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PAPR and BER performance of OFDM with Various Modulation Methods under AWGN Channel

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Abstract

The Orthogonal Frequency Division Multiplexing (OFDM) is also known as multicarrier technology. Wideband digital communications in the recent past have increasingly utilized OFDM. It can withstand difficult channel circumstances, efficiently utilize spectrum resources, decrease ISI, and operate at a high data rate, among many other benefits. It has been used in several wireless and wired communication systems, including fourth generation Long-Term Evolution (4G LTE) mobile communications. The performance assessment and analysis of the OFDM system under Additive White Gaussian Noise (AWGN) channel has been carried out in this work. The factors in which system performance is assessed include the signal quality, Bit Error Rates (BERs), and Signal to Noise Ratios (SNRs) of the received signals. To improve performance while employing multicarrier modulation, the subcarriers must be kept orthogonal to one another, in the process known as OFDM. The sole focus of this study is the performance analysis of PAPR, BER, and SNR utilizing various modulation methods and schemes.

Keywords: AWGN, BER, OFDM, SNR, M-ary Phase Shift Keying (M-PSK), Peak-To-Average Power Ratio (PAPR), Quadrature Amplitude Modulation (QAM)

1. Introduction

When the symbol period is increased relative to the time delay, the Inter Symbol Interference (ISI) issues in single carrier communication systems are greatly decreased [1-2]. The communication technology is ineffective because of the extended symbol period's extremely low data flow. Therefore, data cannot be sent at a rapid pace using a single channel of communication. Daily demand is rising for broadband communications. To accommodate

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this growing need, multicarrier communication is employed [1-6]. The frequency spectrum of the communication channel is divided into numerous carriers using the Frequency Division Multiplexing (FDM) multicarrier technology. The carriers are placed near together to attain a high data rate. ICI is another potential issue [7-8]. By putting guard bands between carriers, this problem is remedied, but as a trade-off, the data rate is decreased. Due to its capacity to deliver high speed without encountering the issue of Inter Carrier Interference (ICI) and ISI, nowadays OFDM technology is widely used among many communication systems. In fact, it is thought to be the most prevalent communication method capable of supporting applications of the digital multimedia [9]. OFDM being known as a unique exemplum of FDM, is used in numerous applications for e.g., digital audio broadcasting, 4G LTE and wireless local area network [10-11].

An important metric in digital communication is the Bit Error Rate (BER) for Orthogonal Frequency Division Multiplexing (OFDM) under various channel conditions. According to the current situation, the need for broadband communications networks is constantly growing due to digital multimedia applications. Over the past ten years, OFDM has been the most widely used communication method for high-speed communications [12]. The future of wireless communications will really use OFDM technology, according to several business executives. The following sections provide information on the OFDM technique identified through simulation as providing the greatest BER performance in an AWGN channel [12-13].

2. OFDM System

The widely used and well-known technology of FDM is quite similar to OFDM. To enable the transmission of numerous messages over a single radio channel, OFDM applies the FDM principles [14]. However, it is done in a much high regulated way, enabling better spectral efficiency. The utilization of several frequencies by each Frequency Modulation (FM) radio station is a straightforward illustration of FDM. Since each station uses a distinct carrier frequency, they do not interfere with one another even when they all transmit at the same time [15]. They are also frequency separated sufficiently away to prevent their transmitted signals from overlapping in the frequency domain, and their bandwidth is restricted. With the exception of the station of interest, all other signals are selectively removed at the receiver before each signal is separately received. The transmitted data can then be recovered by demodulating this filtered signal [14-15].

Several things set OFDM apart from FDM. Each radio station transmits on a distinct frequency in conventional broadcasting, essentially employing FDM to keep the stations apart. However, there is no synchronization or coordination between any of these stations. In digital audio broadcasting using OFDM, the information from multiple stations is multiplexed and transmitted as a single data stream [16]. Then, this data is sent via an OFDM ensemble, which consists of a tightly packed number of subcarriers. The OFDM signal's subcarriers are all time and frequency synced to one another, which makes it possible to precisely manage ICI. Due to the orthogonal nature of the modulation, they do not result in ICI. To avoid interference, FDM transmission signals often require a sizable frequency guard-band between channels. The total spectral efficiency declines as a result. However, this guard band is much reduced with OFDM due to the orthogonal packing of the subcarriers, increasing spectral efficiency [17-18].

Figure 1 depicts a full OFDM transceiver system. In this approach, the system is strengthened to provide the burst error protection by adding FEC coding and interleaving. Coded OFDM refers to an OFDM system that includes channel coding and interleaving. Binary input data is gathered and FEC coded using techniques like convolutional codes in the digital world [18]. In order to achieve diversity gain, the coded bit stream is interleaved. After that, a collection of channel-coded bits 1 for BPSK, 2 for QPSK, 4 for QPSK, etc. is put together and mapped to the appropriate constellation points. The data are currently serial and are represented as complex numbers. At this time, known pilot symbols that have been mapped using recognized mapping techniques can be added [30]. The IFFT procedure is carried out on the parallel complex data after applying a serial to parallel converter. The modified data is once more grouped according to the necessary number of transmission subcarriers. According to the system specification, a Cyclic Prefix is added to every block of data, and the data is multiplexed in a serial form [19-21].

The data is now OFDM modulated and prepared for transmission. The digital data is converted to the time domain analogue data using a DAC and up-converted to transmission frequency after RF modulation. The OFDM signals traverse every complication and hostile wireless channel following the transmissions of the signals from the transmitter antenna [22-24]. The signal is down converted by the receiver after reception and converted by an Analog-to-Digital Converter (ADC) into a digital signal. The synchronization of the carrier frequency occurs when the received signal is being down converted. Symbol timing synchronization is accomplished following ADC conversion. The OFDM signal is demodulated using an FFT block [25]. The demodulated pilots are then used for channel estimation. The complicated received data are acquired using the estimations and are then de-mapped in accordance with the transmission constellation diagram. Right now, the original transmitted bit stream is recovered via FEC decoding and de-interleaving.

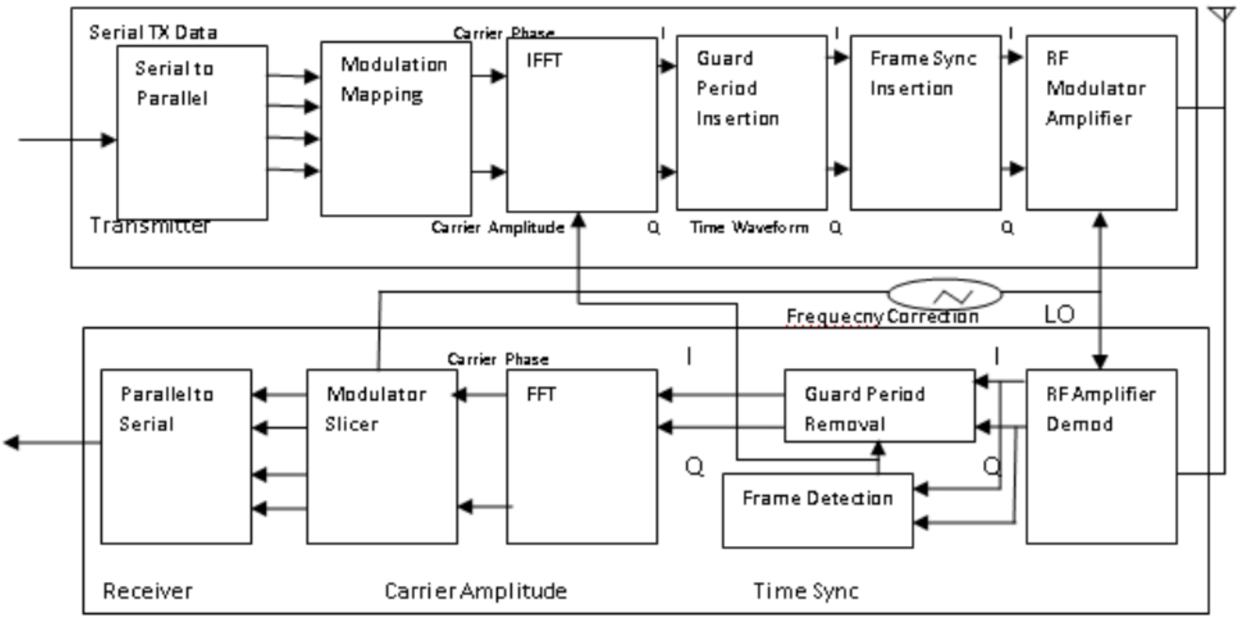


Figure 1. OFDM - Transceiver [31]

3. AWGN Channel & Modulation Techniques

3.1 Additive White Gaussian Noise

A channel model known as AWGN, assumes that the main barrier to communication is the addition of wideband or white noise that has a Gaussian amplitude distribution and a constant spectral density [26]. Prior to taking into account these other occurrences, it creates straightforward and understandable mathematical models that are helpful for getting insight into the fundamental behaviour of a system. The earths black body radiation, shot noise, Johnson-Nyquist noise also known as the thermal vibration in atom, and other heated objects, as well as astronomical sources like the Sun, are some of the natural sources of Gaussian noise [27]. A lot of satellite and deep space communication lines can be modeled well after the AWGN channel. Due to multipath, terrain blockage, interference, etc., it is a bad model for the majority of terrestrial networks. However, for terrestrial route modeling, AWGN is frequently used to mimic ground clutter, self-interference, multipath, terrain blocking, interference, and background noise on the channel being studied [28].

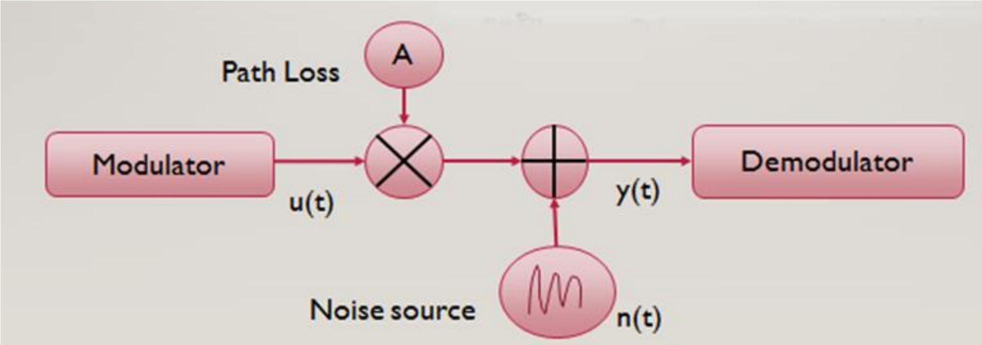


Figure 2. AWGN Channel

3.2 Modulation Techniques

The use of modulation methods is crucial in wireless communications. The data symbols that will be conveyed in the carrier will be processed in this manner. Nowadays, the majority of wireless communications are digital in nature, making careful bandwidth management crucial. In this stage, where the constellation controls the bandwidth use, the type of modulation utilized is crucial. Maximizing spectral efficiency is one of modulation's objectives. The speed at which data may be delivered within a given bandwidth is measured by spectral efficiency [28-29]. Bits per second per Hz (b/s/Hz) is the measuring unit. Several methods have been developed to obtain and enhance spectral efficiency.

The impact of fading channels on many digital modulation techniques is analyzed in this section. The bit error probability (PBER) sometimes referred to as BER, is a performance indicator for accurately assessing schemes of modulation. Eqn (1) is used in assessing the BER performance in any digital modulation method in a slow flat fading channel.

$$P_{BER} = \int_{0}^{\infty} P_{BER,AWGN}\left(\delta\right) P_{df}\left(\delta\right)\, d\delta \qquad (1)$$

Here represents the “probability of error” for a certain modulation scheme in an AWGN channel at a given SNR , h is channel gain, and the probability density function is . In a nonfading AWGN channel, Eb/No is the “ratio of bit energy to noise power density”.

3.2.1 Binary Phase Shift Keying (BPSK)

There are two message signals in binary shift keying. The signal that is sent in BPSK is sinusoid with a set amplitude. When the data is at one level, the phase is fixed, but when the data is at a higher level, the phase is 180 degrees different [29]. For M-PSK in the AWGN channel, the BER is provided by,

$$BER_{MPSK} = \frac{2}{Max\left(\log_2 M, 2\right)} \sum_{k=1}^{Max\left(\frac{M}{4},1\right)} Q\left[\sqrt{\frac{2\log_2 \mathrm{M}\, E_b}{N_0}}\,\mathrm{Sin}\left(\frac{(2k-1)\Pi}{M}\right)\right] \tag{2}$$

For M=2, $BER_{BPSK} = Q\left[\sqrt{\frac{2E_b}{N_0}}\right]$ where $Q\left[x\right] = \frac{\int_x^{\infty} e^{\left(\frac{-y^2}{2}\right)} dy}{\sqrt{2\Pi}}$ (3)

$BER_{BPSK} = \frac{erfc\left(\sqrt{\frac{E_b}{N_0}}\right)}{2}$, here, complementary error function is erfc. The relation between erfc and Q is given by,

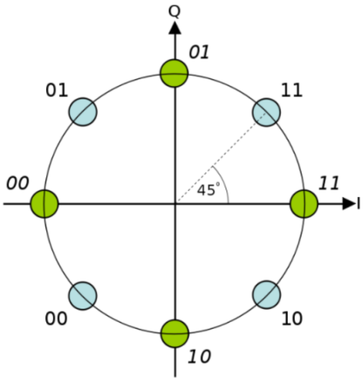
$$Q\left(x\right) = \frac{erfc\left[\frac{x}{\sqrt{2}}\right]}{2} \tag{4}$$

For M>4, for M-PSK, the BER is given by

$$BER_{MPSK} = \frac{2}{log_2 M} Q\left[\mathrm{Sin}\left(\frac{\Pi}{M}\right)\sqrt{\frac{2E_b \log_2 M}{N_0}}\right] \tag{5}$$

3.2.2 Quadrature Phase Shift Keying (QPSK)

The borders between local and global communication have been disintegrating ever since the invention of electronics, and as technology has advanced, the world has become smaller and more freely accessible for the exchange of knowledge and information. Bell and Marconi's groundbreaking work laid the groundwork for the modern information era and opened the door for advancements in telecommunications. Local communications were traditionally conducted through wires since it was an economical approach to guarantee a dependable delivery of data. Information has to be transmitted using radio waves in order to communicate over large distances. Even while this was practical in terms of technology, radio waves transmission generated concerns about data corruption and frequently required powerful transmitters to get over obstacles like bad weather, big buildings, and electromagnetic interference from other sources.



Phase of QPSK	2bits Inputs
π/4	10
3π/4	00
5π/4	01
7π/4	11

Figure 3. Diagram of the QPSK constellation with gray coding

For QPSK, $$P_{BER} = Q\left[\sqrt{\frac{2E_b}{N_0}}\right] \quad (6)$$

The symbol error rate is given by,

$$P_{SER} = 1-(1-P_{BER})^2 \quad (7)$$

$$P_{SER} = 2Q\left[\sqrt{\frac{E_b}{N_o}}\right]-Q^2\left[\sqrt{\frac{E_b}{N_o}}\right] \quad (8)$$

If the SNR is high, the probability of symbol error may be approximated:

$$P_{SER} \approx 2Q\left[\sqrt{\frac{E_b}{N_o}}\right] \quad (9)$$

3.2.3 Quadrature Amplitude Modulation (QAM)

QAM is a method that simultaneously blends amplitude and phase fluctuations in a carrier. This method allows for larger data rates while maintaining the same bandwidth. The method entails sending several bits for each carrier symbol in a period. A special phase-amplitude combination is referred to as a "symbol" in this context. The M in M-QAM stands for the number of bits that are broadcast for each distinct amplitude/phase combination per time interval or symbol. The most basic QAM variant is 2-QAM, often known as QPSK.

It is possible to calculate the BER of 16-QAM in the AWGN channel more precisely by,

$$BER_{16QAM,AWGN} = \frac{4\left[1-\frac{1}{\sqrt{M}}\right]}{\log_2 M}\sum_{M=1}^{\sqrt{\frac{M}{2}}} Q\left[\sqrt{\frac{3E_b \log_2 M}{N_0\left(M-1\right)}}\right] \tag{10}$$

3.2.4 Binary Frequency Shift Keying (BFSK)

While receiver of BPSK supplies a coherent phase reference for demodulating the signal received, in some applications non-coherent formats are used to do away with a phase reference. Binary frequency-shift keying is a term used to describe this kind of incoherent format. The non-coherent BFSK BER in the AWGN channel has been written as,

$$P_{BER,AWGN} = \frac{e^{\left[\frac{-E_b}{2N_0}\right]}}{2} \tag{11}$$

4. Simulation Results

MATLAB simulation tool is used for the implementation. The system has been implemented, and several modulation techniques are compared in the AWGN channel using OFDM. The efficiency has been observed, on applying many modulation schemes to the AWGN channel under OFDM. The simulation results show the BER performance. The parameters used in simulation are provided in Table 1.

Table 1. Simulation Parameters

Parameters	Values
Number of subcarriers	128
Cyclic prefix Length	32
No. of bit errors	100
No. of bits transmitted	1e7
Modulation alphabet, M	2, 4, 8
Bits/symbol, K	1, 2, 3
FFT size	64
Data subcarriers	52
OFDM symbols	10^4
Noise model	AWGN

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The BER performance of 8-DPSK (Differential Phase Shift Keying) OFDM in AWGN channel is shown in figure 4. For BER 10−1, with BPSK, the Signal to Noise Ratio (SNR) requirement of AWGN channel is of 5dB.

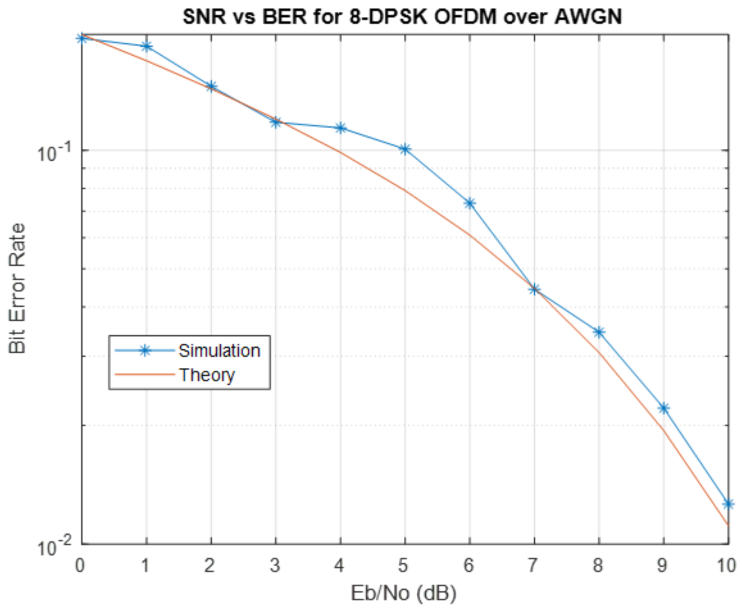

Figure 4. BER performance of 8-DPSK OFDM in AWGN

Figure 5 shows the graph plotted for SNR vs BER of 8-PSK. For 8-PSK at the BER value of 10-2, the SNR value of 7.31 dB is obtained for AWGN channel.

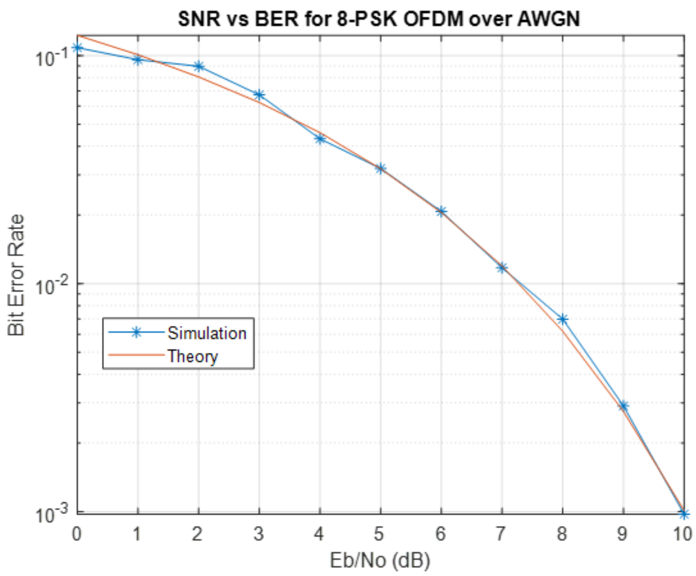

Figure 5. SNR vs BER of 8-PSK OFDM in AWGN

Figure 6 shows the comparison of BER performance between AWGN theory and simulation of BPSK. According to the results, the OFDM BER performance over the AWGN channel provides SNR of 9.4 dB at 10-5.

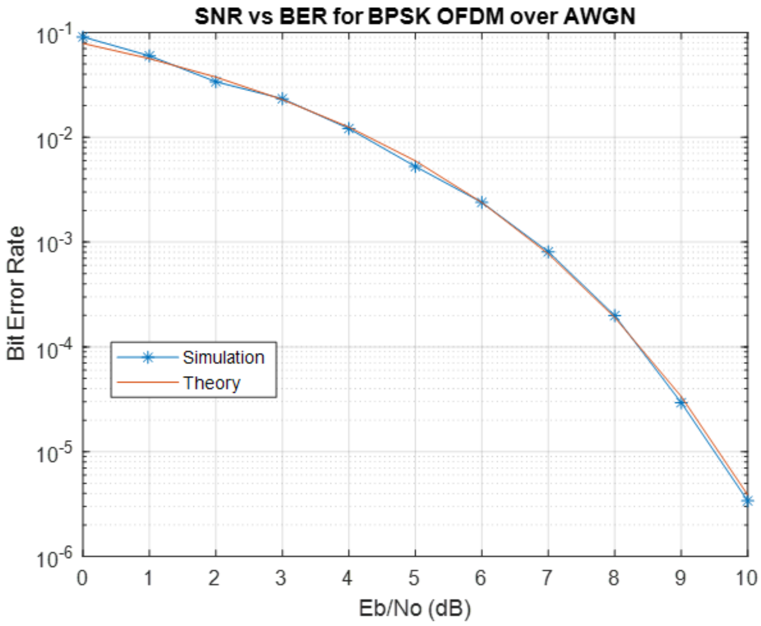

Figure 6. SNR vs BER of BPSK OFDM in AWGN

Figure 7 represents BER performance of DBPSK modulation over AWGN. At BER of 10-4, AWGN channel provides SNR of 9.34dB.

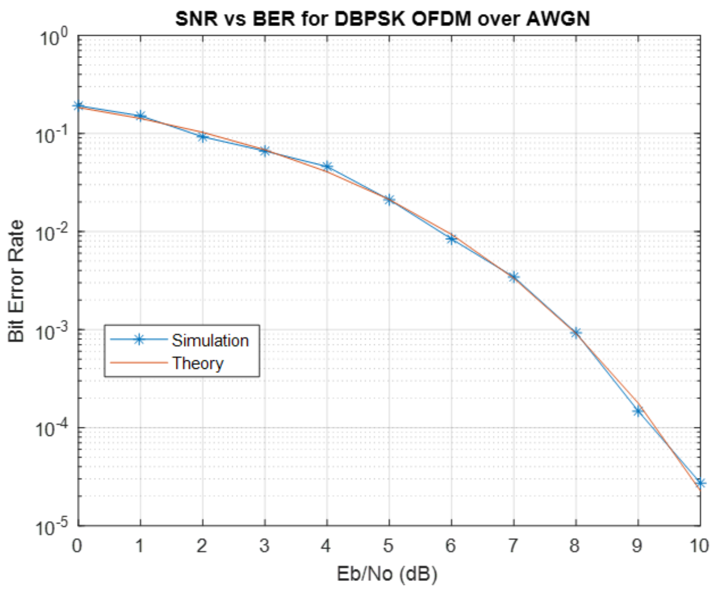

Figure 7. BER performance of DBPSK OFDM over AWGN

The analysis of BER of DQPSK OFDM in AWGN channel is shown in figure 8. For BER 10−4, with DQPSK, the SNR requirement of AWGN channel is of 8dB.

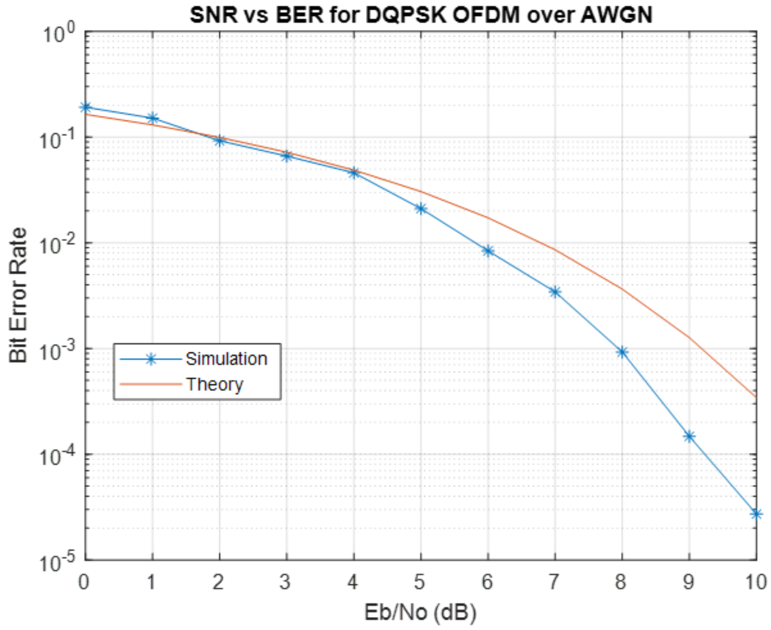

Figure 8. SNR vs BER of DQPSK

Figure 9 represents BER performance of QPSK modulation over AWGN. At BER of 10-5 AWGN channel provides SNR of 9.56dB.

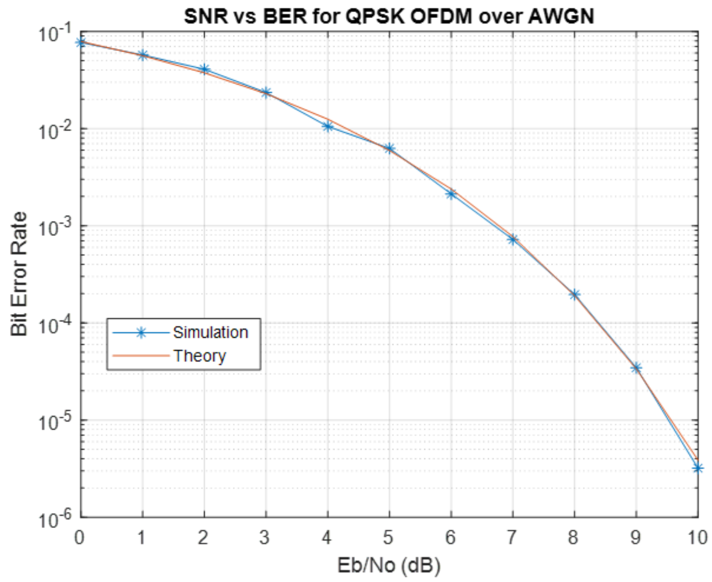

Figure 9. SNR vs BER of QPSK

Figure 10 shows the analysis of BER of the OFDM under various SNRs. The evaluation is done for the AWGN channel model using the SNR of 0 to 35dB with QAM order (16, 64, 256). According to the result, in order to improve the performance of BER, the lower order QAM is preferable than the higher order QAM. At SNR=20dB, 16-QAM has BER value of 1x10-5, 64-QAM has BER of 5x10-2 and 256-QAM has BER of 4.3x10-1.

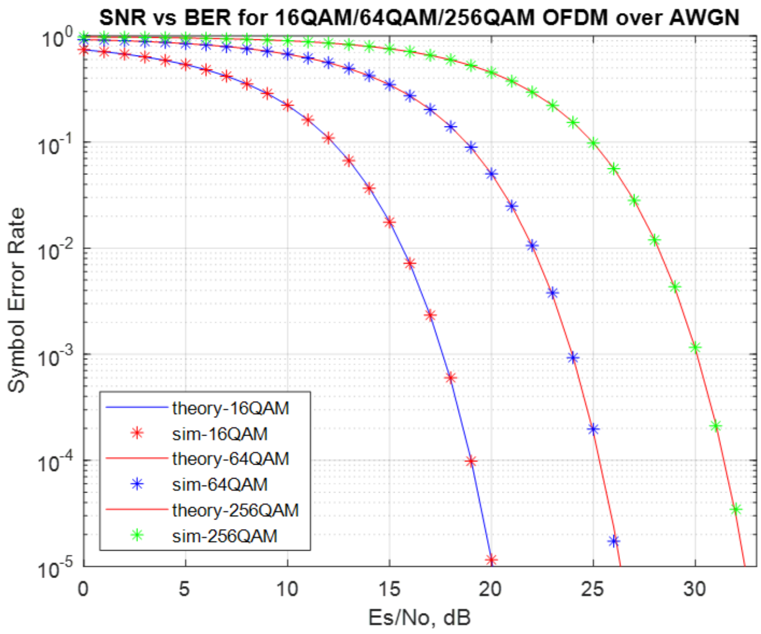

Figure 10. BER performance of 16, 64, 256-QAM

Table 2. BER analysis of various modulations under AWGN

Modulation	BER Performance at	
	SNR = 5 dB	SNR = 10 dB
256-QAM	1	$9x10^{-1}$
64-QAM	$9x10^{-1}$	$8.2x10^{-1}$
16-QAM	$5.5x10^{-1}$	$2.2x10^{-1}$
8-DPSK	$8.1x10^{-2}$	$1.2x10^{-2}$
8-PSK	$3.5x10^{-2}$	$1x10^{-3}$
QPSK	$3.2x10^{-2}$	$3.45x10^{-4}$
DBPSK	$2x10^{-2}$	$2.1x10^{-5}$
BPSK	$7x10^{-3}$	$2.8x10^{-6}$
DQPSK	$5.2x10^{-3}$	$2.7x10^{-6}$

Figure 11 shows the performance of BER for various modulation signals over AWGN channel. AWGN under OFDM is observed to be efficient under different modulation schemes. An efficient system has the lowest BER, even when the SNR is low. From the results, it can be found that at any instant, for SNR (e.g.,10 dB) the bit error rate is maximum for 256 QAM and is minimum for DQPSK.

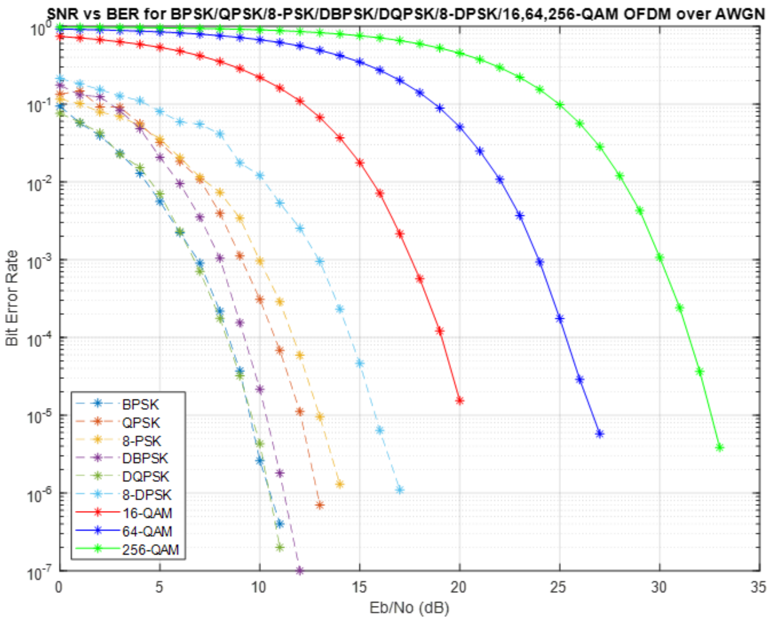

Figure 11. BER performance of various modulations under AWGN

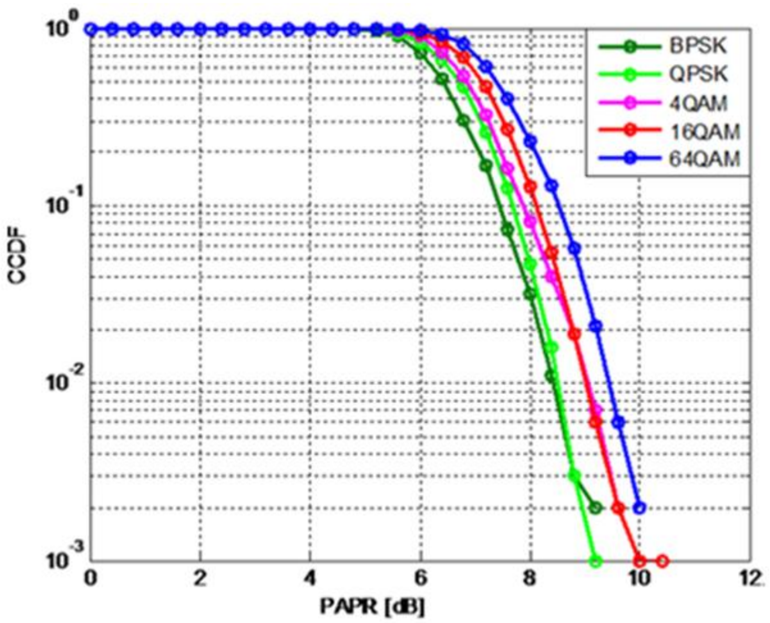

Figure 12. PAPR performance of various modulations

Table 3. PAPR analysis of various modulations

Modulation	PAPR(dB) at CCDF	
	CCDF = 10^{-1}	CCDF = 10^{-2}
64 QAM	8.34	9.32
16 QAM	8.13	9.1
4 QAM	7.86	9.1
QPSK	7.34	8.21
BPSK	7.12	8.16

5. Conclusion

High data rates are easily handled by OFDM systems. However, fading channels are a regular occurrence in wireless communications. After producing signal losses during transmission, they have an impact on the process of signal reception. A performance of several modulation schemes in the AWGN channel for an OFDM system is implemented in this research work. Graphing BER versus SNR for a certain modulation scheme assisted in determining the effectiveness of the modulation strategies in terms of accuracy or reliability. The simulation findings show that the BER for DQPSK is low.

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