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A SIMULATION AND ANALYSIS OF OFDM SYSTEM FOR 4G COMMUNICATIONS

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***Abstract*— The goal for the next generation of mobile communications system is to seamlessly integrate a wide variety of communication services such as high speed data, video and multimedia traffic as well as voice signals. OFDM technique has been widely used in many wired and wireless multicarrier communication systems such as IEEE 802.11a, digital audio/video broadcasting (DAB/DVB), asymmetric DSL (ADSL), and in upcoming technology- LTE (4G). OFDM is spectrally efficient and can provide high data rates with sufficient robustness to channel imperfections. The aim of this paper is to model a Matlab simulation of 4G OFDM system and to analyze the Bit Error Ratio (BER) performance. In this proposed work, bit error rate is calculated and measured with respect to Signal to Noise Ratio (SNR), Doppler Effect, and guard interval. BPSK, QPSK, 16QAM, 64 QAM schemes are used as modulation techniques. Multipath Additive White Gaussian Noise (AWGN) is used as a communication channel. The effect of SNR and guard intervals on OFDM signals improves the system performance.**

***Index Terms*— AWGN, Bit Error Rate (BER), Guard interval, OFDM, Signal-to-Noise Ratio (SNR).**

I. INTRODUCTION

The technology needed to tackle the challenges to make these services available is popularly known as the Fourth Generation (4G) OFDM System. Although the principles of Orthogonal Frequency Division Multiplexing (OFDM) modulation [1] [2] have been in existence since 1960, in the last few years OFDM modulation is emerged as a key modulation technique of commercial high speed communication systems. The principal reason of this increasing interest is due to its capability to provide high speed data rate transmissions with low complexity and to counteract the intersymbol interference (ISI) introduced by dispersive channels. For this reason OFDM modulation has been adopted by several digital wire line and wireless communication standards, such as the European digital audio and video broadcasting standards, as well as local area networks.

The rest of the paper is organized as follows. In section II shows the literature review. Section III describes the mathematical tools and techniques for OFDMsystems. Section IV describes OFDM system design. Simulation results are described in section. Finally, section VI concludes the paper.

The main idea behind OFDM is the so-called Multi-Carrier Modulation (MCM) transmission technique. MCM is the principle of transmitting data by dividing the input bit stream into several parallel bit streams, each of them having a much lower bit rate, and by using these sub-streams to modulate several carriers. The first systems using MCM were military high frequency radio links in the late 1950s and early 1960s, like Kineplex, Andeft and Kathryn. OFDM is a special form of MCM with densely spaced sub-carriers and overlapping spectra, whose main idea was patented by Chang, from the Bell Labs, in 1966. OFDM abandoned the use of steep band pass filters that completely separated the spectrum of individual sub-carriers, as it was common practice in older analogue FDMA systems. Instead, OFDM time domain waveforms are chosen such that mutual orthogonality is ensured even though carrier spectra may overlap. Orthogonality is achieved by performing a Fourier Transform (or equivalently a Fast Fourier Transform) on the input stream.

Implementation aspects have delayed the introduction of OFDM into real systems. For instance, the complexity of a real-time FFT requires powerful digital signal processors, which were not available at the time when OFDM was invented. Furthermore, in order to keep the orthogonality between the different subcarriers, highly stable oscillators are required in the transmitter and receiver, as well as linear power amplifiers. Now days many of the implementation problems appear solvable and OFDM has gained a big interest since the beginning of the 1990s [3]. This interest is mainly motivated by the advantages OFDM offers when transmitting through a fading channel.

II.RECENT WORKS IN OFDM

Orthogonal frequency division multiplexing has become a promising physical layer modulation technology for beyond 3G or 4G wireless communications due to effective inter-symbol interference mitigation for high speed data transmission. However, the timing of the OFDM symbol remains an important and challenging issue in OFDM receiver design. An erroneous timing decision creates inter-symbol interference (ISI), inter-carrier interference (ICI), channel attenuation, and channel estimation error, which leads to a penalty on the collected OFDM symbol

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signal to noise ratio (SNR) resulting in an irreducible error floor. Michael Mao Wang et al. Quantifies such effects and derives an optimal OFDM symbol timing solution in the sense of maximizing the signal to interference ratio (SIR) of the collected OFDM symbol. A practical timing algorithm, referred to as the equilibrium algorithm, is then developed to approximate the optimal timing decision.

Yu-Wei Lin et al. proposed a pipelined FFT processor, which is based on Mixed-Radix Multi-Path Delay Feedback (MRMDF) structure, can deal with the simultaneous multiple input sequences more efficiently for MIMO OFDM applications. Furthermore, the hardware costs of memory and complex multipliers can be saved by means of delay feedback and data scheduling approaches. The higher-radix FFT algorithm is also realized in this processor to reduce the number of complex multiplications.

II.MATHEMATICAL TOOLS & TECHNIQUES FOR OFDM SYSTEMS:

OFDM is a special case of multicarrier transmission, where a single data stream is transmitted over a number of lower rate subcarriers. OFDM is a combination of modulation and multiplexing. Multiplexing generally refers to independent signals, those produced by different sources. In OFDM, multiplexing is applied to independent signals but these independent signals are a sub-set of the one main signal. The signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier.

In a 1971 paper [4], Weinstein and Ebert suggested that the multicarrier modulated signal is effectively the Fourier transform of the serial data stream and the bank of coherent demodulators the

Inverse Fourier transforms. In this paper the following is the mathematical derivation used to show the validity of the argument:

Consider a data sequence ($d_0, d_1, \ldots, d_{n-1}$), where each d_n is a complex number $d_n = a_n + j b_n$.The result of a DFT operation on the vector $\{2 d_n\}_{n=0}^{N-1}$ is then the vector S= ($S_0, S_1, \ldots, S_{n-1}$) of N complex numbers, with

$$s_m = \sum_{n=0}^{N-1} 2\, d_n e^{-j(2\pi nm/N)} = 2\sum_{n=0}^{N-1} d_n\, e^{-j2\pi f_n t_m},$$

m=0, 1….N-1 (1)

Where

$$f_n \triangleq \frac{n}{n\Delta t} \tag{2}$$

$$t_m \triangleq m\Delta t \tag{3}$$

And Δt is an arbitrarily chosen interval. The real part of S has components:

$$Y_m = 2\sum_{n=0}^{N-1}(a_n \cos 2\pi f_n t_m + b_n \sin 2\pi f_n t_m),$$

m=0, 1 …N-1 (4)

If these components are applied to a low pass filter at time intervals Δt, a signal is obtained that closely approximates the frequency division multiplexed signal as

$$y_{(t)} = 2\sum_{n=0}^{N-1}(a_n \cos 2\pi f_n t + b_n \sin 2\pi f_n t),$$

$$0 \le t \le N\Delta t \tag{5}$$

In order to recover the modulated data, a DFT with twice the sampling rate is employed. This is necessary since only the real part of the modulated signal in transmitted. Therefore, the DFT operates on the 2N samples

$$= y(k\frac{\Delta t}{2}) = 2\sum_{n=0}^{N-1}(a_n \cos\frac{2\pi nk}{2N} + b_n \sin\frac{2\pi nk}{2N}),$$

K=0, 1….2N-1 (6)

The result of DFT operation is then

$$z_1 = \frac{1}{2N}\sum_{k=0}^{2N-1} Y_k e^{-j(2\pi k/2N)} = \begin{cases} 2a_0, & l = 0 \\ a_1 - jb_1, & l = 1,2,\ldots N-1 \\ irrelevant, & l > N-1 \end{cases}$$

The original data a_l and b_l can then be extracted as the real and imaginary parts of (except at l = 0) [5]. Since the sinusoidal components of the parallel input are time limited, they have a shaped power spectrum. This special shape ensures that as long as the components are samples at the right instance, the neighbouring components have zero contribution. This orthogonal nature of the OFDM symbols helps prevent ICI.

In this paper, we also proposed some simple equalization schemes and studied the effect of linear channel distortions.

III.OFDM SYSTEM DESIGN

For performing the simulations, the chain shown in Figure1 was developed under MATLAB environment. This paper is mainly dependent on this system model. This model has implemented the basic characteristics of OFDM systems. MATLAB environment has assisted to implement that purposes.

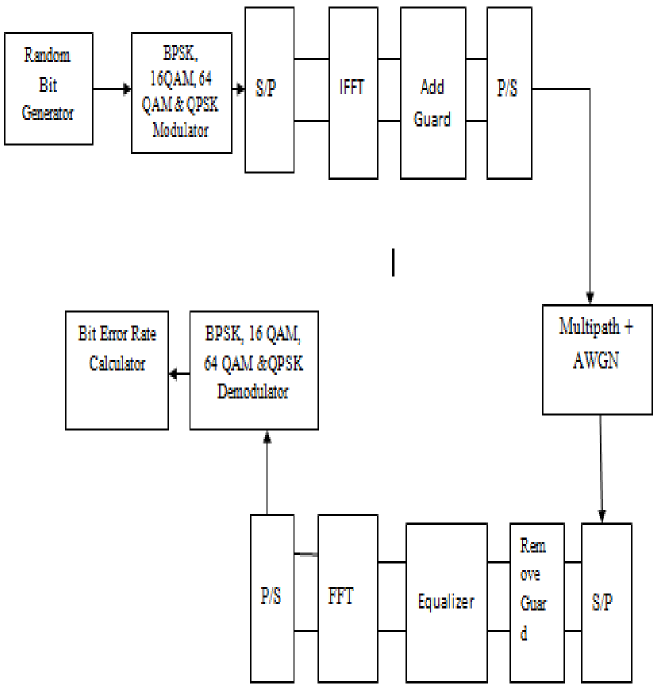

Fig.1. Block diagram of the system implemented.

A. Algorithm

The following is a general overview on the operation of the system.
1. Generate a binary message with a length divisible by the number of subcarriers
2. Modulate the signal using BPSK. This is done quite easily by the following operation out = msg. 2 − 1
3. Perform Serial-to-Parallel (S/P) conversion using the MATLAB function reshapes
4. Perform the Inverse FFT
5. Add a cyclic extension to each symbol. The length of the extension to add in us is defined by the input parameter guard length
6. Perform Parallel-to-Serial (P/S) conversion to make the signal ready for transmission
7. Pass it through the Rayleigh fading multipath channel with Additive White Gaussian Noise. An estimate of the channel at a rate defined by estRate is also performed simultaneously
8. Perform S/P conversion
9. Remove the guard cyclic prefix
10. using the channel estimate obtained, perform Equalization of the received signal
11. Perform the FFT to recover the signal
12. Perform P/S conversion
13. Demodulate the BPSK symbols using a decision boundary of 0: demod = double (real (RXmsg) >= 0)
14. Calculate the bit error rate of the system

B.ORTHOGONALITY

It is possible to arrange the carriers in an OFDM signal so that the sidebands of the individual carriers overlap and the signals can still be received without adjacent carrier interference. In order to do this the carriers must be mathematically orthogonal. The 'orthogonal' part of the OFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. Two periodic signals are orthogonal when the integral of their product over one period is equal to zero.

For the case of continuous time:

$$\int_0^T \cos(2\pi n f_0 t)\cos(2\pi m f_0 t)dt = 0, \ (m \neq n)$$

For the case of discrete:

$$\sum_{k=0}^{N-1} \cos\left(\frac{2\pi kn}{N}\right)\cos\left(\frac{2\pi km}{N}\right)dt = 0, (m \neq n)$$

To maintain orthogonality between sub-carriers, it is necessary to ensure that the symbol time contains one or more multiple cycles of each sinusoidal carrier waveform. In the case of OFDM, the sinusoids of our sub-carriers will satisfy this requirement since each is a multiple of a fundamental frequency. Orthogonality is critical since it prevents inter-carrier interference. ICI occurs when the integral of the carrier products are no longer zero over the integration period, so signal components from one sub-carrier causes interference to neighboring sub-carriers. As such, OFDM is highly sensitive to frequency dispersion caused by Doppler shifts, which results in loss of orthogonality between sub-carriers.

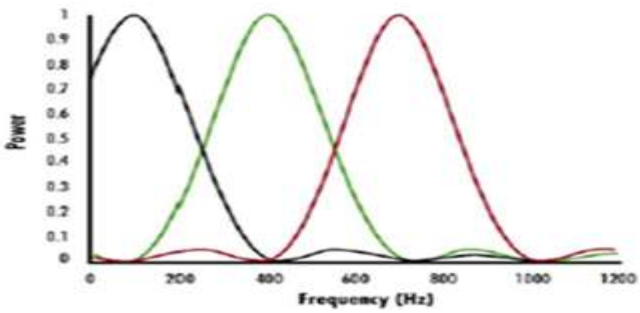

Fig2: Orthogonal Of Subcarriers

1. NUMBER OF CARRIERS:

The number of subcarriers can be determined based on the channel bandwidth, data throughput and useful symbol duration. The carriers are spaced by the reciprocal of the useful symbol duration. The number of carriers corresponds to the number of complex points being processed in FFT. For HDTV applications, the numbers of subcarriers are in the range of several thousands, so as to accommodate the data rate and guard interval requirement.

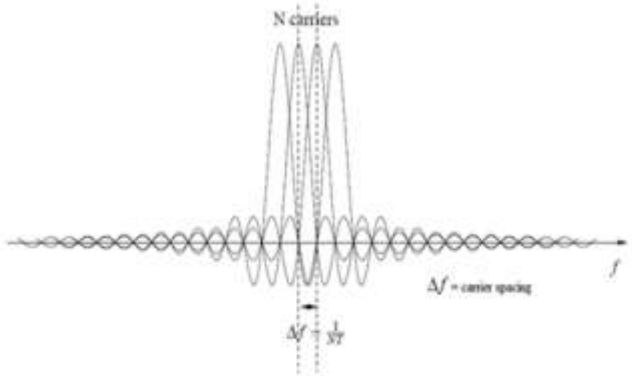

Fig3: OFDM Subcarriers

2. MODULATION SCHEME

The modulation scheme in an OFDM system can be selected based on the requirement of power or spectrum efficiency. The type of modulation can be specified by the complex number dn=an+jbn. The symbols an and bn can be selected to (1, 3) for 16-QAM and 1 for QPSK. Consider a data sequence (d0, d1, d2, dN-1), where each dn is a complex number dn=an+jbn. (an, bn=1 for QPSK, an, bn=1, 3 for 16-QAM).

3. QUADRATURE AMPLITUDE MODULATION:

Quadrature Amplitude Modulation (QAM) is a modulation scheme in which two sinusoidal carriers, one exactly 90 degrees out of phase with respect to the other, are used to transmit data over a given physical channel. Because the orthogonal carriers occupy the same frequency band and differ by a 90 degree phase shift, each can be modulated independently, transmitted over the same frequency band, and separated by demodulation at the receiver. For a given available bandwidth, QAM enables data transmission at twice the rate of standard pulse amplitude modulation. A broad class of digitally-modulated carrier signals C (t) can be expressed in double sideband suppressed carrier Quadrature component notation as

C (t) = I (t) coswct + Q (t) sinwct

Where I (t) and Q (t) are the in-phase and Quadrature phase modulator base band signal sequences, respectively. In the case of QAM, I (t) and Q (t) are the pulse sequences whose amplitudes are data-dependent. The incoming serial binary data stream d (t) is split into two binary parallel branches to constitute the I (t) and Q (t) symbol streams.

M-LEVEL QAM:

In M-level QAM the bit data is suitably assembled into N symbols (M=2N) and each symbol transmitted by a carrier wave having a unique amplitude and phase. The duration of each symbol determines the bandwidth of the QAM signal. Figure shows an M-level constellation where each dot represents the position of the phasor relative to the intersection of the axes marked I (In phase) and Q (Quadrature). Each AM carrier is transmitted with amplitude of either - (N-1) d…-3d, -d, d, 3d… (N-1) d, where d is the coordinate spacing shown in figure. The N-level AM components are binary encoded using N/2 Gray coded bits for each level. For example, the 4-level AM components of 16-QAM are binary encoded using two Gray coded bits for each level; Gray codes 00, 01, 11and 10, are assigned to levels -3d, -d, d and 3d, respectively.

CONSTELLATION DIAGRAM:

A constellation diagram is the representation of a digital modulation scheme on the complex plane. The diagram is formed by choosing a set of complex numbers to represent modulation symbols. These points are usually ordered by the gray code sequence. Gray codes are binary sequences where two successive values differ in only one digit. The use of gray codes helps reduce the bit errors. The real and imaginary axes are often called the in-phase and the Quadrature. These points are usually arranged in a rectangular grid in QAM, though other arrangements are possible. The number of points in the grid is usually a power of two because in digital communications the data is binary. Upon reception of the signal, the demodulator examines the received symbol and chooses the closest constellation point based on Euclidean distance. It is possible to transmit more bits per symbols by using a higher-order constellation QAM, but this is more susceptible to noise because the points are closer together, resulting in a higher bit error rate (BER).

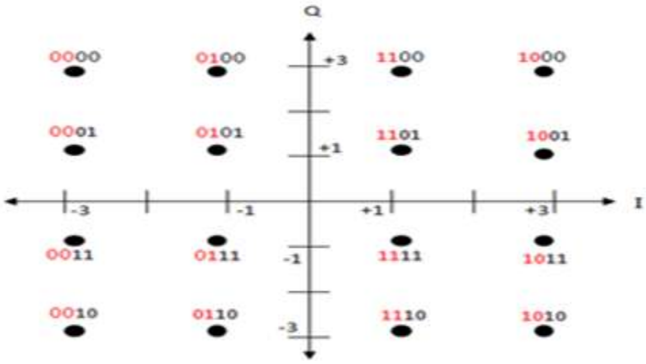

Fig4: QAM Constellation Diagram

4. CYCLIC PREFIX:

The Cyclic Prefix is a periodic extension of the last part of an OFDM symbol that is added to the front of the symbol in the transmitter, and is removed at the receiver before demodulation. Mathematically, the Cyclic Prefix converts the linear convolution with the channel impulse response into a cyclic convolution. This results in a diagonalised channel, which is free of ISI and ICI interference. The Cyclic Prefix has two important benefits:

1. The Cyclic Prefix acts as a guard space between successive OFDM symbols and therefore prevents Inter-symbol Interference (ISI), as long as the length of the CP is longer than the impulse response of the channel.

2. The Cyclic Prefix ensures orthogonality between the sub-carriers by keeping the OFDM symbol periodic over the extended symbol duration, and therefore avoiding Inter-carrier Interference (ICI).

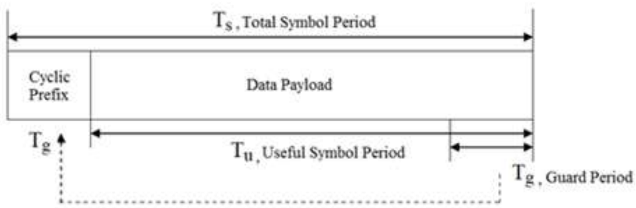

Fig5: Cycle prefix

QPSK:

QPSK is a multilevel modulation techniques, it uses 2 bits per symbol to represent each phase. Compared to BPSK, it is more spectrally efficient but requires more complex receiver.

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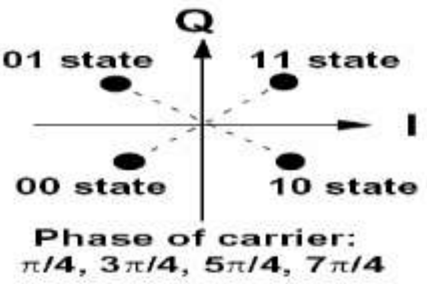

Fig6: Constellation Diagram for QPSK

Figure above shows the constellation diagram for QPSK with Gray coding. Each adjacent symbol only differs by one bit. Sometimes known as quaternary or quadriphase PSK or 4-PSK, QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol, shown in the diagram with Gray coding to minimize the BER - twice the rate of BPSK. Figure below depicts the 4 symbols used to represent the four phases in QPSK. Analysis shows that this may be used either to double the data rate compared to a BPSK system while maintaining the bandwidth of the signal or to maintain the data-rate of BPSK but halve the bandwidth needed.

5. Additive White Gaussian Noise (AWGN) Channel:

In the study of communication systems, the classical (ideal) additive white Gaussian noise (AWGN) channel, with statistically independent Gaussian noise samples corrupting data samples free of intersymbol interference (ISI), is the usual starting point for understanding basic performance relationships. An AWGN channel adds white Gaussian noise ti the signal that passes through it. In constructing a mathematical model for the signal at the input of the receiver, the channel is assumed to corrupt the signal by the addition of white Gaussian noise as shown in Figure 5.1 below, therefore the transmitted signal, white Gaussian noise and received signal are expressed by the following equation with s (t), n (t) and r (t) representing those signals respectively:

$$r(t)=s(t)+n(t)$$

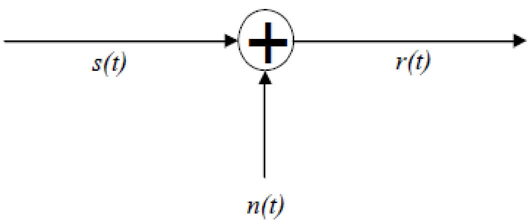

Fig7: Received signal corrupted by AWGN

Where n(t) is a sample function of the AWGN process with probability density function (pdf) and power spectral density as follows:

$$\emptyset_{nm}(f) = \frac{1}{2}N_0(W|HZ)$$

Where N0 is a constant and called the noise power density.

IV. SIMULATION RESULTS

The effect of SNR and guard intervals on OFDM signals are simulated in this paper. The simulation results are given below:

A. Simulation Results of BER Performance vs. SNR

At first we generate a random signal using a random bit generator. The signal is modulated using different modulation techniques such as BPSK, QPSK and 16QAM, 64QAM. Then the signal is passed away through AWGN channel. The signal is demodulated and checked the errors. The simulation is dependent on signal to noise ratio (SNR). Here SNR used as average symbol-energy-to-noise ratio. Different values of BER are obtained from the simulation graph with respect to different values of SNR. The simulations are performed using sub carriers 100 and bit rate 100bps.

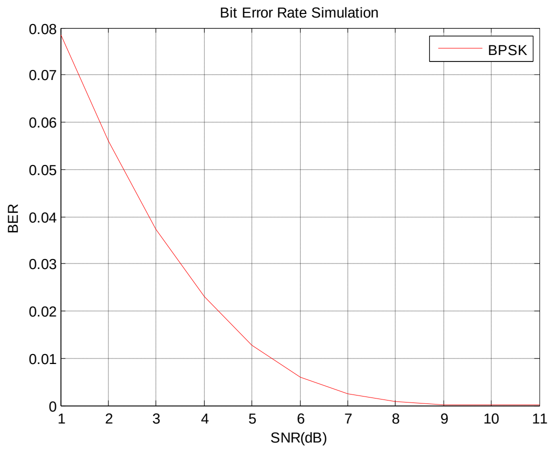

Fig8: BER vs. Channel SNR for BPSK.

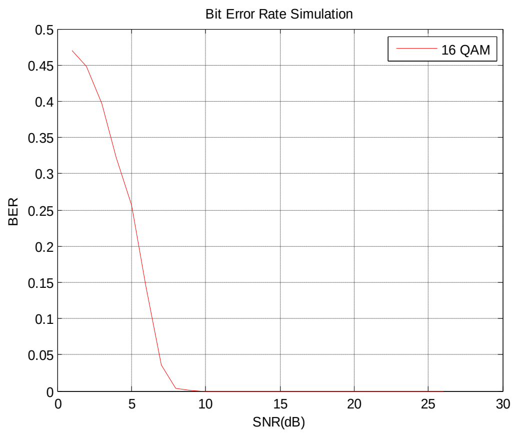

Fig9: BER vs. Channel SNR for 16QAM.

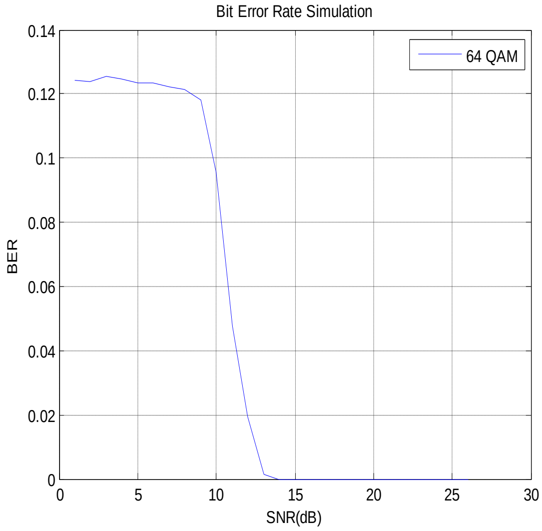

Fig10: BER vs. Channel SNR for 64QAM.

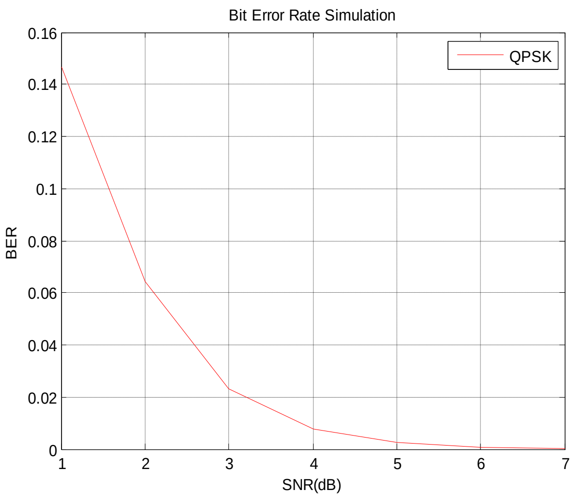

Fig11: BER vs. Channel SNR for QPSK

From the simulation results we can show that the transmission can tolerate a SNR>28 dB using 16QAM, 64 QAM. QPSK transmission can tolerate a SNR of >15-17 dB BPSK transmission can tolerate a SNR of >7-10 dB Among these modulation techniques 16 QAM can tolerate highly than BPSK and QPSK. Bit error performance can be calculated and measured approximately using 16QAM modulation techniques.

V.CONCLUSION

Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI) is dominant problems in OFDM Systems. These problems are solved with the help of guard period/cyclic prefix. In the case of BER vs. SNR when we are increasing signal to noise ratio (SNR), bit error rate (BER) is decreasing in the same way. At that time bit error rate is zero. We use three modulation techniques such as BPSK, QPSK and 16QAM. BER depends on sub-carriers and symbol time. The minimum signal to noise ratio (SNR) required for BPSK is 7dB, 12dB for QPSK and 26dB for 16QAM. In case of Guard length on the BER performance when we are increasing guard length, bit error rate is reducing in the same way. At that time bit error rate is zero.

Finally, from the analysis of the system simulations, it is concluded that a cyclic prefix at least as long as the maximum multipath delay spread is required for complete protection against ISI effects. Also during low velocity and hence Doppler spread conditions it is possible to have lower channel estimation rate for improved data throughput efficiency.

VI. ACKNOWLEDGEMENT

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