Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 7, Issue 24, pages 31-38, 2021

Analysis the Performance of OFDM Using BPSK, QPSK, 64-QAM, 128-QAM & 256-QAM Modulation Techniques

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***Abstract** – At the present era of communication technology, every user wants a communication system that has higher data transmission capability and reliability. Orthogonal Frequency Division Multiplexing (OFDM) is a frequency division multiplexed multi carrier transmission method and each multiplexed signal is orthogonal to each other. This technology is known as core technology of the new generation wireless mobile communication systems. This technology has higher data transmission capability and reliability as well as has the ability to combat frequency selective fading or narrowband interference while maintaining high spectrum utilization. The aim of this paper is to analyze the performance of the OFDM technology using different modulation techniques. This paper is mainly focused on the calculation of the Bit Error Rate (BER) to analyze the performance of OFDM systems. In this paper, we considered BPSK, QPSK, 64-QAM, 128-QAM and 256-QAM modulation techniques. All the simulations are performed by using the MATLAB framework.*

Keywords-OFDM, BPSK, QPSK, M-QAM, AWGN, BER.

I. Introduction

Wireless communication technology has done our communication systems easier, speedy and reliable. In order to meet the demand of higher quality services, the present era needs a communication system that contains higher data transmission capability and reliability [1]. Orthogonal Frequency Division Multiplexing (OFDM) is such a key wireless technology that is used in high speed communication systems such as- Wi-Fi, WiMAX, LTE (4G cellular networks), satellite and many others. OFDM is also a key broadband wireless technology. High data rates 4G, Wi-Fi, WiMAX are possible because of OFDM technology [2].

OFDM technology mainly consists of modulation and multiplexing techniques [2]. Modulation technique is defined as the process, where one of the properties of the carrier signal like the amplitude, phase, or the frequency is changed according to the baseband signal. Multiplexing refers to the technique where two or more signals combine and use the same channel for transmission [3].

Frequency Division Multiplexing (FDM) technique allows multiple users to share one link by dividing available bandwidth into different non-overlapping sub-channels. OFDM is a special case of FDM. OFDM is a special form of multicarrier transmission technique. In OFDM transmission technique, the signals are orthogonal to each other. The term orthogonal means that two or multiple objects act independently. For this case, any neighbor signals in OFDM operate without dependence on, or interference with one another i.e. signals are multiplexed in a way that the peak of one signal occurs at null of the other neighbor signals [4][5].

OFDM would allow more data transmissions than FDM and OFDM would better utilize the available bandwidth, thus offering a higher data transmission rate. Due to use of a multicarrier system in OFDM, it is possible to get a more reliable communication system as well as provides an improved spectral efficiency, lower multipath distortion and allows preventing inter-symbol interference. There are some drawbacks of OFDM such as- higher peak to average ratio, more sensitive to carrier frequency offset and phase drift [6][7].

All the simulations are implemented on MATLAB 9.0 (2016a) and the system configuration is Core i3-2.40 GHz processor with windows 10 based 64 bit operating system.

Rest of the paper is organized as follows: Section I contains the introduction of this paper, Section II and III describe about the channel model and modulation techniques of this paper, Section IV discuss about the principle of OFDM, Section V and VI presents the proposed system architecture and system specifications, Section VII discusses the simulation results and discussion and finally the conclusion of this research work has been drawn in Section VIII.

II. CHANNEL MODEL

Generally, it is most important to know about the characteristics of the channel for evaluating the performance of OFDM using various modulations techniques. The communication channels are categorized into three types based on their characteristics of the communication channels such as- AWGN channel, Rayleigh fading channel and Rician fading channel. In this work, we considered only AWGN channel to evaluate the Bit Error Rate of OFDM using different modulation techniques. This channel is very popular due to its non-fading properties and simplicity. The time of passing signals through the channel the AWGN channel adds White Gaussian noise to the signal [8][9][10]. The Probability density function is always following Gaussian distribution and the equation of Gaussian distribution is expressed as-

$$f_g(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \tag{1}$$

Where x = Random variable
μ = Mean value
σ = Standard deviation

Through AWGN channel a received signal is expressed as-

$$r(t) = x(t) + n(t) \tag{2}$$

Where $x(t)$ = Transmitted signal
$n(t)$ = Additive White Gaussian noise

The model of the AWGN channel is shown in Fig.1

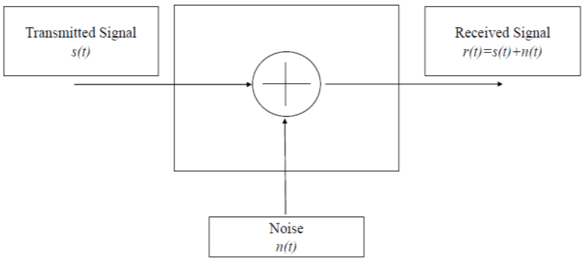

Fig. 1. AWGN channel model

III. MODULATION TECHNIQUES

In this work, for the performance analysis of OFDM, we have used BPSK, QPSK and M-QAM (where M=64, 128 and 256) modulation techniques. The description of these modulation techniques are given in the following-

A. *Binary Phase Shift Keying (BPSK)*

In Binary Phase Shift Keying, the phase of the carrier wave is modulated by the binary symbol 0 and 1. BPSK uses binary phases (0° and 180°) to transmit bits 0 and 1 and also uses 1 bit per symbol. When the binary input changes 1 to 0 or 0 to 1 then the modulated signal will be changed its phase at 180° [11][12][13][14][15][16]. The modulated carrier signals are represented as follows:

For a binary 0,

$$S_1(t) = A_c \cos(2\pi f_c t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \tag{3}$$

For a binary 1,

$$S_2(t) = A_c \cos(2\pi f_c t + \pi) = -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \tag{4}$$

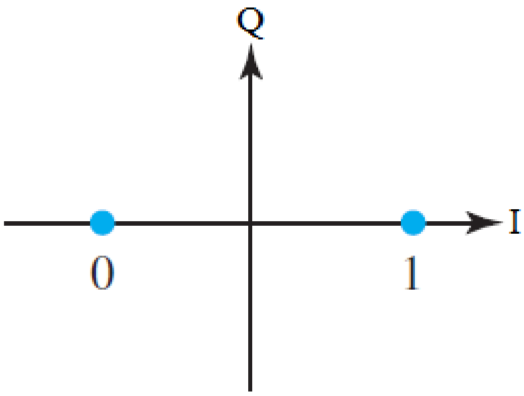

Fig. 2. Constellation diagram for BPSK

For BPSK, the Probability of Bit Error is expressed as-

$$P_{be,BPSK} = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{5}$$

B. *Quadrature Phase Shift Keying (QPSK)*

In the QPSK method, it uses 2 bits per symbol. For 2 bits per symbol, we need 4 phases and there are 4 possible combinations with two bits that are 00, 01, 10 and 11. The four phases are $\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}$ and $\frac{7\pi}{4}$ [15][16][17].

In QPSK modulation technique, the four modulated carrier signals are represented for binary 11, 01, 00 and 10 as:

$$S_1(t) = A_c \cos(2\pi f_c t + \theta_1) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c + \frac{\pi}{4}\right) t \tag{6}$$

$$S_2(t) = A_c \cos(2\pi f_c t + \theta_2) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c + \frac{3\pi}{4}\right) t \tag{7}$$

$$S_3(t) = A_c \cos(2\pi f_c t + \theta_3) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c + \frac{5\pi}{4}\right) t \tag{8}$$

$$S_4(t) = A_c \cos(2\pi f_c t + \theta_4) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c + \frac{7\pi}{4}\right) t \tag{9}$$

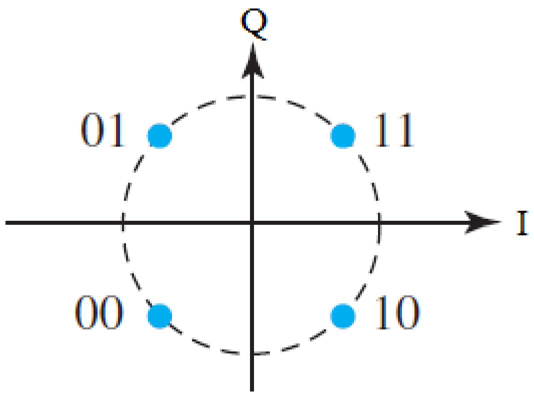

Fig. 3. Constellation diagram for QPSK

And for QPSK, the Probability of Bit Error is expressed as-

$$P_{be,QPSK} = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b \log_2(4)}{2N_0}}\right) = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \quad (10)$$

C. Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation is a kind of modulation in which phase of the two carriers are changed by 90 degree and the modulated wave consists of both amplitude and phase variations. It may also be considered as a mixture of amplitude and phase modulation i.e. in QAM modulation technique not only changing the phase like PSK but also changing the amplitude. The QAM are often used in digital cable television, cable modem and point-to-point wireless system applications and extensively used in satellite communication systems [14][16][17][18][19].

The M-ary QAM modulated signal is expressed as:

$$S_i(t) = \sqrt{\frac{2E_{min}}{T_s}}\, a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}}\, b_i \sin(2\pi f_c t), \quad 0 < t < T_s, \quad for\ i = 1,2, \ldots\ldots, M \quad (11)$$

Where, E_{min} indicated the signal energy for the minimum amplitude, a_i and b_i indicates a pair of random integers.

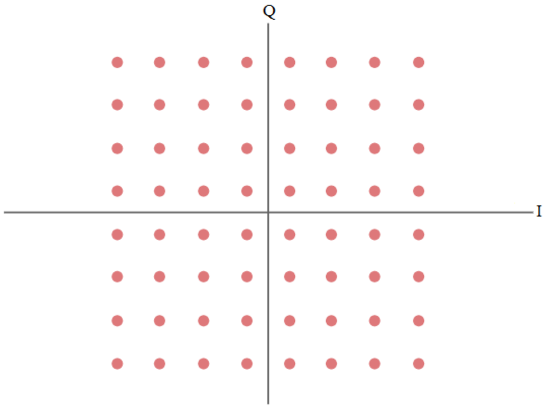

Fig. 4. Constellation diagram for 64-QAM

If the M-ary QAM is coherently detected then the Probability of Bit Error is expressed as:

$$P_{be,MQAM} \cong 2\left(\frac{\sqrt{M}-1}{\sqrt{M}\log_2 M}\right) erfc\left(\sqrt{\frac{3\log_2 M}{2(M-1)}\frac{E_b}{N_0}}\right) \quad (12)$$

When M = 64, 128 and 256 then we get,

$$P_{be,64QAM} \cong \frac{7}{24}\, erfc\left(\sqrt{\frac{E_b}{7N_0}}\right) \quad (13)$$

$$P_{be,128QAM} \cong 0.26\, erfc\left(\sqrt{\frac{21E_b}{254N_0}}\right) \quad (14)$$

$$P_{be,256QAM} \cong \frac{15}{64}\, erfc\left(\sqrt{\frac{4E_b}{85N_0}}\right) \quad (15)$$

IV. Principles of OFDM

The basic block diagram of an OFDM system is shown in Fig. 5.

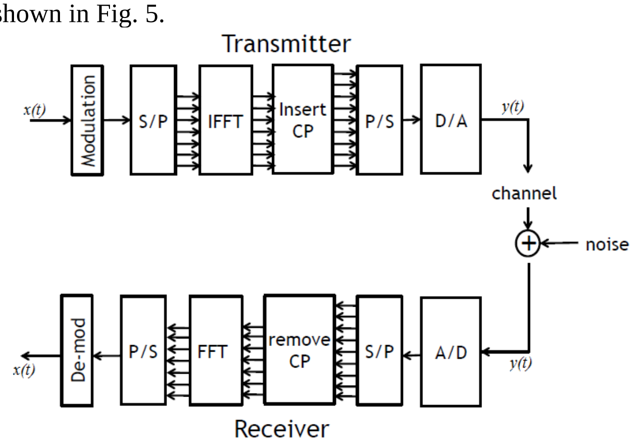

Fig. 5: Basic Block Diagram of an OFDM system

The main idea of OFDM is to divide a channel into N sub-channels, one carrier on each sub-channel, called a subcarrier, and each subcarrier is orthogonal to each other [20].

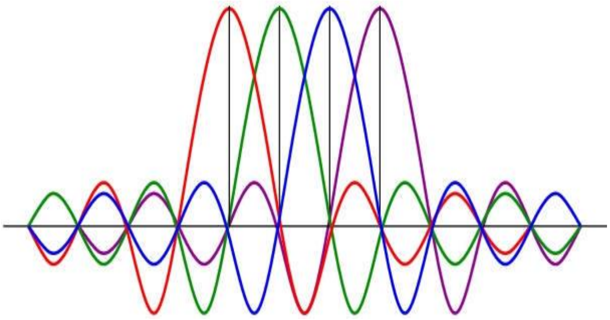

Fig. 6. Spectrum of OFDM signals

Let, $\psi_n(t)$ and $\psi^*{}_m(t)$ are two exponential signals. Where

$$\psi_n(t) = e^{j2\pi f_k t}$$

$$\psi^*{}_m(t) = e^{-j2\pi f_i t}$$

The signals are orthogonal to each other if and only if the Eq. 16 is satisfied.

$$\int_0^T \psi_n(t)\,\psi^*{}_m(t) = \begin{cases} 0, & n \neq m \\ 1, & n \neq m \end{cases} \tag{16}$$

Now

$$\frac{1}{T}\int_0^T e^{j2\pi f_k t}\; e^{-j2\pi f_i t}\,dt$$

$$= \frac{1}{T}\int_0^T e^{j2\pi \frac{k}{T}t}\; e^{-j2\pi \frac{i}{T}t}\,dt$$

$$= \frac{1}{T}\int_0^T e^{j2\pi \frac{(k-i)}{T}t}\,dt$$

$$= \begin{cases} 0, & \forall_k = i \\ 1, & k \neq i \end{cases}$$

So, we can conclude that our condition is satisfied.

In implementation, a high-speed serial input data signal stream is converted into N parallel low-speed sub-data streams, and modulated onto each sub-carrier for transmission. After serial/parallel conversion, N parallel data are simultaneously output and modulated on N subcarriers [21].

The number of N subcarriers can be expressed as-

$$f_n = f_c + \frac{n}{T_s} \tag{17}$$

Then an OFDM signal at the m[th] moment can be expressed as-

$$S_m(t) = Re\left\{\sum_{n=0}^{N-1} d(n)e^{j2\pi f_n t}\right\}, 0 < t < T \tag{18}$$

Since, OFDM is emitted after the serial-parallel conversion of N symbols, the symbol rate is the original OFDM symbol rate1/N, so we can write $T_s = NT_s$.

When the guard interval between OFDM symbols is not considered, we can write

$$S_m(t) = Re\left\{\sum_{n=0}^{N-1} d(n)e^{j2\pi f_n t}\right\}$$

$$= Re\left\{\sum_{n=0}^{N-1} d(n)e^{j2\pi \frac{n}{NT_s}t}e^{j2\pi f_c t}\right\}$$

$$= Re\{X(t)e^{j2\pi f_c t}\} \tag{19}$$

Where

$$X(t) = \sum_{n=0}^{N-1} d(n)e^{j2\pi \frac{n}{NT_s}t}$$

And $X(t)$ = complex equivalent baseband of the transmitted signal.

Sampling $X(t)$ with a sampling rate of $1/T_s$, then when $k = kT_s$, the sampled value $X(k)$ satisfies

$$X(k) = X(kT_s) = \sum_{n=0}^{N-1} d(n)e^{j2\pi \frac{n}{NT_s}t} \tag{20}$$

$X(k)$ is exactly the result of the N-point inverse discrete Fourier transform (IDFT) of d(n). In practical applications, we can use the IFFT operation to complete the subcarrier modulation process of the OFDM complex equivalent baseband signal, and complete the demodulation process with Fast Fourier Transform (FFT) [22][23].

By using IFFT and FFT, we can transform the frequency-domain samples into time-domain samples and time-domain samples into frequency-domain samples.

$$x(t) = \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} X[k]e^{j2\pi kt/N} \tag{21}$$

and

$$X[k] = \frac{1}{N}\sum_{t=\frac{N}{2}}^{\frac{N}{2}-1} x(t)e^{-j2\pi kt/N} \tag{22}$$

Where $x(t)$ = Time-domain
$X[k]$ = Frequency-domain

V. Proposed System Architecture

The proposed OFDM system architecture [24] is shown in Fig. 7.

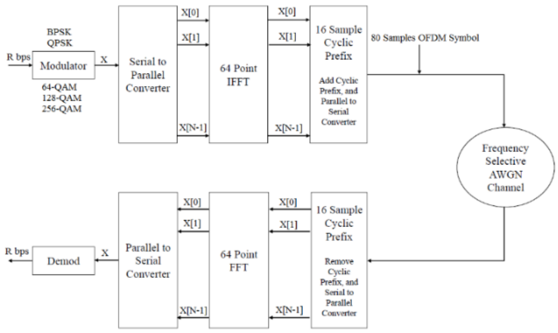

Fig. 7. Proposed OFDM System Architecture

VI. System Specifications

All the system specifications are shown in the following TABLE I.

TABLE I. System Specifications

PARAMETERS	VALUES
Channel bandwidth	20 MHz
Modulation types	BPSK,QPSK,64-QAM, 128-QAM, 256-QAM
FFT size (Nfft)	64
CP length (Ncp)	16
Number of used subcarriers (Nused)	52
Number of pilot subcarriers per symbol (Nref)	4
Number of data subcarriers per symbol (Ndata)	48
Number of null subcarriers (Nleft, Ndc, Nright)	12 Nleft=6, Nright=5, Ndc=1

VII. Simulation Results and Discussion

To analyze the performance of OFDM [25][26][27], Bit Error Rate (BER) is measured with respect to under the different Signal-to Noise Ratio (SNR) conditions. In this study, to plot the OFDM performance curve, we considered the BER and SNR values at y-axis and x- axis respectively as well as the SNR range considered from -10 to 10dB. The simulation results for the performance of OFDM based on BPSK, QPSK, 64-QAM, 128-QAM and 256-QAM modulation techniques over AWGN are depicted in the following:

A. *Performance of BPSK modulation with and without OFDM over AWGN*

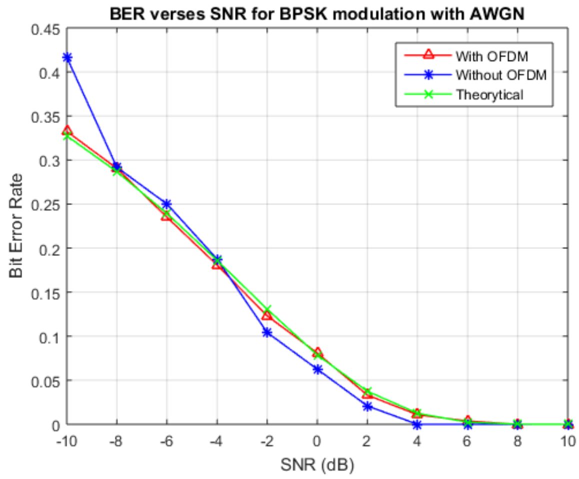

Fig. 8. BER versus SNR for BPSK modulation with AWGN

Fig. 8 shows that the BER performance of BPSK modulation over AWGN channel with and without OFDM as well as the theoretical performance also be shown. From the Fig. 8, we can see that the performance of BPSK modulation for the theoretical and with OFDM is almost the same. There is little difference between these performances. On the other hand, in the performance between with and without OFDM, we can see that the BER for without OFDM is comparatively higher than with OFDM under the low SNR conditions. So, it will be concluded that by using OFDM we can achieve a comparatively lower BER.

The calculated BER of BPSK Modulation for theoretical, with and without OFDM is recorded in the TABLE-II.

TABLE II. BER of BPSK Modulation for Theoretical, with and without OFDM

SNR	BPSK with OFDM	BPSK without OFDM	BPSK Theoretical
-10	0.3325	0.4167	0.3274
-8	0.2904	0.2917	0.2867
-6	0.2350	0.2500	0.2392
-4	0.1808	0.1875	0.1861
-2	0.1231	0.1042	0.1306
0	0.0808	0.0625	0.0786
2	0.0331	0.0208	0.0375
4	0.0108	0.0000	0.0125
6	0.0037	0.0000	0.0024
8	0.0000	0.0000	0.0002
10	0.0000	0.0000	0.0000

B. *Performance of BPSK and QPSK modulations with OFDM*

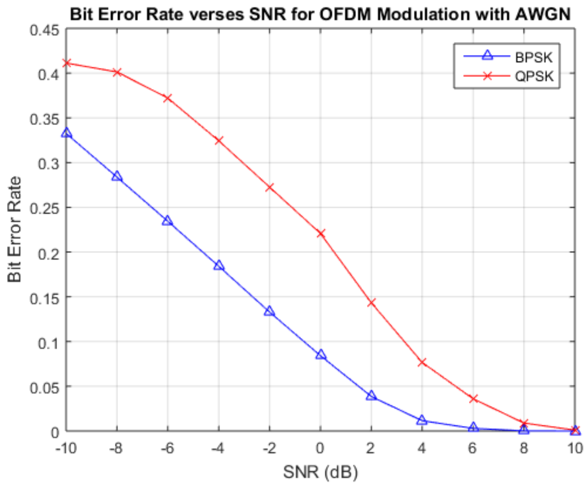

Fig. 9. BER versus SNR for OFDM Modulation with AWGN

In Fig. 9 the BER performance for the BPSK and QPSK modulation techniques with OFDM over AWGN channel has been simulated. By analyzing the performance of BPSK and QPSK techniques, it will be concluded that with the presence of OFDM the BPSK technique is performed better than the QPSK technique i.e. BPSK provides less BER than the QPSK technique.

The calculated BER of BPSK and QPSK modulations with OFDM is recorded in the TABLE-III.

TABLE III. BER OF BPSK AND QPSK MODULATIONS WITH OFDM

SNR	BPSK	QPSK
-10	0.3327	0.4113
-8	0.2838	0.4014
-6	0.2344	0.3721
-4	0.1842	0.3244
-2	0.1329	0.2726
0	0.0842	0.2207
2	0.0385	0.1432
4	0.0115	0.0766
6	0.0029	0.0360
8	0.0002	0.0089
10	0.0000	0.0010

C. *Performance of 64-QAM, 128-QAM and 256-QAM modulations with OFDM*

In Fig. 10 the BER performance for the 64-QAM, 128-QAM and 256-QAM modulation techniques with OFDM over AWGN channel has been simulated. From the Fig. 10, it is clearly seen that with the presence of OFDM the 64-QAM modulation technique provides the minimum BER than the 128-QAM and 256-QAM techniques at both low and high SNR.

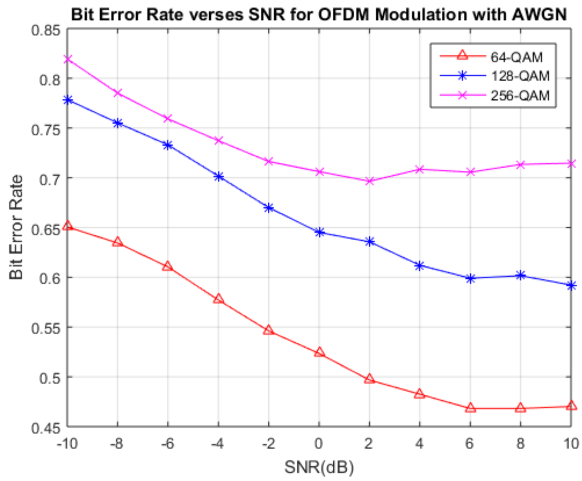

Fig. 10. BER versus SNR for OFDM Modulation with AWGN

The calculated BER of 64-QAM, 128-QAM and 256-QAM modulations with OFDM is recorded in the TABLE IV.

TABLE IV. BER OF 64-QAM, 128-QAM AND 256-QAM MODULATIONS WITH OFDM

SNR	64-QAM	128-QAM	256-QAM
-10	0.6506	0.7785	0.8194
-8	0.6345	0.7552	0.7851
-6	0.6104	0.7331	0.7592
-4	0.5772	0.7017	0.7373
-2	0.5461	0.6700	0.7164
0	0.5235	0.6451	0.7062
2	0.4968	0.6357	0.6965
4	0.4825	0.6121	0.7085
6	0.4682	0.5991	0.7056
8	0.4682	0.6016	0.7134
10	0.4702	0.5922	0.7147

Finally, from the analysis of all the modulation techniques in the Fig. 8, Fig. 9 and Fig. 10 it can be said that there is a relation between the BER and SNR values. All the figures of simulation results clearly shows that the BER values are decreasing with the increasing of the SNR values and this is accomplished due to when increases the value of SNR the amount of noise is decreased and when the noise power decreases the BER values are also be decreased. So, the relation can be expressed as – the BER and SNR values are inversely proportional to each other and also BER is proportional to noise power. The low SNR values produce a large amount of noise and high SNR values produce less amount of noise. Finally, from the above discussion, it can be concluded that with the presence of OFDM the BPSK modulation technique is performed better than the other techniques which has been implemented for this work.

ACKNOWLEDGMENT

We would like to cordially thank all the teachers of the department of Computer Science and Engineering, Islamic University-Bangladesh and most importantly our beloved parents for their continuous support.

CONCLUSION

In this paper, we have tried to present the theoretical information about the Orthogonal Frequency Division Multiplexing (OFDM) system and also discussed about different modulation techniques which are popularly used in OFDM systems. In this paper, we have proposed an OFDM system architecture as well as a comparative analysis has been accomplished by analyzing the performance of that OFDM system for different modulation techniques where we have used BPSK, QPSK, 64-QAM, 128-QAM and 256-QAM modulation techniques. By analyzing the performances of OFDM system, we have proposed a relation between BER and SNR and the relation is expressed as- the BER and SNR values are inversely proportional to each other and finally we have concluded that with the presence of BPSK modulation technique, the OFDM system is performed better performance compared to the others.

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