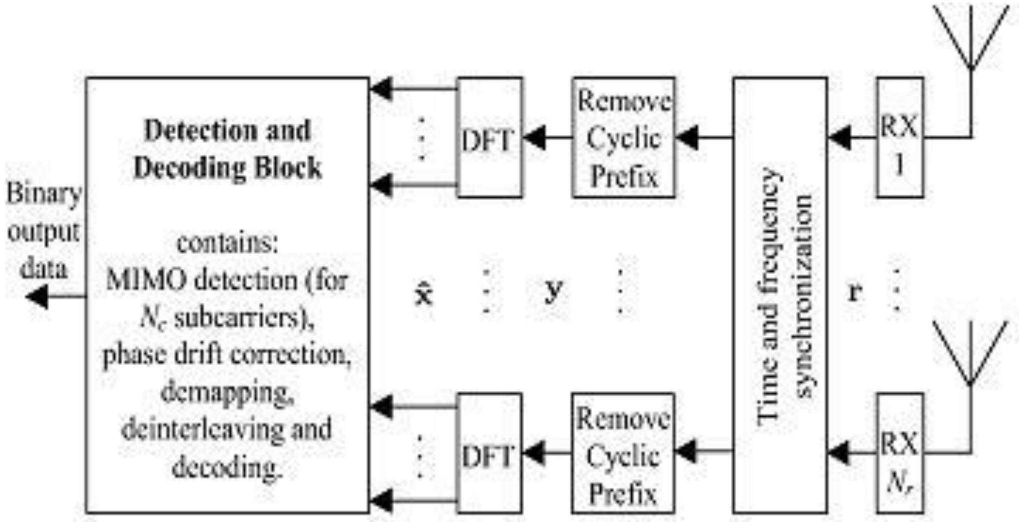

Figure 3: Block Diagram of MIMO-OFDM Receiver

IMPLEMENTATION

We have implemented MIMO-OFDM model using simulink for WLAN standard as shown in Figure 4. This represents an end-to-end baseband model of the physical layer of a wireless local area network (WLAN) according to the IEEE 802.11a standard. This model contains various components that model the essential features of the WLAN 802.11a standard. The top row of blocks contains the transmitter components while the bottom row contains the receiver components. The model supports all mandatory and optional data rates 6, 9, 12, 18, 24, 36, 48, and 54 Mb/s. The model also illustrates adaptive modulation and coding over a dispersive multipath fading channel, whereby the simulation varies the data rate dynamically.

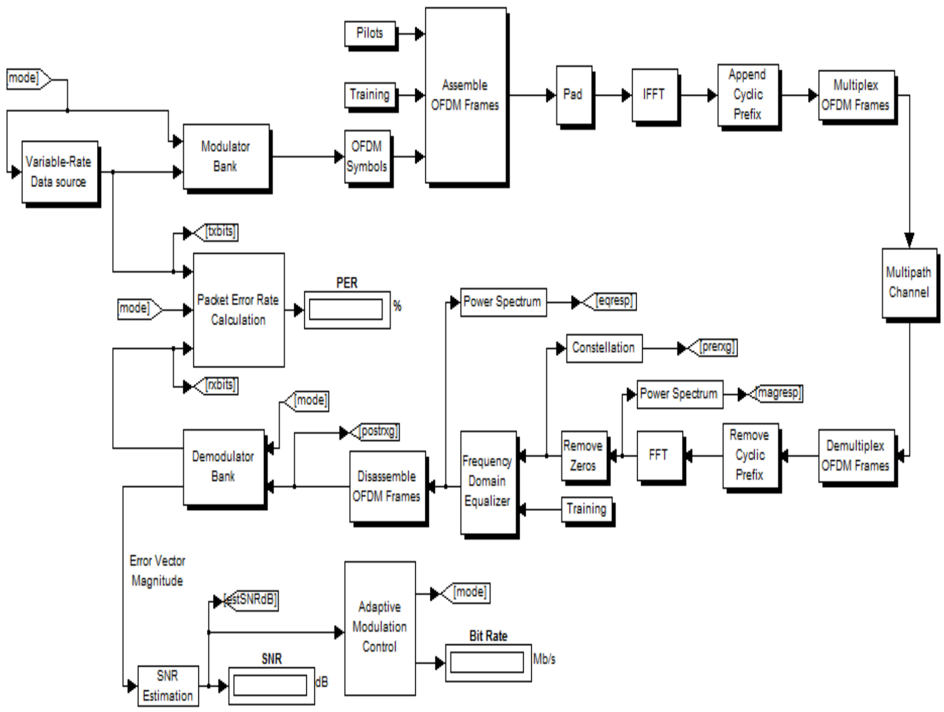

Figure 4: MIMO-OFDM System

Random binary data is generated by Random Integer block (variable rate data source). This randomly generated data is then modulated by modulator bank (Here we have used BPSK, QPSK, M-QAM modulations). This modulated data is converted to OFDM symbols and again modulated by OFDM modulator. Pilot signals and training symbols (preambles) are used for time synchronization (to avoid intersymbol interference, ISI) and frequency synchronization (to avoid inter-carrier interference, ICI, caused by Doppler shift). Zero padding blocks append zeros to the specified dimension if it is not available at the input of IFFT block.

The cyclic prefix, which is transmitted during the guard interval, consists of the end of the OFDM symbol copied into the guard interval, and the guard interval is transmitted followed by the OFDM symbol. Ultimately it decides the number of subcarriers to be used. Now OFDM frames are multiplexed and transmitted through the multipath channel. After passing through the channel the data is first demultiplex the OFDM frames and then demodulated by the OFDM demodulator which is consist of Remove Cyclic Prefix, FFT, Remove Zero Pad blocks in sequence. Cyclic prefix which is attached to OFDM signal before transmission is to be removed by Remove Cyclic Prefix block.

Then FFT will process the data to get the data same as that of input given to the IFFT block. After this one has to remove the zero padding. Now demodulator is used to demodulate this data to obtain random binary data transmitted by the random integer generator block.

In MATLB 7.10 following toolboxes are required to implement above simulink model (1) Signal Processing Toolbox (2) Communication Toolbox. The main simulation parameters are based on the IEEE 802.11a standard and summarized in Table I.

Table 1: Simulation Parameters

System Parameter	Parameter Value
Modulation	BPSK, QPSK, 16-QAM, 64-QAM
Bandwidth	20 MHz
Number of subcarriers	52
Number of data subcarriers	48
Number of pilot tones	4
OFDM symbol duration	4µs
Guard interval	800ns
Length of Cyclic prefix	16
FFT/IFFT length	64
Convolutional coding rate	1/2, 2/3, 3/4

SIMULATION RESULTS

Figure 4 shows the implementation of the MIMO-OFDM model for WLAN (IEEE802.11a) standard using different modulation techniques. Here we have used BPSK, QPSK, 16QAM and 64QAM modulations with coding rate 1/2, 2/3 and 3/4. Simulation result for BPSK as shown in Figure 5. It contains the transmitted data, constallation, receiver power spectrum, bit rate, and BER. The transmitted data has symbol duration of 4.8µs including guard interval of 0.8µs. The constallation having two point equalized and unequalized signals.

We can achieve the bit rate upto 54Mbps. Simulation result for QPSK as shown in Figure 6. It shows 4 point constellation of both equalized and unequalized signals and also shows SNR and BER values. Similarly Figure 7 and Figure 8 shows the simulation results of 16QAM and 64QAM respectively. BER performance of MIMO-OFDM system for different modulation techniques as shown in Figure 9. From this figure we can observe that for BER value of 10^{-3} we obtain E_b/N_0 value of 14db for BPSK and QPSK, 17.25db for 16QAM and 21db for 64QAM.

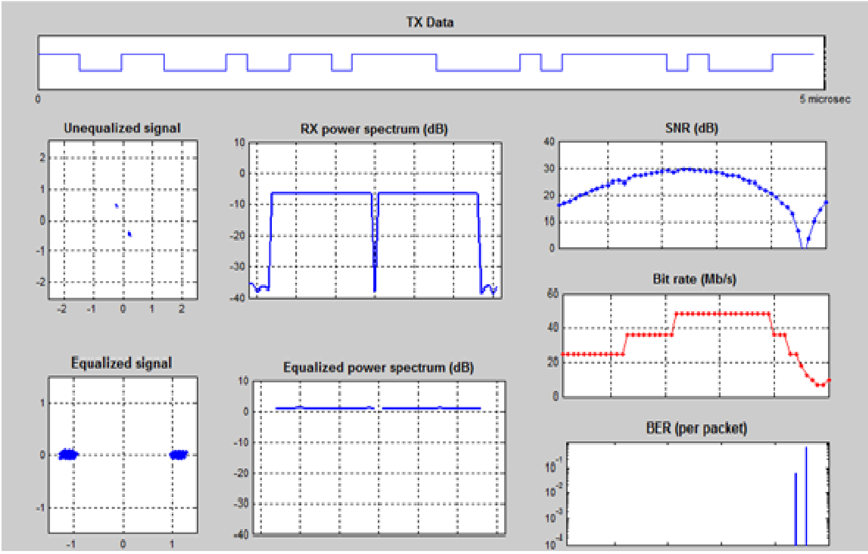

Figure 5: Simulation Result for BPSK

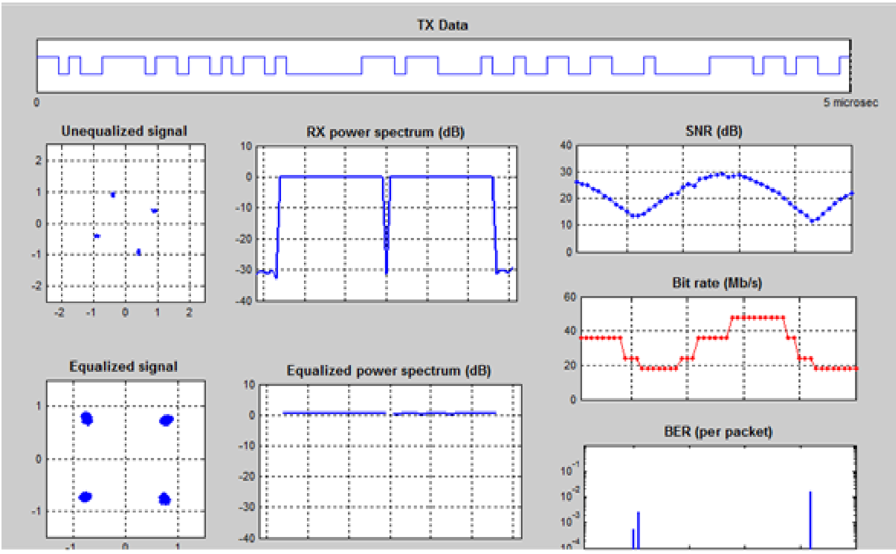

Figure 6: Simulation Result for QPSK

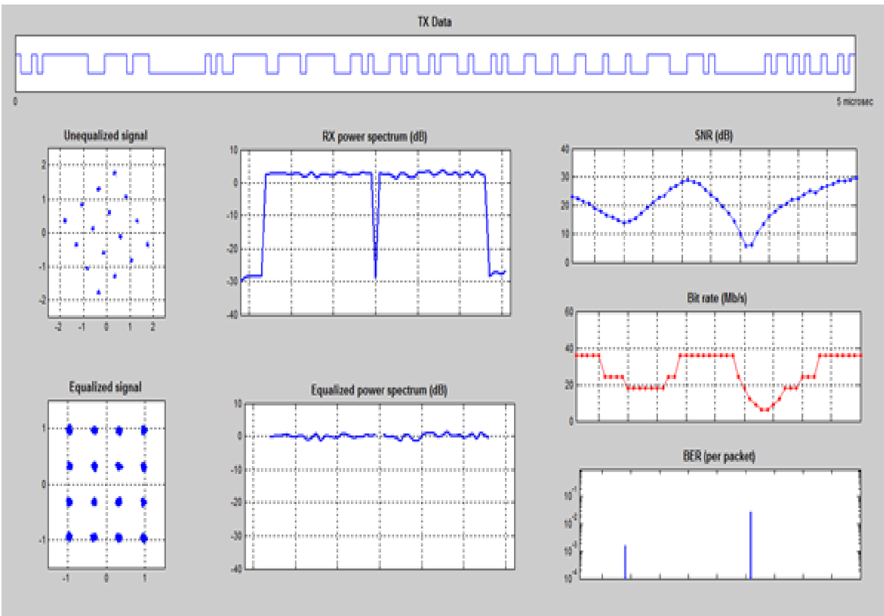

Figure 7: Simulation Result for 16QAM

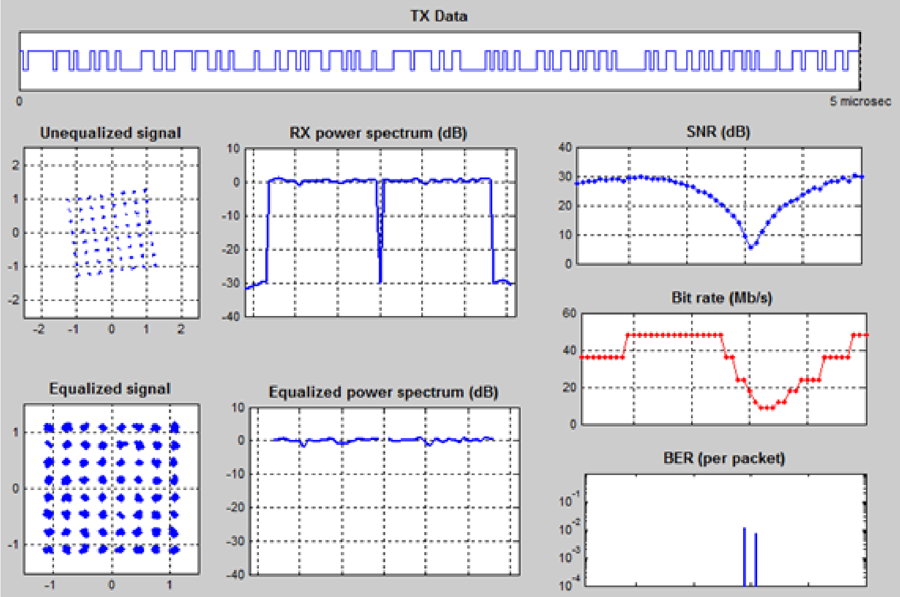

Figure 8: Simulation Result for 64QAM

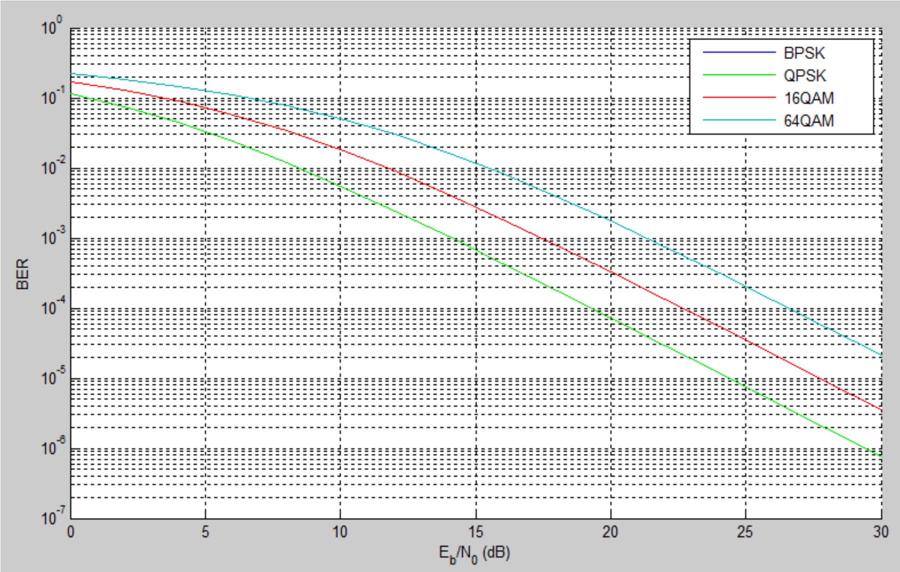

Figure 9: BER Performance of MIMO-OFDM System for WLAN

CONCLUSIONS

The simulink model of MIMO-OFDM system for WLAN (IEEE802.11a) standard is implemented as shown in Figure 4. The simulation results for different modulation techniques as shown in Figure 5, 6, 7,8 and 9. From the Figure 9 we observe that for BER value of 10^{-3} we obtain SNR value of 14 dB for BPSK and QPSK, 17.25 dB for 16QAM and 21dB for 64QAM. High SNR value is obtained for 64QAM compared to BPSK, QPSK and 16QAM. From this we conclude that better BER and SNR value can be achieved for higher order modulation techniques. For future work this performance can be enhanced for higher order MIMOs as well as modulation techniques.

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