www.ijaceeonline.com ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

BER Performance of SISO-OFDM Scheme based on FFT over an AWGN Channel

Nouri Ahwaas
PG Scholar, Department of Electrical and Computer, Elmergib University, Libya
Email: n.ahwaas@elmergib.edu.ly

Mohamed A. Elalem
Associate Professor, Department of Electrical and Computer, Elmergib University, Libya
Email: maelalem@elmergib.edu.ly

Abstract: *OFDM is turning into the chosen modulation technique for wireless communication to reduce multipath fading effects and to provide massive data rates. OFDM is a multicarrier transmission system that utilizes the method of ripping smaller subcarriers of frequencies to agitate multipath drawback. Multipath distortion and Frequency interference are decreased through this system. The aim of this paper is to analyze the performance of the SISO-OFDM technology using different modulation techniques. This paper is mainly focused on the performance of the Bit Error Rate (BER) of SISO- OFDM systems Based on FFT over an AWGN. In this paper, we considered BPSK, QPSK, 16-QAM, 64-QAM and 256-QAM modulation techniques. All the simulations are performed by using the MATLAB framework.*

Keyword: *OFDM; BPSK; QPSK; QAM; BER; SISO.*

1. INTRODUCTION

Wireless communication technology has made 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 wireless technology key 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.

Modulation technique is defined as the process where one of the properties of the carrier signal like the amplitude, phase, or 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. 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 as it can be seen in Figure 1.

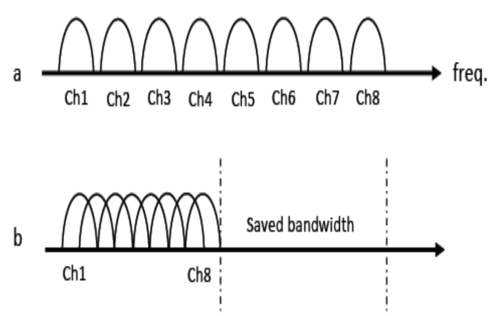

Figure 1 Multi-carrier signal composed of 8 subcarriers. a) FDM spectrum. b) OFDM spectrum.

Figure 1 shows spectrally the difference between an FDM system and an OFDM system. The upper part of the image (a) shows the spectrum of a multicarrier system with eight subcarriers separated by certain guard bandwidth in which no orthogonality between the subcarriers is needed. The lower part (b) shows the spectrum of an OFDM system also composed of eight subcarriers but whose frequencies are orthogonal with each other and thus a sizeable amount of bandwidth is spared.

OFDM would allow more data transmissions than

Cite this paper:
Nouri Ahwaas, Mohamed A. Elalem, "BER Performance of SISO-OFDM Scheme based on FFT over an AWGN Channel", International Journal of Advances in Computer and Electronics Engineering, Vol. 6, No. 9, pp. 1-8.

ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

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.

One of the main reasons to use OFDM is to increase robustness against channels that have frequency selective fading or narrowband interference. In the systems those work in a single carrier system (before OFDM has been employment), a single fade or interferer in the carrier frequency can cause the entire link to fail or being in outage, but in a multicarrier system, only a small percentage of the subcarriers will be affected by fading. At the receiver, the error-correction schemes can then be used to detect and possibly correct the data carried by the subcarriers.

OFDM was received the interest of a lot of researchers due to its great advantages in transmission. In [3], the study concentrated on OFDM with pilot-based channel estimation techniques over frequency selective fading channels. The authors propose a specific approach to channel equalization for Orthogonal Frequency Division Multiplex systems. Inserting an equalizer realized as an adaptive system before the FFT processing, the influence of variable delay and multi path mitigation. Through extensive computer simulations, the study investigates the performance of the channel equalized system. The results show much higher convergence and adaptation rate compared to one of the most frequently used algorithms - Least Mean Squares (LMS)

The authors in [4] introduce a design and an implementation of a wireless communication system with MATLAB program based on OFDM. The transmitted signal is modulated with PSK modulation, and then multiplexed with OFDM technique to achieve a higher data rate transmission. The signal is then transmitted through a frequency selective channel. The received faded signal is demultiplexed and demodulated. The simulation results show a robustness against frequency selective faded channel. The maximum obtained bit error rate is in order of 10^{-5} which indicates that the signal recovering is very good.

The subject of OFDM is also studied by different aspect in [5], in which the study provides a comparative study on the performance of different modulation schemes using orthogonal frequency division multiplexing but in this case in terms of their spectral efficiency, reliability, peak-to-average power ratio (PAPR), power efficiency, out-of-band emission, and computational complexity. Based on the provided comparative study, the relationship and interaction between these different modulation schemes and the requirements of fifth generation (5G) networks is discussed and explained.

There are some drawbacks of OFDM such as- higher peak to average ratio, more sensitive to carrier frequency offset and its sensitivity to phase noise [6].

This paper analyzes the performance of the OFDM technology as Single Input Single Output (SISO) base, using different modulation techniques such as BPSK, QPSK, 16-QAM, 64-QAM and 256-QAM. The comparison and performance metric in this work is mainly focused on the Bit Error Rate (BER) of SISO-OFDM systems based on FFT over Additive White Gaussian Noise (AWGN) channel. Simulation analysis is implemented using Matlab (2020a) tool.

The rest of the paper is organized as follows. Section 2 describes the system model and assumptions. Section 3 briefly describes the most digital modulation schemes that will be used in this work. Section 4 illustrate the block diagram of SISO-OFDM system model and explains its parts. Section 5 presents the simulation results and discussion. The conclusion is given in Section 6.

2. SYSTEM MODEL and ASSUMPTIONS

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 two types based on their characteristics such as AWGN channel and multipath channel. The second channel could be characterized as Rayleigh fading channel if None Line of Sight (NLOS) path is possible to occur between the transmitter and receiver. If a Line of site path is possible brtween the two terminals, then the channel is characterized by Rician fading channel. In this work, and for sake of simplicity, AWGN is only considered. It is also very popular channel model due to its non-fading properties compared with the other complex type channels. In this model, the only impairment to communication is a linear addition of wideband white noise with a constant spectral density (in watts per hertz of bandwidth). The study evaluates the Bit Error Rate of OFDM using different digital modulation techniques. The time varying model of passing signals through the AWGN channel adds white gaussian noise to the signal [7]. Through AWGN channel, the received signal $r(t)$ is expressed as

$$r(t) = x(t) + n(t), \quad (1)$$

where x(t) is the transmitted signal and n(t) the random sample function of the noise term modeled as Additive White Gaussian Noise with zero mean and variance σ^2.

3. MODULATION TECHNIQUES

In this work, the performance analysis of the SISO-OFDM is studied and evaluated. We have used the major digital modulation schemes such as BPSK, QPSK and M-QAM (Where M=64, 128 and 256) modulation techniques and apply them on OFDM transmission.

ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

The brief descriptions of these modulation techniques are given in the following subsections.

3.1 Binary Phase Shift Keying (BPSK)

In Binary Phase Shift Keying, the phase of the carrier wave is modulated by the binary symbol 0 & 1.

BPSK uses binary phases (0° and 180°) to transmit bits 0 and 1 and uses 1 bit per symbol (this is why called binary). When the binary input changes 1 to 0 or 0 to 1, then the modulated signal will change its phase at 180° [8]. The constellation diagram of BPSK is shown in Figure 2 and the modulated carrier signals are mathematically represented as follows:

For a binary 0,

$$s_1(t) = A_c \cos(\omega_c t) = \sqrt{\frac{2E_b}{T_b}} \cos(\omega_c t) \qquad (2)$$

For a binary 1,

$$s_2(t) = A_c \cos(\omega_c t + \pi) = -\sqrt{\frac{2E_b}{T_b}} \cos(\omega_c t) \qquad (3)$$

where $\omega_c = 2\pi f_c$, f_c is the carrier frequency.

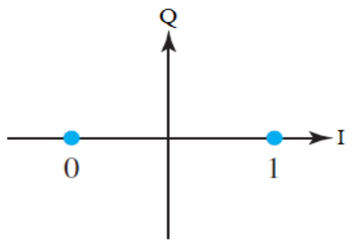

Figure 2 Constellation diagram for BPSK

From Equation (1) and for BPSK, $x(t) \in \{-A, A\}$ and $n(t) \sim \mathbb{N}\,(0, \sigma^2)$, where A is the pulse amplitude and σ^2 is the noise variance; $\sigma^2 = N_o$. The abbreviation $\mathbb{N}$ denotes to the Gaussian (Normal) random variable distribution. The real part of Equation (1) also follow the normal distribution with same mean and half of the variance, i.e., $n_r(t) \sim \mathbb{N}\left(0, \frac{\sigma^2}{2}\right) = \mathbb{N}\,(0, \frac{N_o}{2})$. In BPSK constellation distance $d_{min} = 2A$ as shown in Figure 2. If we define γ_b as a metric of energy per bit to noise power ratio as

$$\gamma_b := \frac{E_b}{N_o} = \frac{A^2}{N_o} = \frac{d_{min}^2}{4N_o}, \qquad (4)$$

then the bit error probability can be calculated as

$$P_b = P\{n > A\} = \int_A^\infty \frac{1}{\sqrt{\pi\sigma^2}} e^{\frac{-x^2}{2\sigma^2/2}} dx \qquad (5)$$

This equation can be in terms of $Q(\cdot)$-Function as

$$P_b = Q\left(\sqrt{\frac{d_{min}^2}{2N_o}}\right) = Q\left(\frac{d_{min}}{\sqrt{2N_o}}\right) = Q(\sqrt{2\gamma_b}), \qquad (6)$$

where the $Q(\cdot)$-function is defined as

$$Q(y) \triangleq \frac{1}{\sqrt{2\pi}} \int_y^\infty e^{\frac{-y^2}{2}} dy \qquad (7)$$

This function is widely used in digital communications. It evaluates the error probability of transmission systems that are disturbed by additive Gaussian noise. Some textbooks use a different function for same purpose, namely the complementary error function, abbreviated as $erfc(\cdot)$. This latter function is defined as

$$erfc(y) \triangleq \frac{2}{\sqrt{\pi}} \int_y^\infty e^{-y^2} dy, \qquad (8)$$

and they are related as

$$Q(y) \equiv \frac{1}{2} erfc\left(\frac{y}{\sqrt{2}}\right) \qquad (9)$$

The integral in these equations cannot be solved analytically, $Q(\cdot)$-Function and $erfc(\cdot)$ evaluations are tabulated. A simple and accurate expression (error less than 0.27 %) is given by

$$Q(y) \approx \left[\frac{1}{(1 - 0.339)y + 0.399\sqrt{y^2 + 5.51}}\right] \frac{e^{-\frac{y^2}{2}}}{\sqrt{2\pi}} \qquad (10)$$

Most modern mathematical software packages such as Matlab, Maple and Mathematica comprise the $erfc(\cdot)$ function as a standard function.

3.2 Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying (QPSK) is a version of Phase Shift Keying in which two bits are modulated per one symbol, selecting one of four possible carrier phase shifts ($\pi/4$, $3\pi/4$, $5\pi/4$ and $7\pi/4$) [2]. QPSK perform by changing the phase of the In-phase (I) carrier from 0° to 180° and the Quadrature-phase (Q) carrier between 90° and 270°. This is used to indicate the four states of a 2-bit binary code. (QPSK) is widely used in the most of the digital transmission systems. QPSK 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 1 that accommodate the above four phases. This is illustrated in Figure 3.

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

$$s_1(t) = A_c \cos(\omega_c t + \theta_1) = \sqrt{\frac{2E_s}{T_s}} \cos\left(\omega_c t + \frac{\pi}{4}\right) \qquad (11)$$

ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

$$s_2(t) = A_c \cos(\omega_c t + \theta_2) = \sqrt{\frac{2E_s}{T_s}} \cos\left(\omega_c t + \frac{3\pi}{4}\right) \quad (12)$$

$$s_3(t) = A_c \cos(\omega_c t + \theta_3) = \sqrt{\frac{2E_s}{T_s}} \cos\left(\omega_c t + \frac{5\pi}{4}\right) \quad (13)$$

$$s_4(t) = A_c \cos(\omega_c t + \theta_4) = \sqrt{\frac{2E_s}{T_s}} \cos(\omega_c t + 7\pi/4) \quad (14)$$

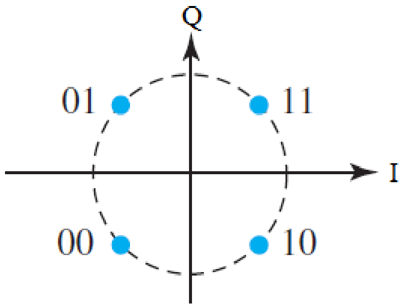

Figure 3 Constellation diagram for QPSK

The BER of QPSK of each branch is the same as BPSK. The symbol probability of error P_s (SER) is the probability of either branch has a bit error

$$P_s = 1 - \left[1 - Q\left(\sqrt{2\gamma_b}\right)\right]^2 \quad (15)$$

Since the symbol energy is split between the two in phase and quadrature components, $\gamma_s = 2\gamma_b$, the we have

$$P_s = 1 - \left[1 - Q\left(\sqrt{\gamma_s}\right)\right]^2 \quad (16)$$

Using the approximation of Q-Function given in [9], Equation (16) can be written as

$$P_s \le \frac{3}{\sqrt{2\pi\gamma_s}} e^{-0.5\gamma_s}, \quad (17)$$

by the assumption that $\gamma_s \gg 0$. Usually, *Gray* coding is used in these modulation schemes and for high signal to noise ratio, the errors may occur only for the nearest neighbour symbols, P_b can be approximated from P_s by $P_b \approx \frac{P_s}{2}$.

3.3 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 of the carriers.

M-ary quadrature amplitude modulation (M-ary QAM) becomes an attractive modulation technique which achieves high rate without increasing the bandwidth transmission in wireless communication systems. A great deal of attention has been devoted

to the study of bit error rate (BER) performance of M-ary square QAM constellations [10] as shown in Figure 3. Approximate expressions for bit error probabilities of M-ary square QAM have been developed by [11,121] based on signal-space concepts and recursive algorithms, respectively.

The QAM is often used in digital cable television, cable modem and point-to-point wireless system applications and extensively used in satellite communication systems [13]. We can find QAM in the most of our live applications. QAM is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. The (I-Q) parts of the QAM signal are combined at the transmitter for transmission. At the receiver, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating information

The M-ary QAM modulated signal is expressed as:

$$s(t) = \sqrt{\frac{2E_{min}}{T_s}} \left(a_i(t) \cos(2\pi f_c t) + b_i(t) \cos(2\pi f_c t) \right) \quad (18)$$

$$\text{for} \quad 0 \le t \le T_s, \text{ and } i = 1, 2, \cdots M,$$

where, E_{min} is the signal energy for the minimum amplitude, a_i and b_i indicate a pair of random integers. T_s is the symbol period and M is the size of the modulation or modulation index. $M = 2^n$, where n is the number of bits that represent each symbol. Figure 4 represents the constellation diagram of QAM in which $M = 64$, i.e., each symbol is represented by 8 bits. Sometimes, it is known as Square QAM Constellations (SQAM)[10].

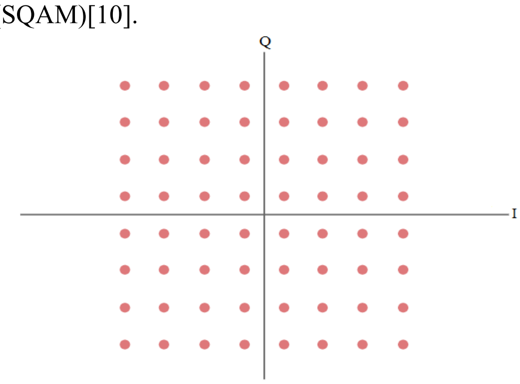

Figure 4: Constellation diagram for 64 QAM

The BER calculation in QAM is quite difficult. There are many approximated closed formula to determine the bit error rate. We will adapt what is presented in [11]

ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

$$P_b \approx \frac{4}{n}\left(1-\frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3n}{M-1}\cdot\frac{E_b}{N_o}}\right), \quad (19)$$

where $n = \text{LOG}_2\, M$ which represents the number of bits per symbol, e.g. $for\ 16QAM, n = 4$.

4. SISO-OFDM MODEL

Figure 5 illustrates the block diagram of the SISO-OFDM system that is used in our analysis.

The system is kept generic and consists of components present in a typical SISO- OFDM system. The transmitter is made up of the encoder, bit-wise interleaver, mapper and inverse FFT (IFET). Though the insertion and the removal of the cyclic prefix (CP) as shown in Figure 6, the channel delay spread is assumed smaller than the guard interval. Perfect channel state information (CSI) is assumed at the receiver. The receiver is composed of FET, demapper, de-interleaver and Viterbi decoder.

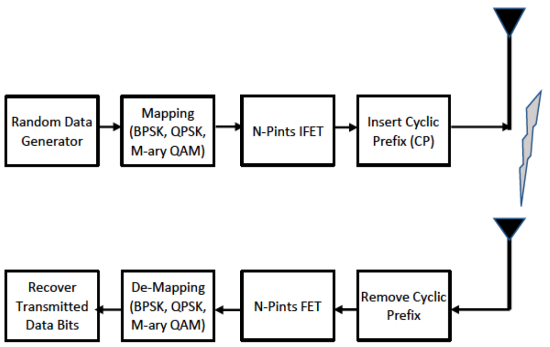

Figure 5: Block diagram of an SISO-OFDM system, the transmitter (upper block) and the receiver (the lower block)

In order to prevent multi-path components interfering from one symbol with the next symbol, a cyclically extended guard interval known as cyclic prefix. The cyclic prefix is a replica of the last samples of the OFDM symbol. This is achieved by adding partial symbol information of each cycle to the beginning of the symbol. Practically, the cyclic prefix emplys a rectangular pulse shape generated as [12]:

$$p[i] = \begin{cases} \frac{1}{\sqrt{N}}, & 0 \le i \le N-1 \\ 0, & \text{otherwise,} \end{cases} \quad (20)$$

where N is the total number of subcarriers. The ratio of the guard interval T_g to the useful symbol duration depends on different systems. Since the insertion of guard interval will reduce data throughput, T_g is usually less than one fourth of T_S [12]. The total symbol duration, T_t, is given as

$$T_t = T_s + T_g \quad (21)$$

Cyclic Prefix (CP) is a copy of the last portion of the SISO-OFDM vector that added to the start of each SISO-OFDM vector. It mitigates the impact of the Inter-Symbol Interference (ISI) caused by the fading channels [13,14].

Cyclic Prefix is the basic concept behind the OFDM technique. The cyclic prefix performs two main functions. The first, it provides a guard interval to eliminate intersymbol interference from the previous symbol. Second, It repeats the end of the symbol so the linear convolution of a frequency-selective multipath channel can be modeled as circular convolution, which in turn may transform to the frequency domain via a discrete Fourier transform. This approach accommodates simple frequency domain processing, such as channel estimation and equalization.

The cyclic prefix is inserted so that each OFDM symbol is preceded by a copy of the end part of that same symbol. Different OFDM cyclic prefix lengths are available in various systems. For example within LTE a normal length and an extended length are available and after Release 8 a third extended length is also included, although not normally used. The main advantages of inserting CP bits in OFDM transmission are: (1) providing robustness, since the addition of the cyclic prefix adds robustness to the OFDM signal. The data that is retransmitted can be used if required, (2) reducing the inter-symbol interference, because the guard interval introduced by the cyclic prefix enables the effects of inter-symbol interference to be reduced.

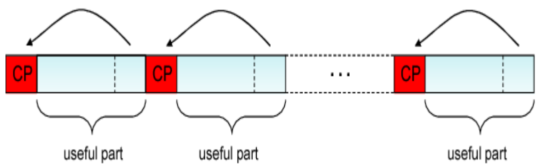

Figure 6: The OFDM symbols contain the CP.

The main disadvantage of using Cyclic prefix in OFDM is that CP reduces data capacity. As the cyclic prefix re-transmits data that is already being transmitted, it takes up system capacity and reduces the overall data rate.

The use of a cyclic prefix is standard within OFDM and it enables the performance to be maintained even under conditions when levels of reflections and multipath propagation are high.

The receiver is composed of FFT, demapper, de-interleaver and FEC decoding.

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

$$X(k) = \sum_{n=0}^{N-1} x[n] e^{-\frac{j2\pi kn}{N}}, \quad k = 0,1,2,\cdots,N- \quad (21)$$

ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

$$x(n) = \sum_{k=0}^{N-1} X[k] e^{\frac{j2\pi kn}{N}}, \qquad n = 0,1,2,\cdots,N- \quad (23)$$

where $X(k)$ is the frequency sampled signal, $x(n)$ is the time sampled signal and N is the total number of samples.

One of other key figure of merit when assessing the performance of a given modulation system is the spectral efficiency η. The spectral efficiency (bits/s/Hz) of the OFDM modulation scheme is expressing the overall efficiency of that system, i.e. how efficient does it use the allocated bandwidth.

$$\eta = \frac{\text{max. data rate (bps)}}{\text{total allocated bandwidth (Hz)}} \quad \text{bit/s/Hz} \qquad (24)$$

Since OFDM system has several overheads that reduce its theoretically attainable spectral efficiency, thinking about OFDM as both a multiplexing and a modulation technique, we can demonstrate that the superior margin of its spectral efficiency is the spectral efficiency of the digital modulation it uses. This efficiency can be written in terms of size if FET/IFET size, cyclic prefix and modulation degree M as

$$\eta = \frac{N_F + \log_2 M}{N_F + N_{cp}} \quad \text{bit/Hz}, \qquad (25)$$

where N_F is the size of FET/IFET and N_{cp} represents the number of guards of cyclic prefix samples.

5. SIMULATION RESULTS AND DISCUSSION

The system specifications and simulation parameters that are used are shown in Table I.

TABLE I SYSTEM PARAMETERS

Parameters	Values
Data rate	1Mbps
Modulation types	BPSK,QPSK,16-QAM, 64-QAM, 256-QAM
Symbol period	192μs
FFT size	256
Subcarriers	200 (192 for data and 8 pilots)
SNR (dB)	0-25

First, the model of Figure 5 is implemented and the functional block parameters for the constituting blocks are set according to Table I. The total bit transferred, numbers of bits in error as well as the BER are taken from the display tool of the entire model. For the same modulation/demodulation blocks pair, the SNR is varied from 0 to 25 with 1 dB increment, the simulation is run for 1 second each time and the result from the display is taken for each step. These steps are repeated for the five modulation/demodulation schemes that are adopted in this paper.

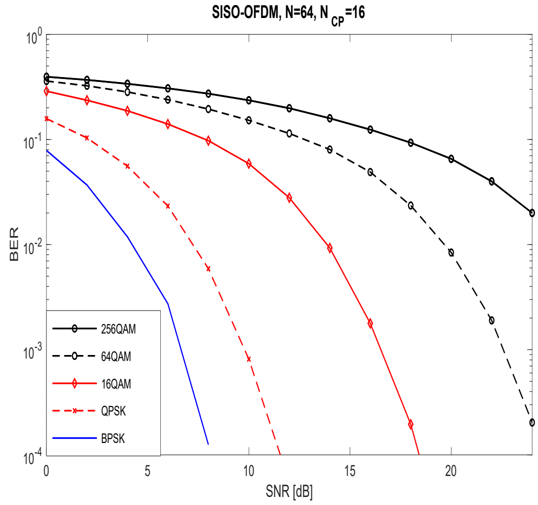

Figure 7 BER versus SNR for the used modulation Techniques

TABLE II BER OF MODULATIONS TECHNIQUES WITH OFDM

SNR	BPSK	QPSK	16QAM	64QAM	256QAM
0	0.078	0.158	0.285	0.360	0.396
5	0.007	0.041	0.160	0.261	0.315
10	0	0.0008	0.059	0.153	0.236
15	0	0	0.002	0.064	0.136
20	0	0	0	0	0.065

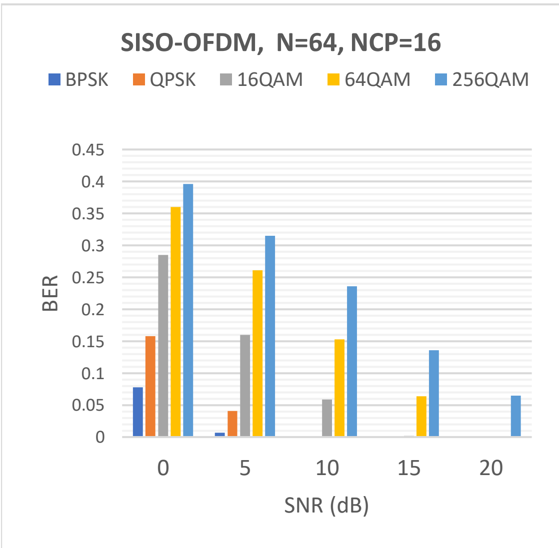

Figure 8 The OFDM symbols contain the CP.

The BER performance of the OFDM system improves as SNR increases. This performance is plotted in Figure 7. From the figure, it is also clear that BPSK has the best performance over all other schemes in

ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

terms of probability of error, QPSK comes the next. Comparison to 16QAM, 64QAM and 256QAM beyond which 16QAM performs best. A BER of 0.001, as noticed from the figure is attainable at about 17 SNR for 16QAM, while 64QAM needs about 10 dB more power to achieve this criterion. It is also obvious that 256QAM cannot achieve even 0.01 BER under 30 dB SNR.

Table II assembles the numerical values of BERs corresponding to their SNRs. Very small values of BER can be achieved for all modulation schemes (except 256QAM) at high value of SNR (20 dB). Figure 8 shows as a bar representing of these comparisons.

Finally, from the analysis of the spectral efficiency of all the modulation techniques, the comparison is done according to Equation (25). Table III demonstrates the spectral efficiency of the five modulations in scheme based on SISO-OFDM technique. Higher modulation order achieves a significant improvement of the overall spectral efficiency.

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 SISO- OFDM the BPSK modulation technique is performed better than the other techniques, which has been implemented for this work.

TABLE III SPECTRAL EFFICIENY FOR THE SELECTED MODULATION SCHEMES BASED ON OFDM

	BPSK	QPSK	16 QAM	64 QAM	256 QAM
M	2	4	16	64	256
$\log_2 M$	1	2	4	6	8
η (b/Hz)	0.97	1.94	3.88	5.82	7.76

6. CONCLUSION

In this paper, various modulation schemes based on SISO-OFDM technique are reviewed, investigated, classified and compared in terms of their probability of error and spectral efficiency., we have tried to present Single Input Single Output (SISO) Orthogonal Frequency Division Multiplexing (OFDM) system and discussed different modulation techniques. It can be concluded that BPSK has a better performance in terms of probability of error compare to other modulation schemes, the next is QPSK. In QAM family, as the modulation index (M) increases, the BER performance degrades. At higher M, small vales of BER cannot be achieved. Conversely, the spectral efficiency metric is significantly better in higher modulation order. There should be a point of trade off to compromise between these two metrics to choose the suitable modulation scheme according to the data transmission requirements.

As a future extension of this work, MIMO-OFDM based on these types of modulations can be studied and evaluated. Also, other types of channels rather than AWGN channel can be investigated to study the impact of these complicated transmission environments.

REFERENCES

[1] Theodore Rappaport, (2001), "Wireless Communications: Principles and Practice" Prentice Hall PTR, USA.

[2] Kiran Bondre, (2012), "BER performance comparison of HIPERLAN/2 for different modulation schemes with 1⁄2 and 3⁄4 code rates", International Journal of Engineering Research and Applications, Vol. 2, Issue 3, pp.1398-1400.

[3] Farhana Enam, Md. Ashraful Islam, Md. Arif Rabbani and Sohag Sarker, (2012), "Performance Evaluation of Orthogonal Frequency Division Multiplexing (OFDM) based Wireless Communication System with implementation of Least Mean Square Equalization technique," International Journal of Computer Science and Information Security (IJCSIS), Vol. 10, No. 11.

[4] Hayder Al Ibraheemi, Mazen M. A. Al Ibraheemi, (2020), "Wireless Communication System with Frequency Selective Channel OFDM Modulation Technique," TELKOMNIKA Telecommunication, Computing, Electronics and Control, Vol. 18, No. 3, pp. 1203-1208.

[5] Ahmad Jaradat , Jehad Hamamreh and Huseyin Arslan, (2019), "Modulation Options for OFDM-based Waveforms: Classification, Comparison, and Future Directions" in IEEE Access, Vol. 7, pp. 17263-17278.

[6] Beena R. Ballal, Ankit Chadha2 and Neha Satam, (2013), "Orthogonal Frequency Division Multiplexing and its Applications", International Journal of Science and Research (IJSR), Vol. 2 Issue 1.

[7] Ramjee Prasad, (2004), "OFDM for Wireless Communications Systems, in OFDM for Wireless Communications Systems", Artech House.

[8] Hardeep Singh, Lavish Kansal, (2014), "Performance Analysis of MIMO Spatial Multiplexing using different Antenna Configurations and Modulation Technique in AWGN Channel" Global Journal of Research in Engineering (GJRE), Vol. 14, Issue 5, USA.

[9] G. K. Karagiannidis and A. S. Lioumpas, (2007), "An Improved Approximation for the Gaussian Q-Function," in *IEEE Communications Letters*, vol. 11, no. 8, pp. 644-646.

[10] Kyongkuk Cho, Dongweon Yoon, Wuncheol Jeong and M. Kavehrad, (2001), "BER analysis of arbitrary rectangular QAM," Conference Record of Thirty-Fifth Asilomar Conference on Signals, Systems and Computers, pp. 1056-1059 vol.2.

[11] J.J. Lu, K.B. Letaief, J.C.-I. Chuang and M.L. Liou, (1999), "M-PSK and M-ary QAM BER computation using signal-space concepts", IEEE Trans. Commun., vol. 47, pp. 181-18.

[12] Ali Zaidi Fredrik Athley Jonas Medbo Gustavsson Giuseppe Durisi Xiaoming Chen, (2018), "5G Physical Layer Principles, Models and Technology Components", Academic Press pp 119-158.

[13] N. A. M Radzi, Nubailah Arshad, (2016), "Performance Assessment of Orthogonal Frequency Division Multiplexing (OFDM) in Wireless Communication System" International Journal of Applied Engineering Research (IJAER), Vol. 11, no. 21, pp. 10475-10483.

[14] B. Ahmed and M. A. Matin, (2015), "Wireless Channels," in *Coding for MIMO-OFDM in Future Wireless Systems*, Brunei: Springer Briefs in Electrical and Computer Engineering, , pp. 11-21.

ISSN: 2456 - 3935
International Journal of Advances in Computer and Electronics Engineering
Volume 6, Issue 9, September 2021, pp. 1 – 8

Authors Biography

Nouri Ahwaas is a PG student of Electrical and Computer Engineering department, Elmergib University. He received his B.Sc. degree from Electrical and Computer Engineering (Elmergib University) in 2012. He is currently working towards M.Sc. degree in Electrical and Computer Engineering at Elmergib University. In addition, he is working at the Documentation and Information Center of Elmergib University since 2013. The areas of interests include Channel Estimation, Equalization and Computer Networks.

M. Elalem is an Associate Professor of the Electrical and Computer Engineering department, Elmergib University. He received the B.S. and M.S. degrees in Electrical and Electronic Engineering from University of Tripoli, Libya in 1990 and 2006, respectively, and PhD degree in Electrical and Computer Engineering from Ryerson University, Toronto, Canada in 2013. During 1993-2008, he worked in Elmergib University, Libya as academic instructor. During 2013-present, he is working in the same university as an Associate Professor. His interesting areas are in Telecommunications, optimization techniques, cognitive radio networks and advanced digital communication schemes.

Cite this paper:

Nouri Ahwaas, Mohamed A. Elalem, “BER Performance of SISO-OFDM Scheme based on FFT over an AWGN Channel”, International Journal of Advances in Computer and Electronics Engineering, Vol. 6, No. 9, pp. 1-8.