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Analysis of the Probability of Bit Error Performance on Different Digital Modulation Techniques over AWGN Channel Using MATLAB

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Abstract – **Due to the demand at the present era of wireless communication technology, it is highly required a dependable communication system that can transmit more data with the lower probability of bit error. The digital modulation technique plays a vital role in modern wireless communication technology. Digital modulation technique provides the ability of more data transmission rates with better communication quality and higher data security using optimum bandwidth. By estimating the Probability of Bit Error, it will be possible to evaluate the quality of the performance of different modulation techniques. The aim of this paper is to discuss about the appropriate information of different digital modulation techniques which are extensively used in digital wireless communication systems. Finally by analyzing the Probability of Bit Error (BER) performance of various digital modulation techniques, it could be concluded that which modulation technique is suitable for different Signal-to-Noise Ratio conditions. This paper is especially focused on the comparison of the Probability of Bit Error (BER) performance among ASK, FSK, PSK and QAM modulation techniques. In this paper, all the simulation of ASK, FSK, PSK and QAM modulation techniques are accomplished by using MATLAB.**

Keywords-Digital Modulation, ASK, FSK, PSK, QAM, AWGN Channel, Signal-to-Noise Ratio, Probability of Bit Error

I. Introduction

Generally a signal has three basic properties that are amplitude, phase and frequency. Modulation technique is defined as the process, where one of these properties of the carrier signal like the amplitude, phase, or the frequency is changed in accordance with the baseband signal. The modulation technique is performed by a device that is called modulator. The demodulation is just opposite to the modulation process and which device is used to perform the demodulation process that is called demodulator. When the amplitude of the carrier signal is changed then it is said to be amplitude modulation and for changing frequency it is said to be frequency modulation furthermore for changing phase it is said to be phase modulation respectively. The modulation process provides some benefits in wireless communication systems such as- reduced the antenna size and interference, multiplexing technique is allowed for different signals [6] [7].

Nowadays for the huge amount of mobile users all over the world it may be highly needed a more reliable communication system with higher data transmission rates and higher channel capacity to communicate with each other or transferring data over a long distance. The better quality of various services in communication systems was a big challenge at a time but recently it is being easily accomplished by using the various digital modulation techniques due to its higher carrying capacity, lower probability of error, better quality, provides higher security and bandwidth services [8][9].

The digital modulation is defined as a special kind of modulation where the message signal (modulating signal) is of digital in nature (binary or M-ary encoded version) and the carrier wave to be modulated is of usually sinusoidal (analog and having fixed frequency) in nature. For the various powerful advantages analog communication system is now fully replaced by digital communication system. For accomplishing the whole process of digital communication system some elements are highly required such as- source encoder, channel encoder, modulator, a specific channel with noise (AWGN channel), demodulator/detector, channel decoder and source decoder [10][11]. The basic block diagram of digital communication systems is mentioned in Fig.1.

The aim of this paper is to present the appropriate theoretical information about all the digital modulation techniques that are very popularly used in digital communication system as well as we have analyzed the theoretical performance of all the modulation techniques. In this paper, we considered the Probability of bit Error for analyzing the performance.

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.

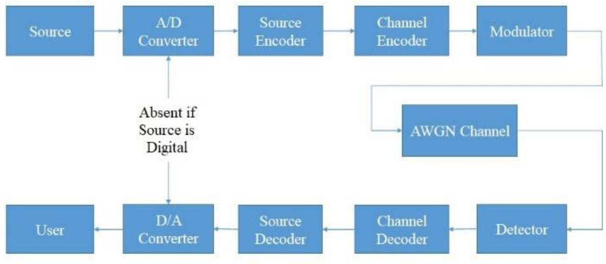

Fig. 1. Basic block diagram of digital communication system

Rest of the paper is organized as follows: Section I contains the introduction of this paper, Section II and III contain the literature review and parameter study of this paper, Section IV explains about the digital modulation schemes, Section V describes the simulation results and discussion and finally the conclusion of this research work is drawn in Section VI.

II. Literature Review

In the Reference [1] the theoretical information about various modulation techniques were discussed as well as different parameters such as- Bit Error Rate, Probability of Error Signal to Noise Ratio, Mean Squared Error and Rate distortion were also discussed. In terms of these parameters different modulation schemes are analyzed and finally concluded which modulation scheme is best under low, medium and high SNR conditions.

In the Reference [2] it was discussed about the digital communication system that is based on M-ary modulation technique and illustrated the comparison of the performance among MPSK, MQAM and MFSK modulation schemes according to their Bit Error Rate performance with considering Additive White Gaussian Noise (AWGN) channel as well as in the conclusion section it will be mentioned that which modulation scheme shows the better performance.

In the Reference [3] it was described about the theoretical approach for different M-ary modulation techniques (MPSK and MQAM) to analyze the graphical representation of the performance of BER vs Eb/No by considering the Additive White Gaussian Noise (AWGN) channel and Multipath Rayleigh Fading channel as well as mentioned the comparison the performance between them.

In the Reference [4] it was shown about the overview of different digital modulation schemes which are used in wireless communication systems as well as concluded that which modulation scheme is performed better among them. The theoretical and simulated Symbol Error Rate (SER) of M-ary ASK, FSK, PSK, QAM and HFQAM modulation schemes are calculated with respect to AWGN channel for analyzing the performance of different modulation schemes.

Reference [5] was especially focused on the measurement of Bit Error Rate for different modulation schemes and mentioned the comparison of various digital modulation schemes performance in WIMAX. MPSK and MQAM modulation schemes were simulated using the MATLAB environment according to various OFDM configurations.

III. Parameter Study

In this paper, some parameters are considered to analyze the performance of various modulation schemes. They are discussed in the following-

A. *Signal-to- Noise Ratio (SNR)*

The term Signal to Noise Ratio is defined as a ratio of transmitted signal power to channel noise power. In a transmission system, high SNR is good for transmitter and receiver [11]. The SNR is calculated by the following Eq.1

$$SNR = \frac{P_S}{P_N} \qquad (1)$$

Where, P_S = transmitted signal power
P_N = channel noise power

Sometimes the SNR values are calculated in decibel unit and it is accomplished by following the Eq.2

$$SNR_{dB} = 10\log_{10}\left(\frac{P_S}{P_N}\right) \qquad (2)$$

B. *Bit Error Rate (BER)*

Bit Error Rate or BER is formally defined as the ratio of the number of error bits and the total number of bits sent. By analyzing the BER value of a transmission system we can evaluate the performance quality of that system. By considering the higher SNR and better transmission channel it is possible to get low BER in a transmission system. BER is often calculated in percentage [11]. The BER is calculated by the following Eq.3

$$BER = \frac{Number\ of\ Error\ Bits}{Total\ Number\ of\ Bits\ Sent} \qquad (3)$$

For an example, let in a transmission system the number of error bits is 2 out of 10, then the

$$BER = \frac{2}{10}\ X\ 100\% = 20\%$$

C. *Probability of Error (Pe)*

An important parameter Probability of error is used to estimate the BER of a transmission system because the BER and Probability of error terms are interrelated to each other i.e. if one is known then the other is calculated [11]. There is an Eq.4 which is used to express the BER as Probability error.

$$P_e = \frac{1}{2}(1 - erf)\frac{E_b}{N_0} \qquad (4)$$

Where, erf is error function and E_b/N_0 is the ratio of signal energy per bit and noise density per bit.

IV. Digital Modulation Schemes

Digital modulation scheme is mainly divided into three categories such as- Amplitude Shift Keying, Frequency Shift Keying and Phase Shift Keying. There is another digital modulation named Quadrature Amplitude Modulation which is the combination of Amplitude Shift Keying and Phase Shift Keying [11]. All the classification of digital modulations is also displayed in the following diagram.

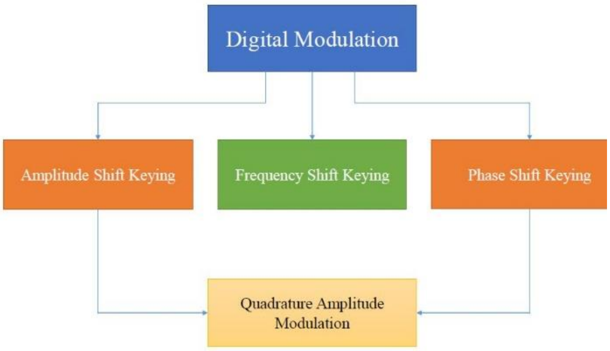

Fig. 2. Classification of Digital Modulation

A. Amplitude Shift Keying (ASK)

Amplitude Shift Keying is the digital modulation technique in which the amplitude of the carrier wave changes with digital signals. In ASK modulation, if the digital binary value is 1 then the carrier wave amplitude remains the same and when the digital binary value is 0 then the amplitude of the carrier wave is considerably weaker. During the transmission of signal, it is required less bandwidth but it is costly as well as less power efficient. The ASK signal is influenced by noise, fading and interference and for this reason the performance of ASK is much poor. The ASK modulation technique is used in various low data rate communication systems as well as for the basic applications it is used in broadcasting of signals and optical fiber communication for laser intensity modulation [12][13][14][16].

For binary level Amplitude Shift Keying digital message signal, the modulated signal is represented by the Eq.5 &6.
For a binary 1,

$$S(t)_{ASK} = A_c m(t)\cos(2\pi f_c t + \phi_c) = \sqrt{\frac{2E_i(t)}{T_b}};\ where\ m(t) = 1 \quad (5)$$

For a binary 0,

$$S(t)_{ASK} = A_c m(t)\cos(2\pi f_c t + \phi_c) = 0\,;\ where\ m(t) = 0 \quad (6)$$

Where, T_b is the time duration of one information bit and n_c is fixed integers, it will be find out the value of carrier frequency f_c by using the Eq.7

$$f_c = \frac{n_c}{T_b} \quad (7)$$

Using MATLAB the implementation of Binary Amplitude Shift Keying (BASK) is shown in Fig. 3.

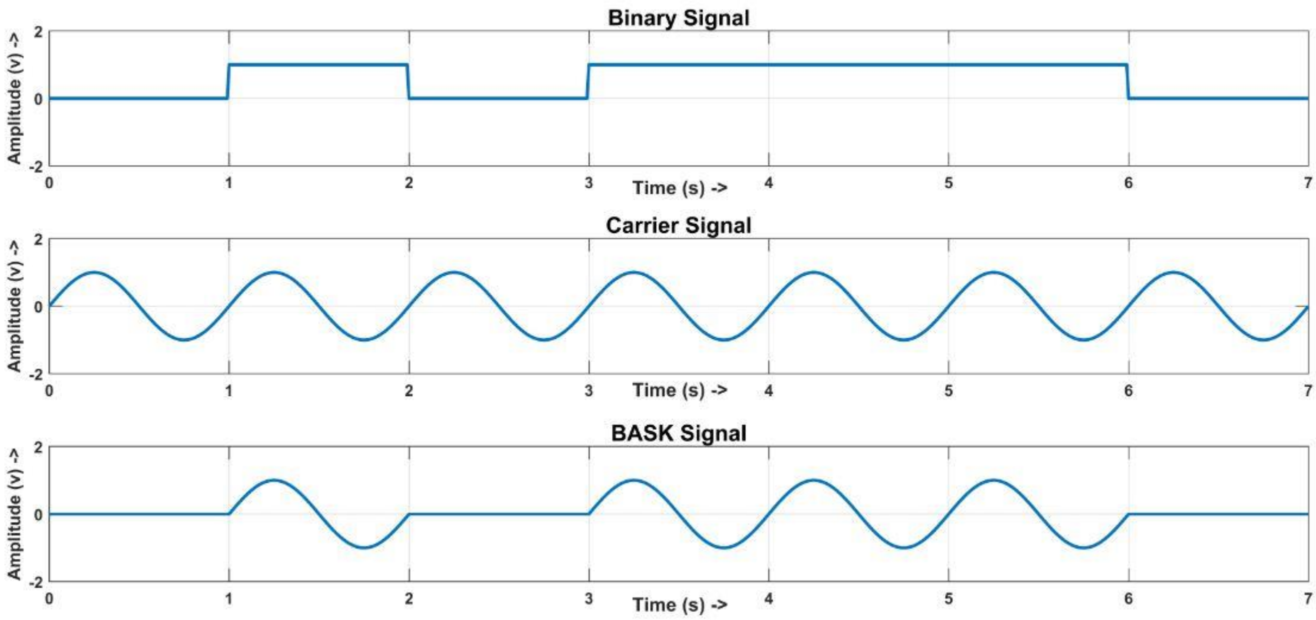

Fig. 3. Implementation of Binary Amplitude Shift Keying (BASK)

For the Multi-Level ASK modulation a modulated signal is represented by the Eq. 8

$$S(t)_{ASK} = \sqrt{\frac{2E_i(t)}{T_b}}\cos(2\pi f_c t) \quad (8)$$

Now if the Multi-Level ASK modulation is coherently detected then the Probability of Symbol Error is expressed by the Eq. 9

$$P_{se,MASK} = \frac{(M-1)}{M} erfc\left(\sqrt{\frac{(3\log_2 M)E_b}{(M^2-1)N_0}}\right) \quad (9)$$

Where, $E_s = (\log_2 M)E_b$

$= \frac{(M^2-1)}{3}E_g$ = Average energy/Symbol

So, the average Probability of Bit Error is expressed by the Eq. 10

$$P_{be,MASK} = \frac{(M-1)}{M\log_2 M} erfc\left(\sqrt{\frac{(3\log_2 M)E_b}{(M^2-1)N_0}}\right) \quad (10)$$

Let, $k = \log_2 M$ bits/symbol.

So, the Probability of Bit Error of Binary ASK or BASK (Where M=2) is-

$$P_{be,BASK} = \frac{1}{2} erfc\left(\frac{E_b}{2N_0}\right) \quad (11)$$

Now, for M = 4,8,16 and 32 we will get some equation for the Probability of Bit Error of M-ASK modulation schemes which are given in the TABLE I.

TABLE I. PROBABILITY OF BIT ERROR EQUATIONS OF M-ASK

M	k	Probability of Bit Error (P_{be})
4	2	$P_{be,4ASK} = \frac{3}{8} erfc\left(\sqrt{\frac{6E_b}{15N_0}}\right)$
8	3	$P_{be,8ASK} = \frac{7}{24} erfc\left(\sqrt{\frac{9E_b}{63N_0}}\right)$
16	4	$P_{be,16ASK} = \frac{15}{64} erfc\left(\sqrt{\frac{12E_b}{255N_0}}\right)$
32	5	$P_{be,32ASK} = \frac{31}{160} erfc\left(\sqrt{\frac{15E_b}{1023N_0}}\right)$

B. *Frequency Shift Keying (FSK)*

Amplitude Shift Keying is the digital modulation technique in which the frequency of the carrier wave changes with digital signals. In FSK modulation, we can see, when digital binary value is 1, the frequency of the carrier wave is higher and when binary value is 0, the frequency of the carrier wave would become lower. In digital communication systems, FSK modulation technique is an important source.

The FSK modulation technique is used in telephone line modem to transmit 300 bits/s at two frequencies 1070 Hz and 1270 Hz as well as it is also used in cordless and paging system applications [12][13][14][16].

For binary level Amplitude Shift Keying digital message signal, the modulated signal is represented by the Eq.12&13

For binary 1,

$$S_{BFSK}(t) = A_c \cos(2\pi f_1 t) = \sqrt{\frac{2E_b}{T_b}}\, cos(2\pi f_c + 2\pi\Delta f\,)t\,, \quad 0 \le t \le T_b \quad (12)$$

For binary 0,

$$S_{BFSK}(t) = A_c \cos(2\pi f_2 t) = \sqrt{\frac{2E_b}{T_b}}\, cos(2\pi f_c - 2\pi\Delta f\,)t\,, \quad 0 \le t \le T_b \quad (13)$$

Where, T_b is represented the bit duration

$$f_c = 0.5(f_H + f_L) = \frac{m}{2T_b} \quad (14)$$

$$\Delta f = 0.5(f_H - f_L) = \frac{n}{2T_b} \quad (15)$$

In Eq.14 & 15 f_H and f_L is the value of higher carrier frequency which is known as mark frequency and lower carrier frequency which is known as space frequency.

Using MATLAB the implementation of Binary Frequency Shift Keying (BFSK) is shown in Fig. 4.

If the FSK modulation is multilevel then the modulated carrier signal is expressed as:

$$S_{MFSK}(t) = \sqrt{\frac{2E_s}{T_s}}\, cos\left(\frac{\pi}{T_s}(n_c + i)t\right) = \sqrt{\frac{2E_s}{T_s}}\, cos\left(2\pi\left(f_c + \frac{i}{2T_s}\right)t\right), \quad 0 < t < T_s\ for\ i = 0,1,2,\dots\dots M \quad (16)$$

Where, $f_c = \frac{n_c}{2T_s}$ (where n_c is a fixed integer) and $E_s = E_b \log_2 M$ and $T_s = T_b \log_2 M$

Now, if the M-ary FSK is coherently detected then the Probability of Symbol Error is expressed as:

$$P_{se,MFSK} \le \frac{1}{2}(M-1)\, erfc\left(\sqrt{\frac{(\log_2 M)}{2}\frac{E_b}{N_0}}\right) \quad (17)$$

So, the average Probability of Bit Error for M-ary FSK is expressed as:

$$P_{be,MFSK} \le \frac{M}{4} erfc\left(\sqrt{\frac{(\log_2 M)}{2}\frac{E_b}{N_0}}\right) \quad (18)$$

Let, $k = \log_2 M$ bits/symbol.

The Probability of Bit Error of BFSK (Where M=2) is expressed as:

$$P_{be,BFSK} = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{2N_0}}\right) \quad (19)$$

Now, for M = 4,8,16 and 32 we will get some equation for the Probability of Bit Error of M-FSK modulation schemes which are given in the TABLE II.

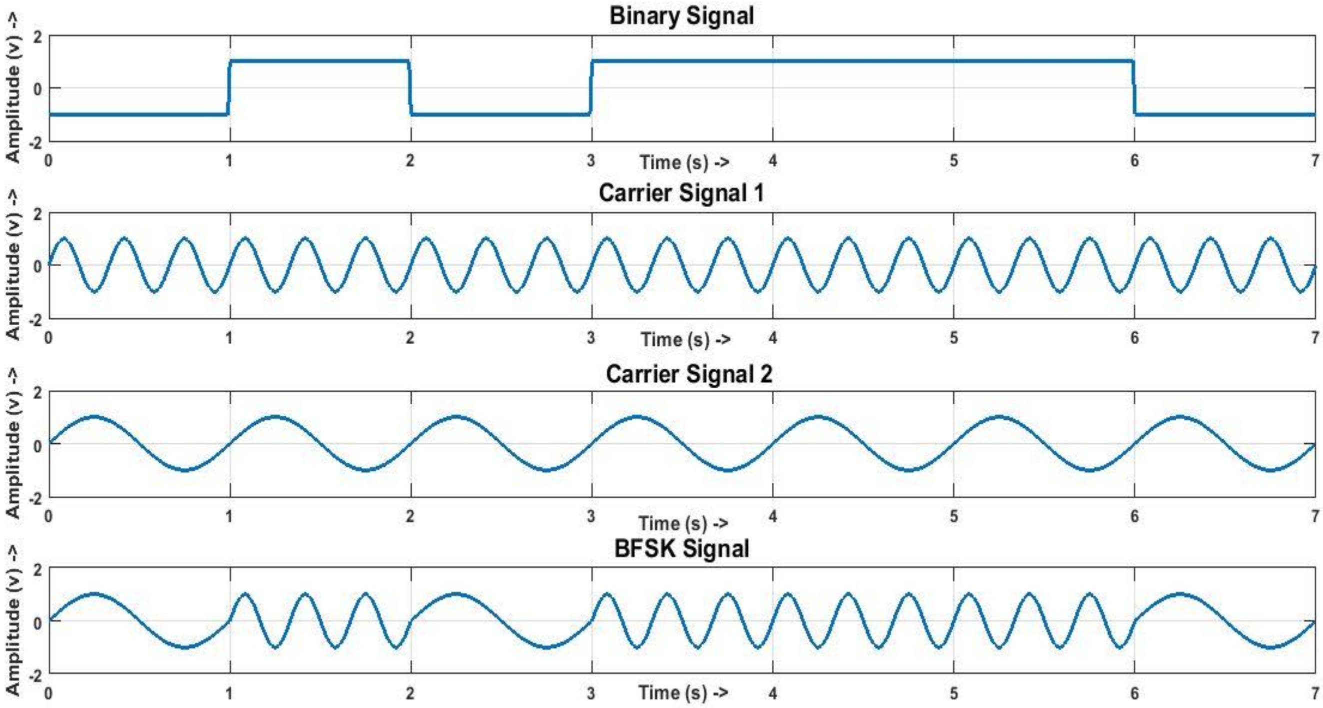

Fig. 4. Implementation of Binary Frequency Shift Keying (BFSK)

TABLE II. PROBABILITY OF BIT ERROR EQUATIONS OF M-FSK

M	k	Probability of Bit Error (P_{be})
4	2	$P_{be,4FSK} \leq erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$
8	3	$P_{be,8FSK} \leq 2erfc\left(\sqrt{\frac{3}{2}\frac{E_b}{N_0}}\right)$
16	4	$P_{be,16FSK} \leq 4erfc\left(\sqrt{\frac{2E_b}{N_0}}\right)$
32	5	$P_{be,32FSK} \leq 8erfc\left(\sqrt{\frac{5}{2}\frac{E_b}{N_0}}\right)$

C. *Phase Shift Keying (PSK)*

Phase Shift Keying is a digital modulation process which transmits data by changing the phase of constant frequency of the carrier wave. In PSK modulation, we can observe that the frequency and amplitude of the carrier wave remain the same. Only change in phase. Specifically phase changes at the point when binary value 1 changes to binary value 0 or where 0 changes to 1. The performance of PSK is comparatively better than ASK and FSK. The PSK modulation technique contains various types of methods such as- BPSK, QPSK, D-BPSK, D-QPSK and M-ary PSK. In space and wireless communication systems, PSK modulation technique is extensively used [12][13][14][15][16].

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°. The modulated carrier signals are represented as:

For a binary 0,

$$S_1(t) = A_c\cos(2\pi f_c t) = \sqrt{E_b}\,\phi_1(t)$$
$$= \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \quad (20)$$

For a binary 1,

$$S_2(t) = A_c\cos(2\pi f_c t + \pi) = \sqrt{E_b}\,\phi_2(t)$$
$$= -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \quad (21)$$

Where, $f_c = \frac{n_c}{T_b}$ (n_c is a fixed integer)

Using MATLAB the implementation of BPSK is shown in Fig. 5.

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 $\frac{7\pi}{4}$.

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

$$S_1(t) = A_c\cos(2\pi f_c t + \theta_1)$$
$$= \sqrt{\frac{2E_s}{T_s}}\cos\left(2\pi f_c + \frac{\pi}{4}\right)t \quad (22)$$
$$S_2(t) = A_c\cos(2\pi f_c t + \theta_2)$$
$$= \sqrt{\frac{2E_s}{T_s}}\cos\left(2\pi f_c + \frac{3\pi}{4}\right)t \quad (23)$$

$$S_3(t) = A_c \cos(2\pi f_c t + \theta_3) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c + \frac{5\pi}{4}\right)t \quad (24)$$

$$S_4(t) = A_c \cos(2\pi f_c t + \theta_4) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c + \frac{7\pi}{4}\right)t \quad (25)$$

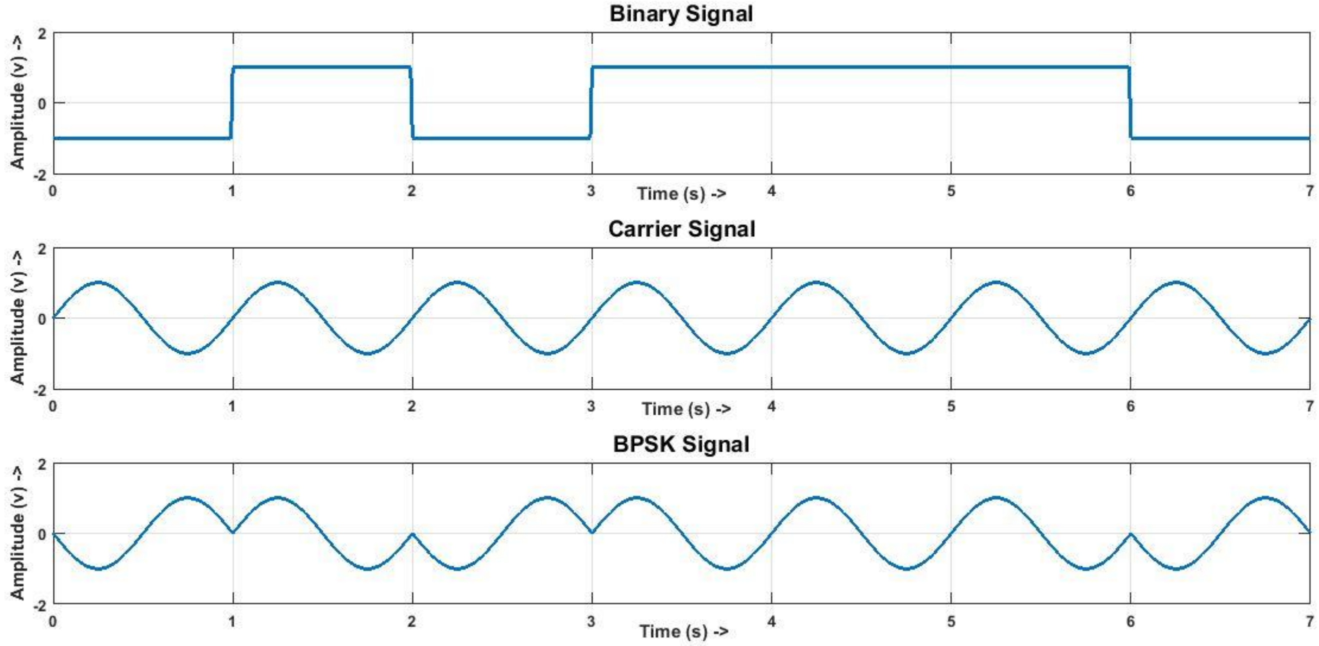

Fig. 5. Implementation of Binary Phase Shift Keying

Using MATLAB the implementation of QPSK is shown in Fig. 6:

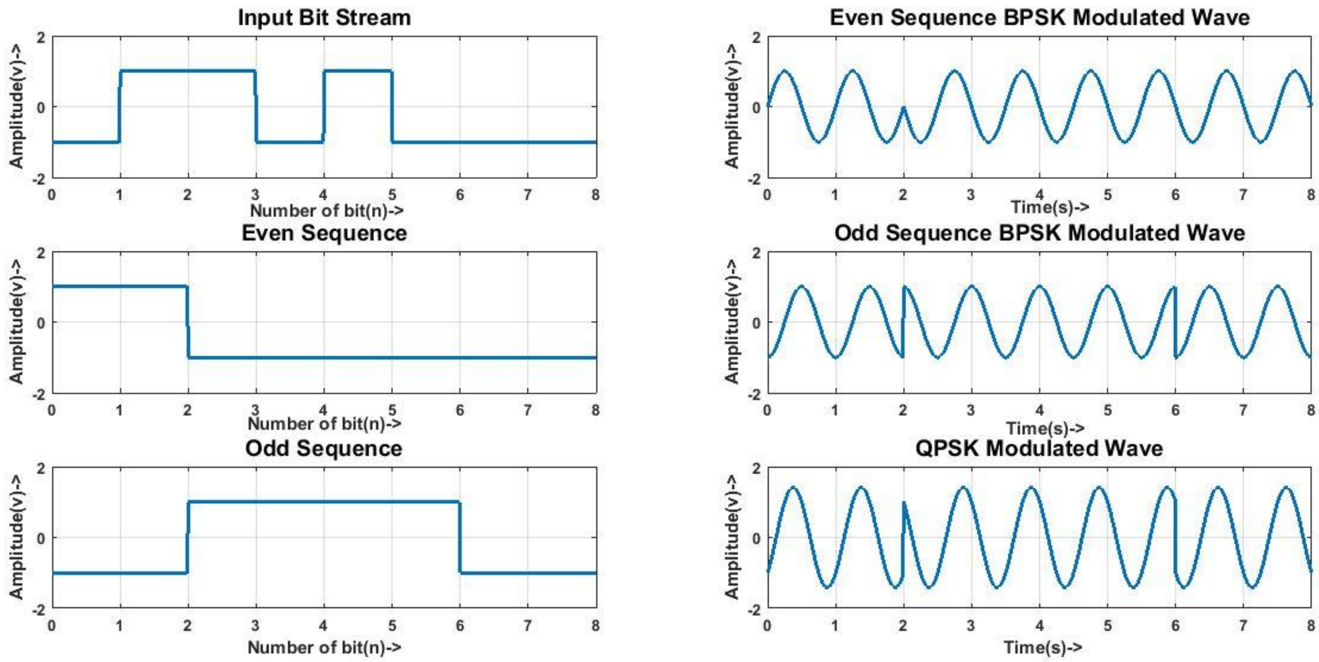

Fig. 6. Implementation of QPSK

If the M-ary PSK modulation is coherently detected the Probability of Symbol Error is expressed as:

$$P_{se,MPSK} \cong erfc\left(\sqrt{(\log_2 M)\,\frac{E_b}{N_0}}\, sin\left(\frac{\pi}{M}\right)\right), M \geq 4 \quad (26)$$

Where, $k = \log_2 M$ bits/symbol

For coherently detected M-ary PSK modulation, the Probability of Bit Error is expressed as:

$$P_{be,MPSK} \cong \frac{1}{\log_2 M} \, erfc\left(\sqrt{(\log_2 M)\,\frac{E_b}{N_0}}\, sin\left(\frac{\pi}{M}\right)\right), M \geq 4 \quad (27)$$

Now for BPSK (where M=2), the Probability of Bit Error is expressed as:

$$P_{be,BPSK} = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \quad (28)$$

And for QPSK (where M=4), the Probability of Bit Error is expressed as:

$$P_{be,QPSK} = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b\ \log_2(4)}{2N_0}}\right) = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \quad (29)$$

Here from the Eq. 28 and Eq. 29 we can observe that the equation of Probability of Bit Error of BPSK and QPSK are the same.

Now, for M = 8,16 and 32 we will get some equation for the Probability of Bit Error of M-PSK modulation schemes which are given in the TABLE III.

TABLE III. PROBABILITY OF BIT ERROR EQUATIONS OF M-PSK

M	k	Probability of Bit Error (P_{be})
8	3	$P_{be,8PSK} \cong \frac{1}{3} erfc\left(0.383\sqrt{\frac{3E_b}{N_0}}\right)$
16	4	$P_{be,16PSK} \cong \frac{1}{4} erfc\left(0.195\sqrt{\frac{4E_b}{N_0}}\right)$
32	5	$P_{be,32PSK} \cong \frac{1}{5} erfc\left(0.098\sqrt{\frac{5E_b}{N_0}}\right)$

In non-coherent detection method, the Probability of Bit Error of D-BPSK is expressed as:

$$P_{be,D-BPSK} = 0.5\, e^{-\frac{E_b}{N_0}} \quad (30)$$

In non-coherent detection method, the Probability of Bit Error of D-QPSK is expressed as:

$$P_{be,QPSK} = Q_1(a,b) - 0.5 I_0(ab) e^{-0.5(a^2+b^2)} \quad (31)$$

where,

$$a = \sqrt{\left(\frac{2E_b}{N_0}\left(1-\frac{1}{\sqrt{2}}\right)\right)}$$

$$b = \sqrt{\left(\frac{2E_b}{N_0}\left(1-\frac{1}{\sqrt{2}}\right)\right)}$$

$$Q_1(a,b) = Marcum\ Q - function$$

$$I_0(ab) = Modified\ Bessel - function$$

D. 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 even be considered as a combination 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 utilized in digital cable television network, cable modem and point-to-point wireless system applications and extensively used in satellite communication systems [12][13][14][15].

The M-ary QAM modulated signal is expressed as:

$$S_i(t) = \sqrt{\frac{2E_{min}}{T_s}}\, a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}}\, b_i \sin(2\pi f_c t), \quad 0 < t < T_s, \quad for\ i = 1,2,\ldots\ldots.., M \quad (32)$$

Where, E_{min} indicated the signal energy for the minimum amplitude, a_i and b_i indicates a pair of random integers. A typical modulated 8-QAM waveform is shown in Fig. 7

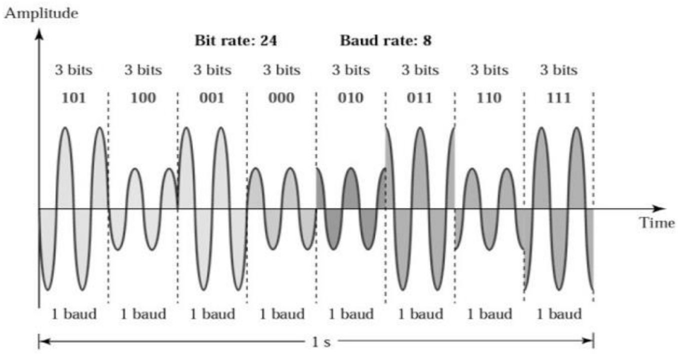

Fig. 7. Typical modulated 8-QAM waveform

The constellation diagram of 4-QAM and 8-QAM is shown in Fig. 8.

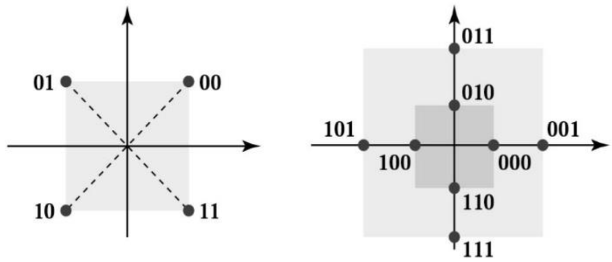

Fig. 8. Constellation diagram of 4-QAM and 8-QAM

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

$$P_{se,MQAM} \cong 2\left(1-\frac{1}{\sqrt{M}}\right) erfc\left(\sqrt{\frac{3\log_2 M}{2(M-1)}\frac{E_b}{N_0}}\right) \quad (33)$$

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

$$P_{be,MQAM} \cong 2\left(\frac{\sqrt{M}-1}{\sqrt{M}\log_2 M}\right) erfc\left(\sqrt{\frac{3\log_2 M}{2(M-1)}\frac{E_b}{N_0}}\right) \quad (34)$$

where, $k = \log_2 M$ bits/symbol

Now, for M = 4, 8, 16, 32, 64, 128 and 256 we will get some equation for the Probability of Bit Error of M-QAM modulation scheme which are given in the TABLE IV.

TABLE IV. PROBABILITY OF BIT ERROR EQUATIONS OF M-QAM

M	k	Probability of Bit Error (P_{be})
4	2	$P_{be,4QAM} \cong \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$
8	3	$P_{be,8QAM} \cong 0.43\, erfc\left(\sqrt{\frac{9E_b}{14N_0}}\right)$
16	4	$P_{be,16QAM} \cong \frac{3}{8}\, erfc\left(\sqrt{\frac{2E_b}{5N_0}}\right)$
32	5	$P_{be,32QAM} \cong 0.33\, erfc\left(\sqrt{\frac{15E_b}{62N_0}}\right)$
64	6	$P_{be,64QAM} \cong \frac{7}{24}\, erfc\left(\sqrt{\frac{E_b}{7N_0}}\right)$
128	7	$P_{be,128QAM} \cong 0.26\, erfc\left(\sqrt{\frac{21E_b}{254N_0}}\right)$
256	8	$P_{be,256QAM} \cong \frac{15}{64}\, erfc\left(\sqrt{\frac{4E_b}{85N_0}}\right)$

V. SIMULATION RESULTS AND DISCUSSION

In wireless communication technology, the analysis of Probability of Bit Error performance of different modulation techniques will be calculated with respect to different Signal to Noise Ratio. For this reason, in this study to plot the Probability of Bit Error (BER) simulation results of different modulation techniques we considered the Probability of Bit Error (P_{be}) and Signal to Noise Ratio (SNR) values at y-axis and x-axis respectively as well as considered the SNR ranges from -4 to 30dB. In this study, we also considered a logarithmic function to calculate the value of the Probability of Bit Error in decibel units. The probability of Bit Error (BER) performance was simulated using MATLAB framework and the simulation results of BASK, M-ASK, BFSK, M-FSK, BPSK, QPSK, D-BPSK, D-QPSK, M-PSK and M-QAM modulation techniques are depicted in the following:

A. *Probability of Bit Error Performance for Different ASK Modulation Techniques*

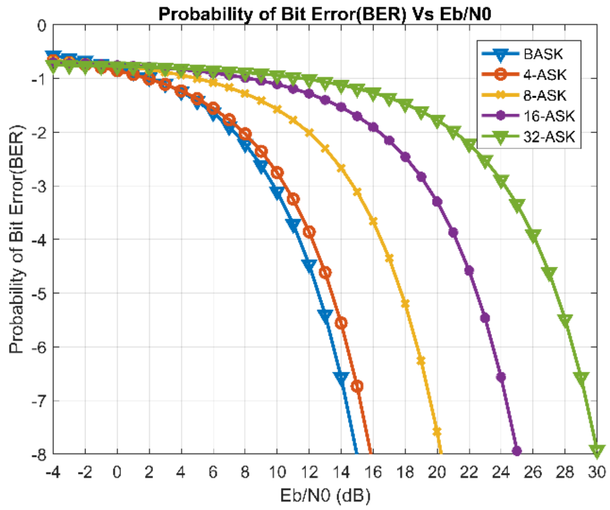

Fig. 9. Probability of Bit Error Performance for Different ASK Modulation Techniques

Fig. 9 shows the simulation results of the BASK and M-ASK modulation techniques. In this figure, 4-ASK, 8-ASK, 16-ASK and 32-ASK modulation techniques were implemented for the M-ASK modulation technique. From the above figure it will be clearly displayed that the BASK, 4-ASK, 8-ASK, 16-ASK and 32-ASK modulation techniques are performed with minimum Probability of Bit Error at 14dB, 15dB, 20dB, 25dB and 30dB respectively.

B. *Probability of Bit Error Performance for Different FSK Modulation Techniques*

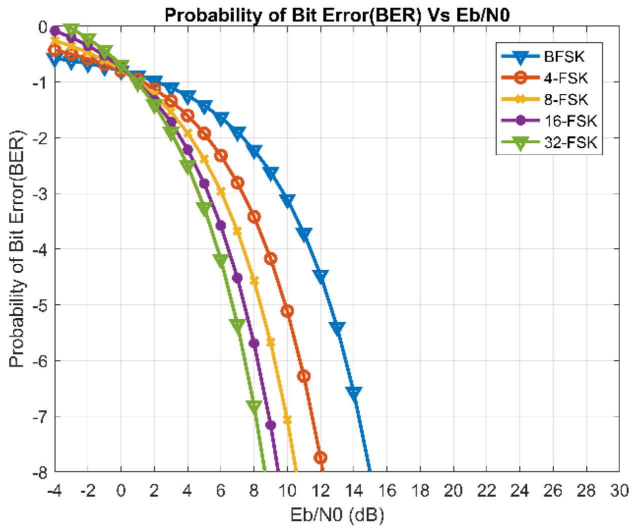

Fig. 10. Probability of Bit Error Performance for Different FSK Modulation Techniques

Fig. 10 shows the simulation results of the BFSK and M-FSK modulation techniques. In this figure, 4-FSK, 8-FSK, 16-FSK and 32-FSK modulation techniques were implemented for the M-FSK modulation technique. From the above figure it will be easily mentioned that all these modulation techniques are performed in a standard SNR value that is up to 14dB. Above figure produced a decision that BFSK and all the M-FSK such as- 4-FSK, 8-FSK, 16-FSK and 32-FSK are performed with minimum Probability of Bit Error at 14dB, 12dB, 10dB, 9dB and 8dB respectively. So we will conclude that with the increasing order of FSK modulation it will be shown that the values of SNR are decreasing as well.

C. Probability of Bit Error Performance for Different PSK Modulation Techniques

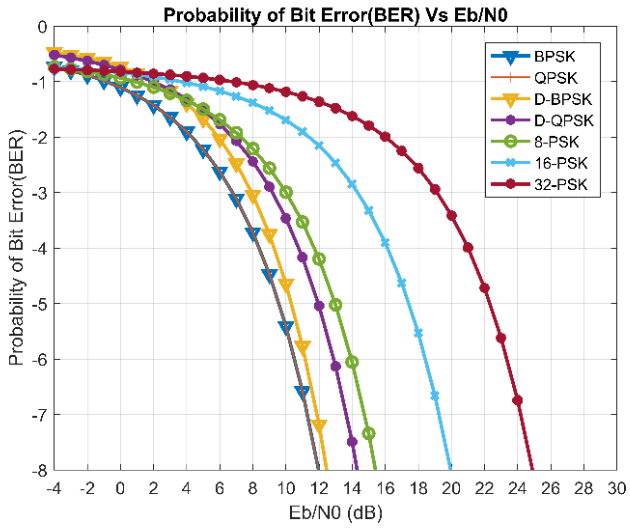

Fig. 11. Probability of Bit Error Performance for Different PSK Modulation Techniques

Fig. 11 depicts the Probability of Bit Error performance curves simulation result of the BPSK, QPSK, D-BPSK, D-QPSK and M-PSK modulation techniques. In this figure for M-PSK technique 8-PSK, 16-PSK and 32-PSK modulations were implemented. From the above figure, it will be mentioned that the Probability of Bit Error of the BPSK and QPSK are the same because the equation of probability of bit error for the both modulations are the same. In this figure D-BPSK, D-QPSK and 8-PSK, 16-PSK and 32-PSK are performed with minimum Probability of Bit Error at 12dB, 14dB, 15dB, 19dB and 24dB respectively.

D. Probability of Bit Error Performance for Different QAM Modulation Techniques

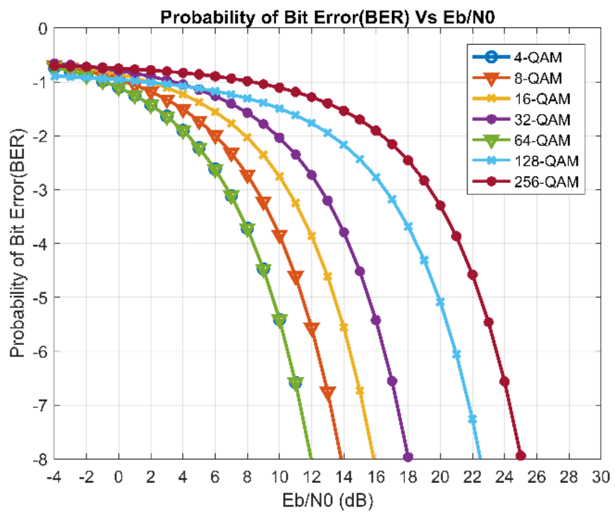

Fig. 12. Probability of Bit Error Performance for Different QAM Modulation Techniques

Fig. 12 shows the simulation result of the M-QAM modulation techniques Probability of Bit Error performance curves where 4-QAM, 8-QAM, 16-QAM, 32-QAM, 64-QAM, 128-QAM and 256-QAM modulations are implemented for M-QAM techniques. From the above figure it will be mentioned that the minimum Probability of Bit Error of these modulation techniques are performed at different SNR values that are ranges in 11dB to 25dB. It will be concluded that the 32-QAM and 256-QAM techniques provide the minimum Probability of Bit Error value among all the techniques.

Finally, from the analysis of all the modulation techniques in the Fig. 9, Fig. 10, Fig. 11 and Fig. 12, it will be summarized that there is a relation between the BER and SNR values in all the figures of simulation results and clearly showed that the BER values are decreasing with the increasing of the SNR values and when increases the value of SNR the amount of noise are decreased and when the noise power decreases the BER values are also be decreased. So the relation will 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 are produced less amount of noise. Furthermore, it will be concluded that for a specific SNR value a specific modulation technique is produced a minimum BER value than the other techniques and it will also be said that the higher order modulation techniques are performed in higher SNR values compared to the others [17][18][19][20].

The following TABLE V shows that the Probability of Bit Error of all modulation techniques in some specific SNR values and the values are considered 1dB, 5dB and 10 dB for low, medium and high SNR value respectively and in every column the minimum Probability of Bit Error (BER) values are marked by red color.

TABLE V. PROBABILITY OF BIT ERROR (BER) IN DIFFERENT SNR

Different Modulation Techniques	**BER (dB)**		
	SNR=1dB	**SNR=5dB**	**SNR=10dB**
BASK	-0.88	-1.42	-3.10
4-ASK	-0.92	-1.37	-2.75
8-ASK	-0.79	-1.00	-1.57
16-ASK	-0.76	-0.86	-1.10
32-ASK	-0.78	-0.83	-0.94
BFSK	-0.88	-1.42	-3.10
4-FSK	-0.94	-1.92	-5.11
8-FSK	-0.98	-2.38	-7.06
16-FSK	-1.00	-2.82	-8.99
32-FSK	-1.01	-3.25	-10.91
BPSK	-1.24	-2.22	-5.41
QPSK	-1.24	-2.22	-5.41
D-BPSK	-0.84	-1.67	-4.64
D-QPSK	-0.88	-1.51	-3.46
8-PSK	-1.01	-1.49	-2.99
16-PSK	-0.87	-1.08	-1.69
32-PSK	-0.83	-0.93	-1.18

4-QAM	-1.24	-2.22	-5.41
8-QAM	-1.05	-1.72	-3.83
16-QAM	-0.92	-1.37	-2.75
32-QAM	-0.84	-1.14	-2.03
64-QAM	-1.24	-2.22	-5.41
128-QAM	-0.98	-1.12	-1.49
256-QAM	-0.76	-0.86	-1.10

From the TABLE V, it will be showed that under the low SNR value (1dB) i.e. there is a large amount of noise and the BPSK, QPSK and 4-QAM modulation techniques are provides same BER that are -1.24 dB each and also these values are the minimum BER values than the other modulation techniques. When the SNR value is 5 dB (medium) the 32-FSK modulation technique provides the minimum BER value that is -3.25dB. Furthermore, when the SNR value is 10 dB (high) i.e. there is less amount of noise the 32-FSK modulation technique also provides the minimum BER value that is -10.91dB. So, from the simulation results it will be said that for under the low SNR value condition BPSK, QPSK and 4-QAM modulation techniques are best and for medium and high SNR value conditions the 32-FSK is best for obtaining better performance.

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CONCLUSION

This paper has attempted to present the appropriate theoretical information of various digital modulation schemes as well as mentioned about some important parameters that are extensively used in digital communication systems. A comparative analysis of different digital modulation techniques according to their Probability of Bit Error performance over AWGN channel are discussed in this paper. The output modulated waveform of some digital modulations according to their digital input and carrier signals are also depicted in this paper. From the analysis of Probability of Bit Error results for various digital modulation schemes, it will be concluded that under the low SNR condition the BPSK, QPSK and 4-QAM techniques provide the minimum Probability of Bit Error value and under the both medium and high SNR conditions the 32-FSK technique provides the minimum Probability of Bit Error value. Finally, it will be concluded that for the low and both medium and high SNR condition BPSK, QPSK, 4-QAM and 32-FSK are more suitable respectively to get better performance.

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