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Performance analysis of OFDM with variations in cyclic prefix and FFT lengths

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a modern and suitable modulation strategy for commercial high-speed broadband wireless communication systems. This is because wireless services and demands have grown so quickly in recent years. While creating wireless communication, the channel environment is crucial. A square grid with identical vertical and horizontal spacing is used for the constellation points in quadrature amplitude modulation (QAM). More bits can be transferred per symbol to higher-order modulation forms. This research has looked at how Orthogonal Frequency Division Multiplexing OFDM systems perform using different modulation techniques on channels with additive white Gaussian noise (AWGN). Using MATLAB software to do an experiment with different modulation methods and parameters such as FFT length and cyclic prefix findings showed that 64-QAM modulation sends the same amount of data faster and with fewer symbols than QPSK 16-QAM. Here, the 64-QAM modulation technique performs better. An extensive literature survey has been carried out. The work done here involved working on many parameters to improve the performance of OFDM, i.e., by reducing BER, changing modulation techniques, and analyzing the trade-off between cyclic prefix length and Bit Error Rate. Compared to the existing work, the proposed system provides better performance.

Contribution/Originality: The 64-QAM modulation approach transmits the same amount of data in less time and with fewer symbols than other modulation methods like Quadrature Phase Shift Keying (QPSK) and 16-QAM. Here, the 64-QAM modulation technique performs better.

1. INTRODUCTION

Due to its reduced link delay, high data rate, dependability, flexibility, better security, and cost-effectiveness as compared to nonoptical technologies, IN OFDM has grown in prominence in recent years [1]. Today's wireless networks employ "OFDM technology," which provides substantial benefits in relation to high-speed data rates across both speech and data traffic. However, interferences resulting from time- or frequency-varying channels degrade the application that works in the physical layer of OFDM [2]. OFDM is an MCM technology in that the accessible bandwidth is separated through multiple orthogonal sub-channels [3]. Optical networks are transitioning beyond fixed spectrum grids to flexible spectrum allocations in order to meet the ever-increasing capacity demands of global IP (Internet Protocol) traffic while improving spectrum utilization efficiency [4]. Other multiplexing techniques, in addition to OFDM, have been introduced as highly promising. Rather than boosting spectral efficiency per user, these strategies improve spectral efficiency collectively within the area in which they are used [5]. Optical networks are switching from fixed spectrum grids to flexible spectrum allocations to fulfil the ever-increasing capacity demands of global IP traffic while improving spectrum utilization efficiency [6].

Multi-user accessibility generally results in problems including fading, shadowing, and inter-symbol interference (ISI). These weaknesses lead to inadvertent mistakes in the communication system, which worsen the system and raise BER values. An MCM method is offered as a workaround for this issue, in which the input serial data stream is sent at a low data rate as a few parallel streams [7]. In contrast to time dispersion of multipath propagation, which results in ISI, the Doppler Shift's frequency dispersion (ICI), which increases bandwidth effectiveness and lowers ISI and ICI [3], causes the ISI. The signal is divided into discrete channels, data modulated, and multiplexed to create the OFDM carrier. A subset of FDM is OFDM. Guard band usage enhances efficiency in OFDM systems by cutting down on bandwidth waste [8]. Numerous methods have been developed to improve the frequency spectrum's execution; one of the most promising is multicarrier modulation [9]. But in multipath fading channels, orthogonality across the sub-channels is broken when the time variation of a fading channel happens during an OFDM symbol period [10]. This causes the ICI.

Every carrier in a symbol time has an integer number of cycles, spectral nulls, and zero overlaps with an adjacent carrier. These methods influence lowering inter-carrier interference in communication. Because of carrier overlap, OFDM systems have higher bandwidth efficiency than conventional systems [11]. When the symbol duration is gradually reduced, the typical way of like a CP at the beginning of every OFDM symbol is no longer adequate due to the biggest delay spread of the channel, limiting the size of the CP and reducing spectral efficiency [12]. OFDM can be implemented using fast Fourier transform (FFT). Power lines across impulsive channels are provided by OFDM applied with a CP in an impulse response length sequence due to its robustness [13]. Numerous modulation techniques have been employed to address and fit novel approaches and potential purposes. Single-carrier modulation (SCM) and multi-carrier modulation (MCM) are the two categories into which this modulation falls. Since MCM provides high digital transmission over channels with high-frequency selectivity and robust multipath characteristics, it is a more efficient modulation technique than SCM [14]. The following are the key contributions to this article:

- In existing FDM, guard spaces between sub-channels waste scarce wireless frequency spectrum. The high complexity of a plethora of independent modulators for the many sub-channels.
- Because of this, the suggested OFDM has unique features, including faster speeds, better immunity to interference, large data capacities, and smart power distribution to subcarriers.
- In any case, the proposed strategy utilizes performance analysis of OFDM with variations in cyclic prefixes and FFT lengths.

The outline structure of the paper is worked out as follows: Section 2 review of comparable works for the proposed technique. In Section 3, a definite clarification of the proposed methodology is offered. Section 4 examines the exploratory results. In Section 5, the paper is discovered.

2. RELATED WORKS

Ajose, et al. [15] this study analyses the performance of the several digital modulation techniques employed in the system and outlines the architecture of an OFDM system. Two modulation techniques were applied to the modelled OFDM system: M-ary QAM (M-QAM) and M-ary phase shift keying (M-PSK) over two distinct channels (AWGN and Rayleigh multipath fading). The number of FFT points needed for transmission was examined, and BER analysis for the various digital modulation schemes was carried out over the two channels. The findings show that lower-order modulation techniques perform better than higher-order schemes over both Rayleigh and AWGN fading channels. Because lower-order methods have lower data rates than their higher-order counterparts, this negatively affects the data rate.

Galmecha, et al. [16] this study model and evaluate the optical performance of many transmission systems that are handled in a high-speed, real-world architecture employing OFDM. Using both direct detection and coherent detection of OFDM together can lower the effects of dispersion in optical communication. This is needed for modern technology to meet the growing needs for data rate and capacity in broadband services. OFDM addresses a variety of optical fibre problems, including chromatic dispersion (CD) and polarisation mode dispersion (PMD).

Kaur [17] recent research on the OOFDM (orthogonal frequency division multiplexing) area warrants further investigation due to its high spectral efficiency and flexibility. The efficacy of signal conditioning variables that can create adaptivity is simulated and analyzed in this study. It provides performance indicators such as Q-factor and BER for 16 and 64-QAM-OOFDM transmissions. With varied polarisation mode dispersion and chromatic dispersion. These signal conditioning variables can be utilized to improve transmission performance by introducing adaptivity in OOFDM transmissions.

Kaviya and Sumathi [18] found that the fifth generation cell organise, GFDM is utilized instead of OFDM because it has a number of appealing properties, such as resistance to repetition-specific blurring, ease of usage, and practicality. While OFDM utilises a single CP for each image, GFDM utilises a single CP for multiple images. The effect of nonlinear distortion on various Multiple-Input Multiple-Output (MIMO-GFDM) structures when the sign passes through the HPA, which emerges with adequacy and stage contortion, is currently being studied. Range research, PAPR inspection, and BER assessment are used to resolve the execution of the suggested strategy.

Kumar and Singh [19] show that next-generation wireless networks, the FBMC modulation approach has shown promise. This work proposes FBMC modulation algorithms for visible-light communication (VLC). The intensity modulation/direct detection (IM/DD) channel is used in a lot of modulation systems. The intention is to rectify a few of the drawbacks of widely utilized OFDM-based methods. Single-carrier modulation techniques, such as multi-level pulse amplitude modulation (M-PAM) and multi-level QAM (M-QAM), are used as MC techniques in order to execute the FBMC modulation method. In order to provide analytical performance, BER and spectral efficiency are used for both DC bias and non-DC bias techniques. Table 1 lists the existing approaches as well as their benefits and drawbacks.

Table 1. Shows the existing methods and their advantages and disadvantages.

Author	Year	Method	Advantages	Disadvantages
Ajose, et al. [15]	2018	M-Aryphase shift keying (M-PSK)	Better data rate.	Transmit power could be affected.
Galmecha, et al. [16]	2021	CD and PMD method	minimize dispersion effects	Increase the requirement of bandwidth.
Kaur [17]	2021	OOFDM	Achieve better transmission performance.	Q-factor and BER are high.
Kaviya and Sumathi [18]	2020	Generalized frequency division multiplexing	The use of a transmitter handling approach minimizes the consequences of sufficiency contortion.	Better PAPR and decreased BER values.
Kumar and Singh [19]	2020	Filter bank multicarrier (FBMC) modulation scheme	Better performance in BER and spectral efficiency.	Power efficiency is low.

3. PROPOSED METHODOLOGY

In this work, we have presented the performance analysis of orthogonal frequency division multiplexing with variations in cyclic prefixes and FFT lengths. Frequency slicing, a technique employed by OFDM, a multicarrier transmission system, is utilized to mitigate the challenges posed by multipath interference. Figure 1 illustrates that the system reduces multipath distortion and frequency interference. The level of interference in signal broadcasting is reduced via OFDM. A type of multicarrier modulation is OFDM. Several closely spaced modulated carriers make up an OFDM signal. As a result, alerts sent close to one another must be separated by a guard band and spaced sufficiently for the receiver to use a filter. Numerous existing and future broadband communication systems have chosen the multicarrier modulation approach of orthogonal frequency division multiplexing as their modulation scheme.

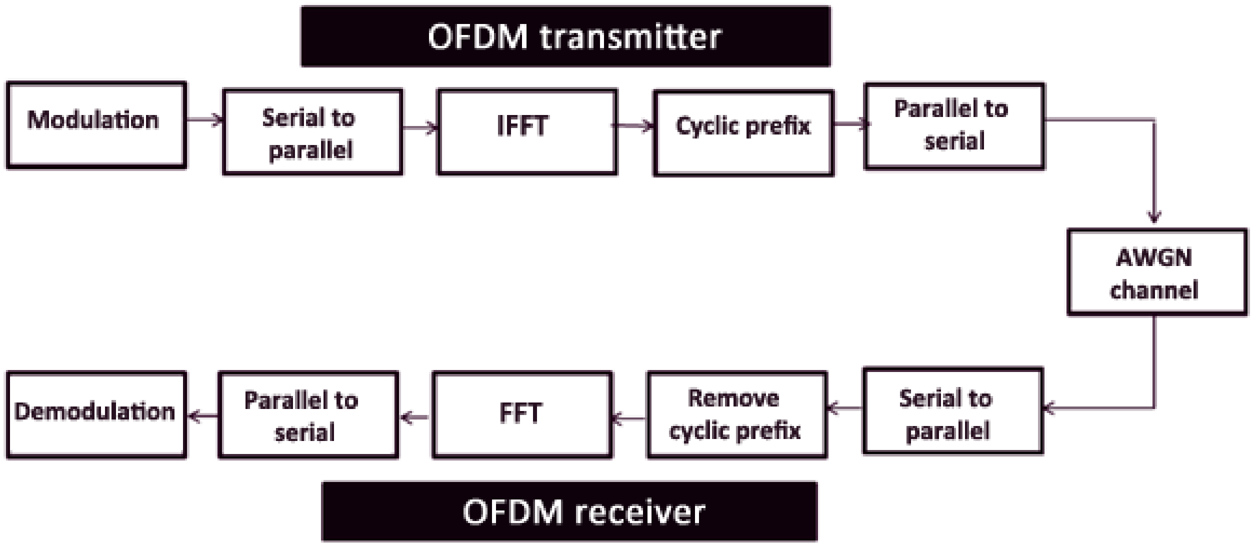


Figure 1. Illustrates the Block diagram of the proposed system.

3.1. Data Source

To execute Orthogonal Frequency Division Multiplexing on it, random data with [0, 1] values are generated for 64 bits as given in Equation 1.

$$OFDM\,(input) = ran\,data\,[0,1] \quad (1)$$

Where, $n = 0,1,2,......n-1$

3.1.1. Modulator

The modulator in the transmitter part modulates the original data. Different modulation methods, like 16-QAM, BPSK (Binary Phase Shift Keying), and QPSK (Quadrature Phase Shift Keying), are used for the data. Here, the 64-QAM is utilized as proposed. The Equation 1 of the data is modulated using 64 QAM and is given in Figure 2.

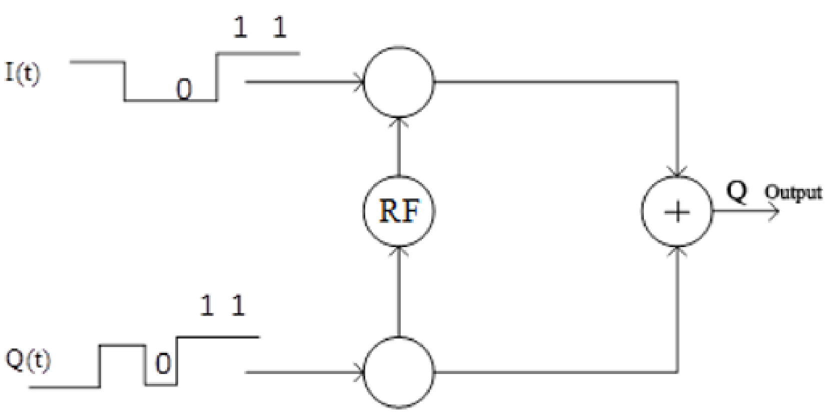


Figure 2. 64- QAM modulation.

Each symbol in 64-QAM is a constellation state with six bits, and there are 64 potential combinations of these constellation states 000 000 to 111 111. Due to the usage of binary data in this modulation method, there are a total of six potential possibilities 26 i.e. 64. The logarithmic value can be used to calculate the number of bits $\frac{1}{6}(bit\ rate)$ by comparing the 64-QAM scheme to other lower-order QAMs like the 16-QAM, BPSK, and QPSK schemes, it is possible to vary the carrier wave's amplitude and phase as well as transmit a proportionally larger number of bits.

3.1.2. Serial to Parallel Converter

The Q_{output} 64-QAM is converted using a serial to parallel converter. Here, the serial data is transformed into several subcarriers in similar forms. Each subcarrier is assigned a unique word to send the parallel data.

3.1.3. Inverse Fast Fourier Transform (IFFT)

OFDM orthogonality is achieved by employing IFFT. IFFT's primary function is to convert a spectrum into a time-domain signal. When a signal is sent across a time-dispersive channel, the cyclic prefix lowers inter-carrier and inter-symbol interference.

$$X_i(n) = \frac{1}{N_i} * \sum_{k=0}^{N-1} X_i(k) * e^{i*2*pi*n*k/N_i} \quad (2)$$

Where, $x_i(k)$ is the frequency domain samples, $x_i(n)$ is the time domain samples, $N_i \rightarrow FFT\ size$

$k \rightarrow 0,1,2........, N_i - 1$

3.1.4. Parallel to Serial Converter

Data from different subcarriers must be combined into a serial form before being transmitted over the AWGN channel. This block converts similar data to serial data sent across the network.

3.1.5. AWGN Channel

This path is needed between the transmitter and receiver to transfer our data. The existence of noise in this medium has a significant influence on the signal and results in distortion of the data content. Information theory uses the AWGN basic noise simulation to replicate the impact of several random processes seen in nature. The data signal after passing through the channel is shown in Figure 3.

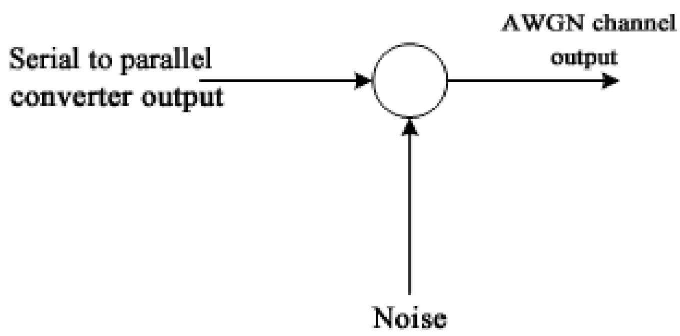


Figure 3. AWGN channel block diagram.

The AWGN of output is given below in Equation 3.

$$AWGN_{output} = s(t)n(t) \quad (3)$$

Where, $s(t)$ is the serial to parallel converter output, and $n(t)$ is the noise signal from the AWGN channel Under QAM modulation for 64-QAM, the AWGN channel has the best performance because it has the lowest BER.

3.1.6. Rayleigh Channel

When a signal is transmitted across a channel like this, Rayleigh fading models predict that the signal's amplitude will follow the Rayleigh distribution, which is the sum of two not-correlated Gaussian random variables with a radial component. The quantity of noise in this channel's BER is much lower than in fading channels. The equation for Rayleigh fading is given in Equation 4.

$$P_{rayleigh}(r) = \left\{ \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2} \right) \right\} s(t)n(t) \ \ for \ \ 0 \le r < \infty \quad (4)$$

$$for \ \ r < \infty$$

3.2. Receiver

3.2.1. Serial to Parallel Converter

The AWGN channel's serial data must be transformed to parallel form, i.e., in the number of subcarriers, so that the cyclic prefix can be eliminated from each subcarrier.

3.2.2. Cyclic Prefix Removal Block

To obtain the original data, the cyclic prefix introduced to eliminate I.S.I. (inter-symbol interference) must first be removed. The OFDM cyclic prefix is based on a simple concept. There are two uses for the cyclic prefix. It first serves as a guard interval to stop the preceding sign from interfering with other symbols. A discrete Fourier transform can be used to convert the circular convolution produced by repeating the linear convolution of a frequency-selective multipath channel into the frequency domain. The method used for cyclic prefixes is given in Figure 4.

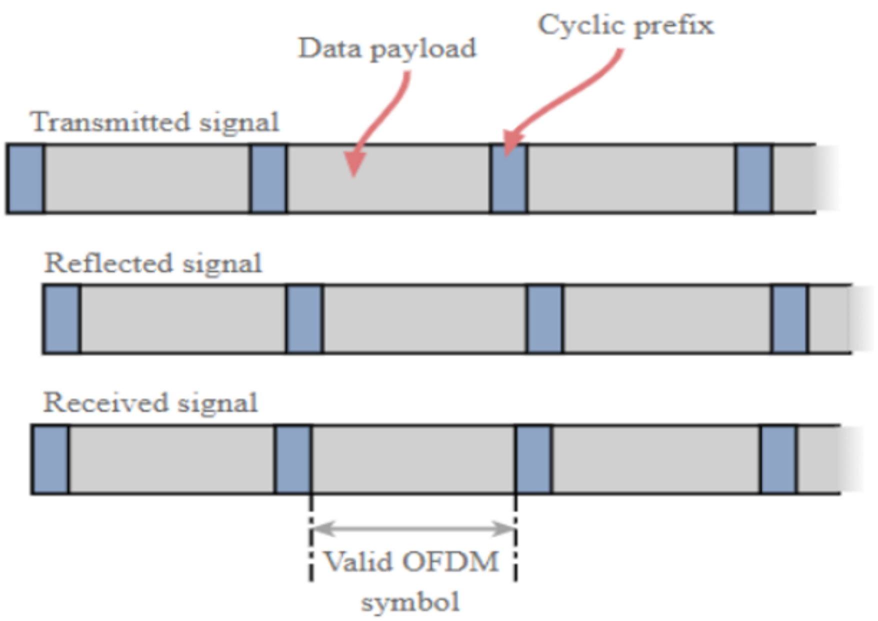


Figure 4. OFDM cyclic prefix.

Different systems offer the OFDM cyclic prefix at varied lengths. In LTE, there are two possible lengths: such as a regular length and an extended length. Since Release 8, a third extended length is now available. However, it is rarely utilized.

3.2.3. Fast Fourier Transform (FFT)

It's on the receiver side and does the opposite of the IFFT on the transmitter side. The FFT of each subcarrier is calculated separately as given in Equation 5.

$$X_i(k) = \sum_{k=0}^{N_i - 1} X_i(n) * e^{i*2*pi*n*k/N_i} \qquad (5)$$

Where, $x_i(n)$ is the time domain sample, $x_i(k)$ and are the frequency domain samples, $N_i \rightarrow FFT\ size$ $k \rightarrow 0,1,2........, N_i - 1$

3.2.4. Parallel to Serial Converter

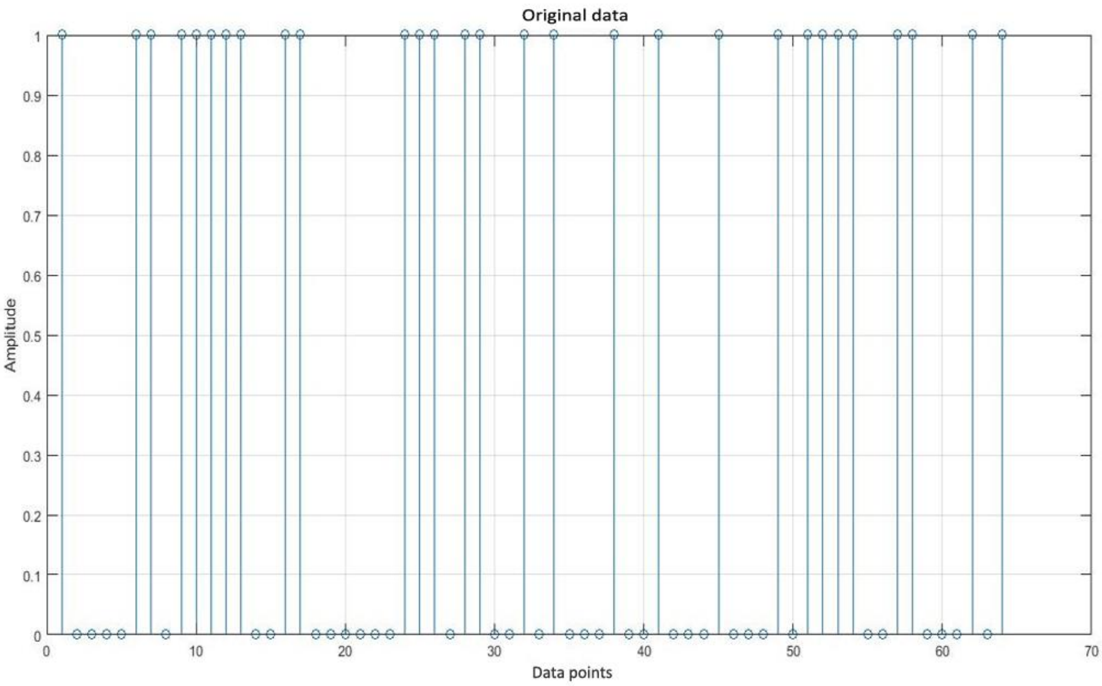
To retrieve the original data, all subcarriers are merged in serial form, i.e., transformed from parallel to serial form.

3.2.5. Demodulation

The serial Bit is demodulated using the suitable modulation technique to recover the original data. We have conducted over 64 bits. Figure 2 of modulation is demodulated to get the original data.

4. RESULT AND DISCUSSION

In section 4, the original data and data are allotted to subcarriers using serial to the parallel converter and the IFFT of some of the subcarriers; data signal with and without cyclic prefix; the OFDM signal ahead of and thereafter traversing via the AWGN channel; and the FFT of some subcarriers. Finally, the original data and demodulated data are evaluated using the Matlab platform.



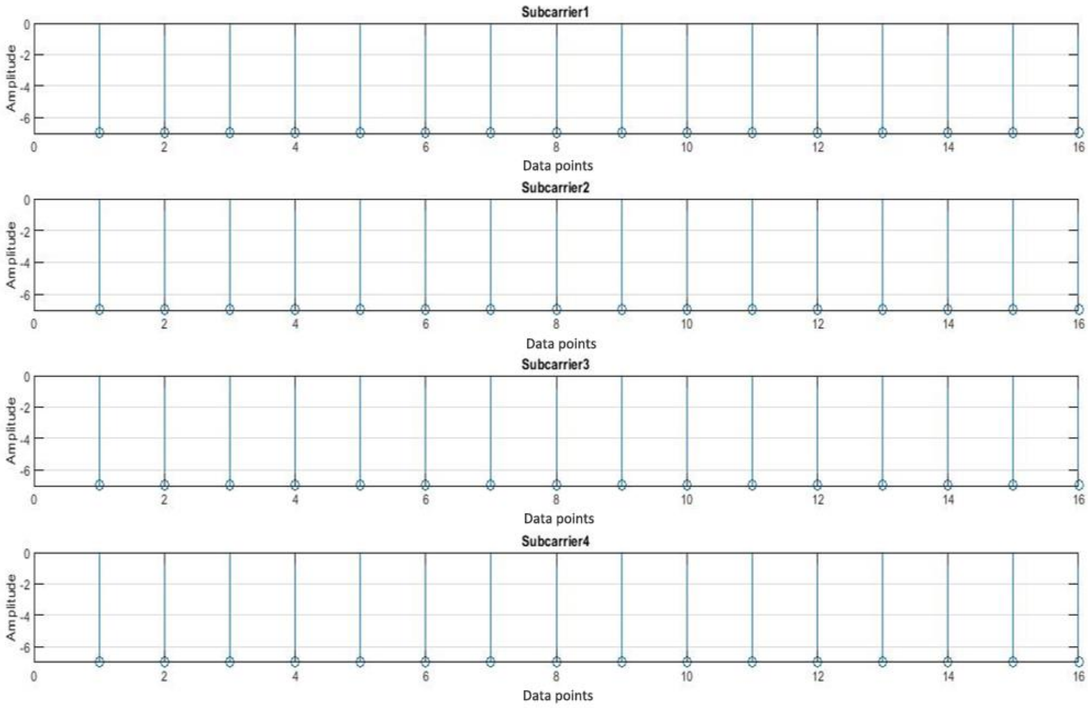
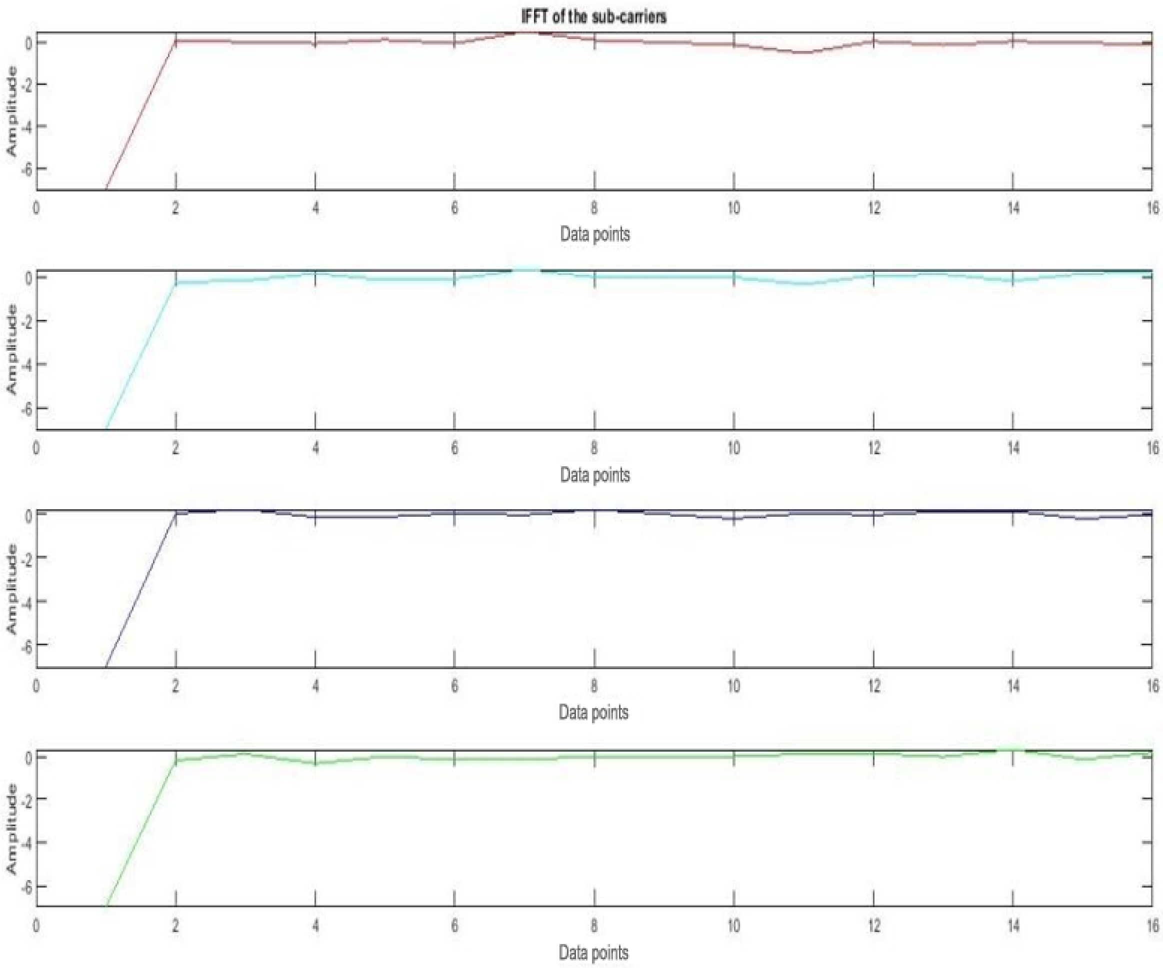


Figure 5. Original data and data allotted to subcarriers using serial to the parallel converter.



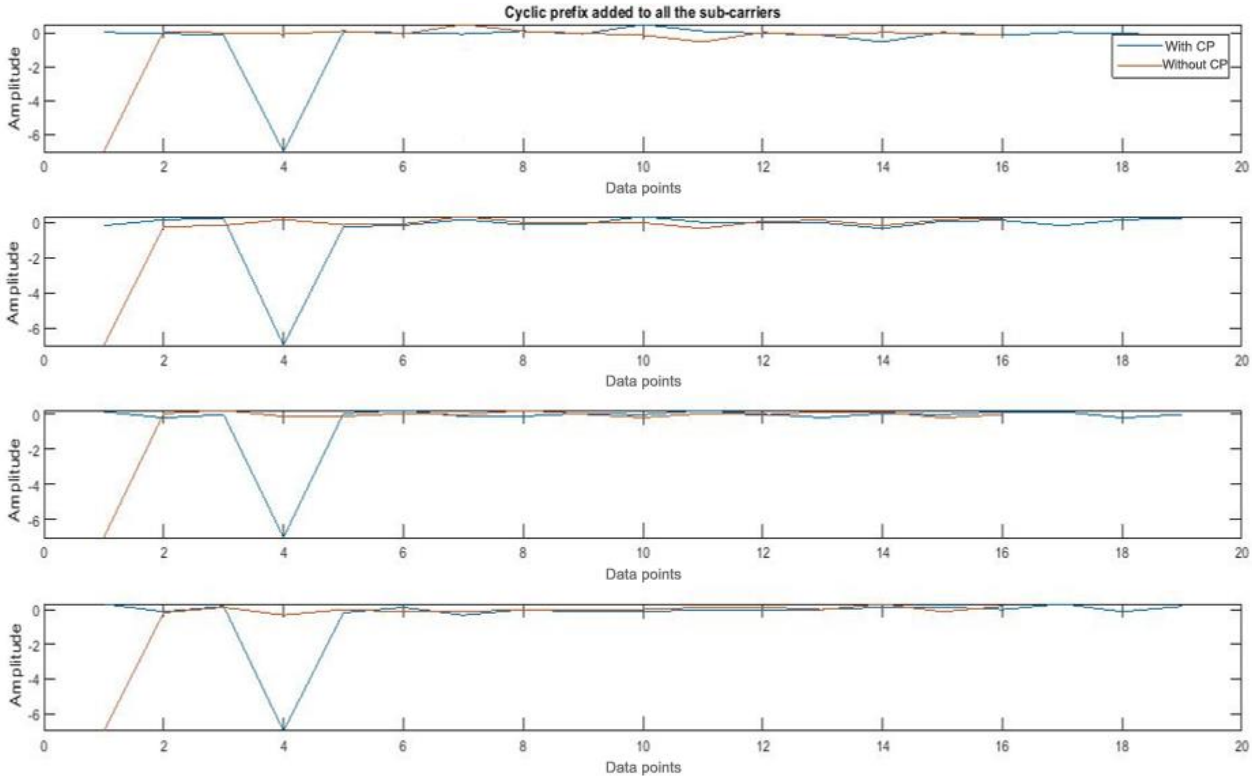
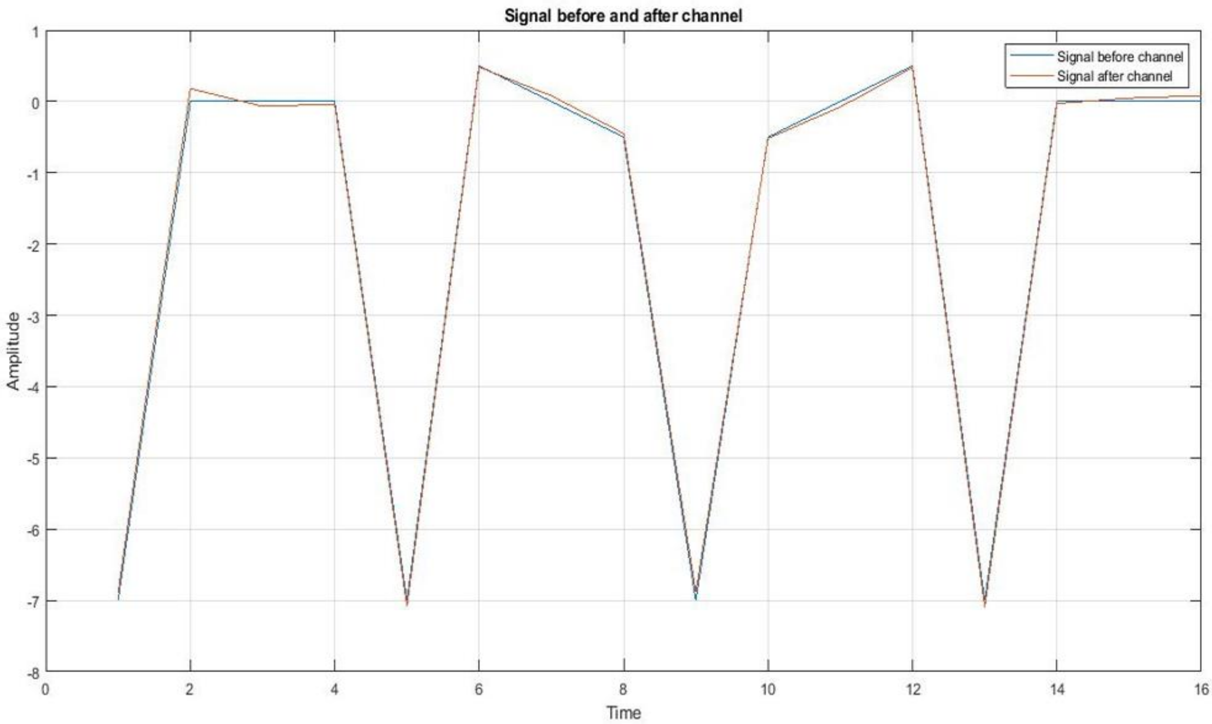


Figure 6. IFFT of some of the subcarriers, data signal with and without cyclic prefix.

In Figure 5 and 6 the original data and data allotted to subcarriers using serial to the parallel converter is determined. The IFFT of some of the subcarriers and data signals with and without cyclic prefixes is also evaluated.



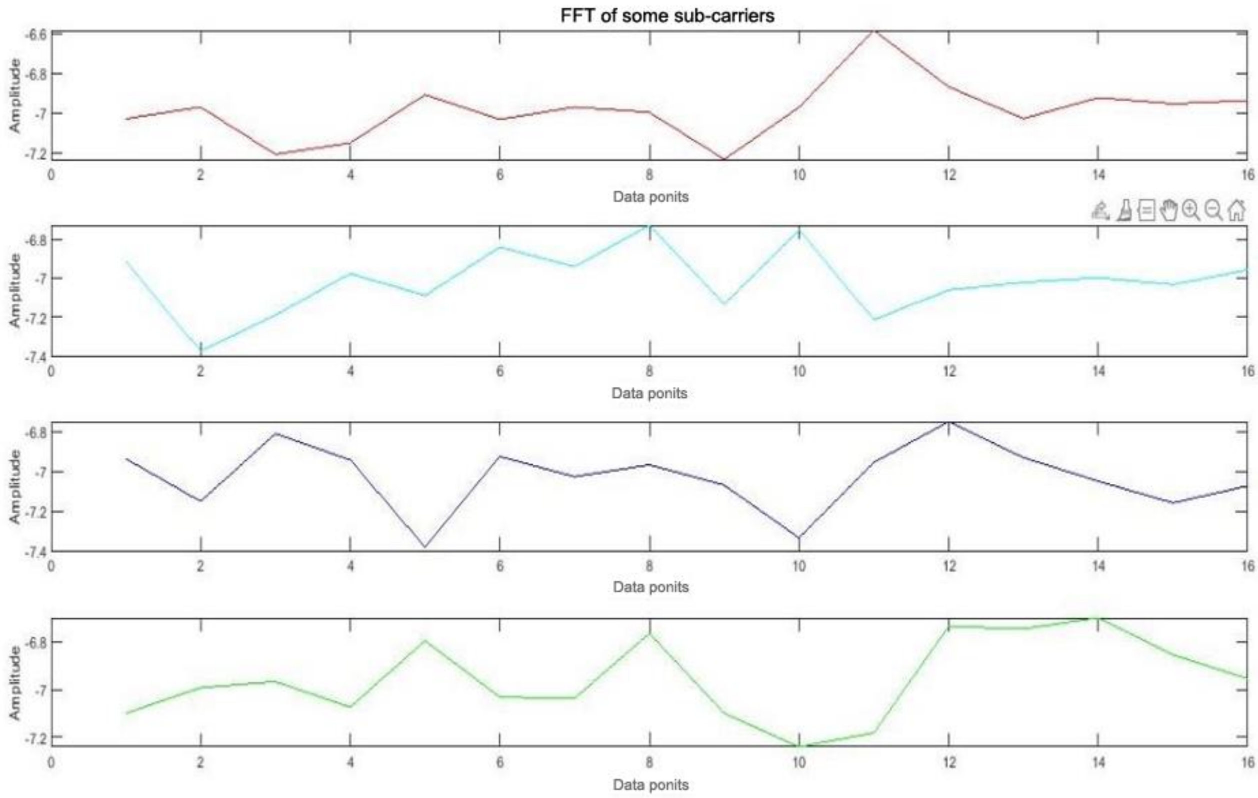


Figure 7. OFDM Signal before and after passing via the AWGN channel and FFT of some subcarriers.

In Figure 7 Noise in the OFDM signal is reduced both before and after it passes through the AWGN channel and in the FFT of Some subcarriers.

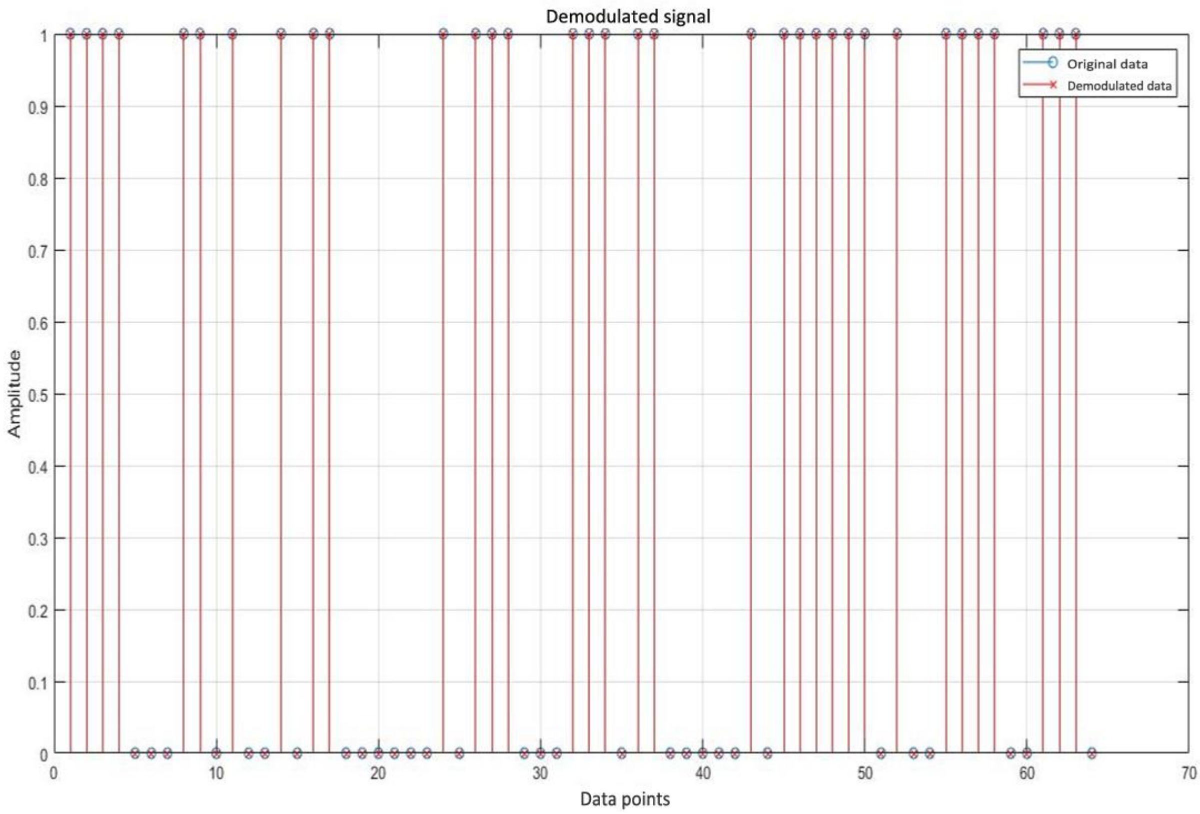


Figure 8. Demodulated and original data.

Figure 8 shows the original data and demodulated data. This graph is for SNR value 30. Hence almost no error is seen in the received data.

4.1. Performance Metrics

The implementation of the proposed work remains on the MATLAB (Matrix Laborator) platform. Here are the SNR vs. Bit error rate graphs even with different FFT lengths, i.e., 16, 64, 256, and 1024, respectively, and the modulation schemes such as BPSK, QPSK, 16-QAM, and 64-QAM are determined.

4.2. Bit Error Rate (BER)

It is the proportion of bits mismatched between the transmitter and the receiver to the total number of bits sent. A description of BER is provided in Equation 6:

$$BER = \frac{ERROR\ NUMBERS}{Total\ Number\ of\ bits\ sent} \quad (6)$$

The bit error rate is low when the SNR is high, and the medium between the receiver and transmitter is in excellent condition at a particular time. Here are random signals produced when the noise in the thesis simulation occurred, followed by an estimate of the BER.

4.3. Signal-to-Noise Ratio (SNR)

Is an estimation of the signal power of the noise. SNR can be defined using the Gaussian noise framework for wireless channels and complex signals, as shown in Equation 7.

$$SNR = \frac{signal\ \ power}{noise\ power} \quad (7)$$

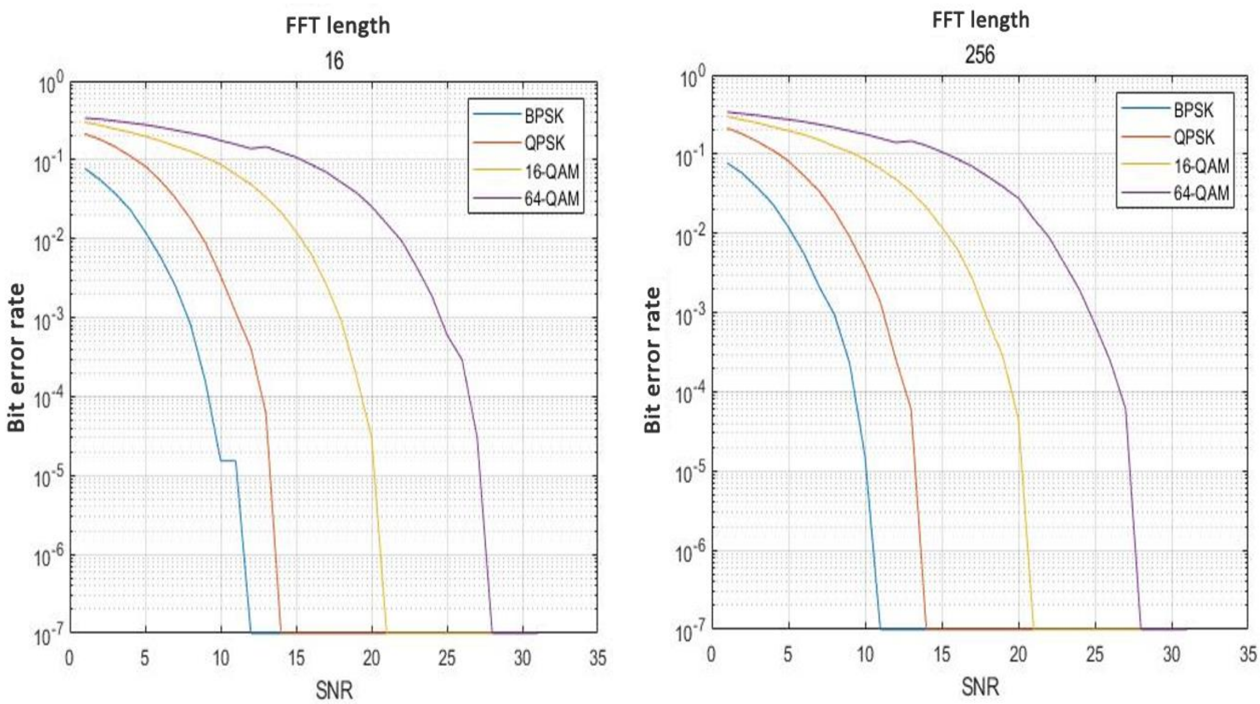


Figure 9. BER versus SNR for FFT lengths 16 and 256.

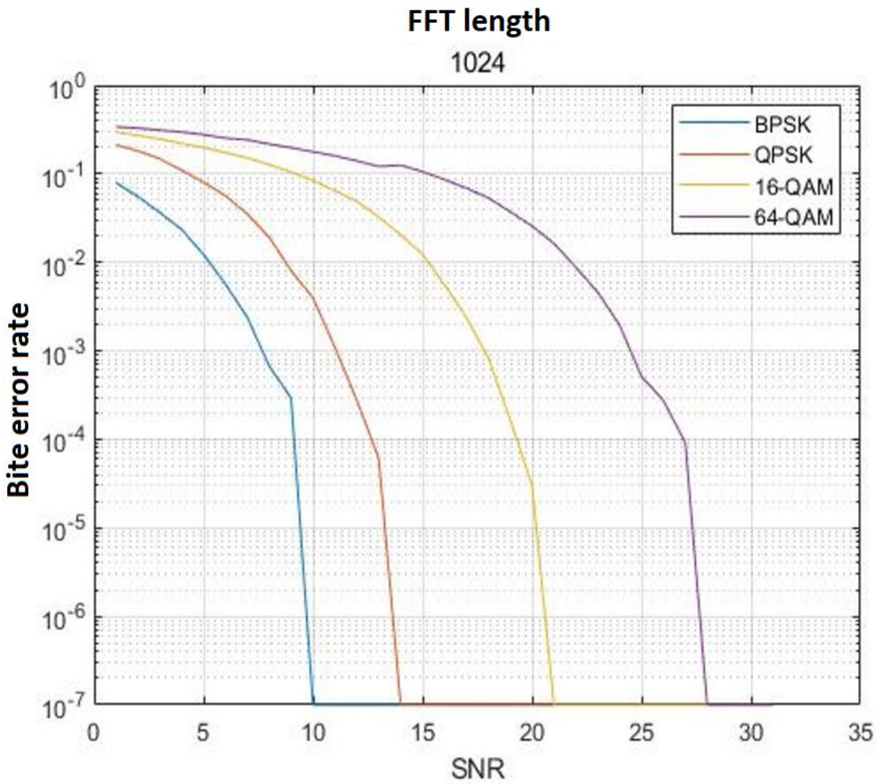


Figure 10. SNR versus BER for FFT length 1024.

Figures 9 and 10 are the graphs of BER vs. SNR for different FFT lengths, i.e., 16, 64, 256, and 1024, respectively, and charts are plotted for other modulation techniques by different colors, BPSK, QPSK, 16-QAM, and 64-QAM.

For FFT length 16
Maximum bit error rate in BPSK is
0.080
Maximum bit error rate in QPSK is
0.211
Maximum bit error rate in 16-QAM is
0.293
Maximum bit error rate in 64-QAM is a
0.338
For FFT length 64
Maximum bit error rate in BPSK is
0.078
Maximum bit error rate in QPSK is
0.213
Maximum bit error rate in 16-QAM is
0.298
Maximum bit error rate in 64-QAM is a
0.338

For FFT length 256
Maximum bit error rate in BPSK is 0.078
Maximum bit error rate in QPSK is 0.212
Maximum bit error rate in 16-QAM is 0.298
Maximum bit error rate in 64-QAM is a 0.338
For FFT length 1024
Maximum bit error rate in BPSK is 0.080
Maximum bit error rate in QPSK is 0.213
Maximum bit error rate in 16-QAM is 0.297
Maximum bit error rate in 64-QAM is a 0.338

The BER vs. SNR for different FFT lengths, i.e., 16, 64, 256, and 1024, are determined. The above outcomes show that the minimum BER in the BPSK modulation technique for FFT length 1024 is evaluated.

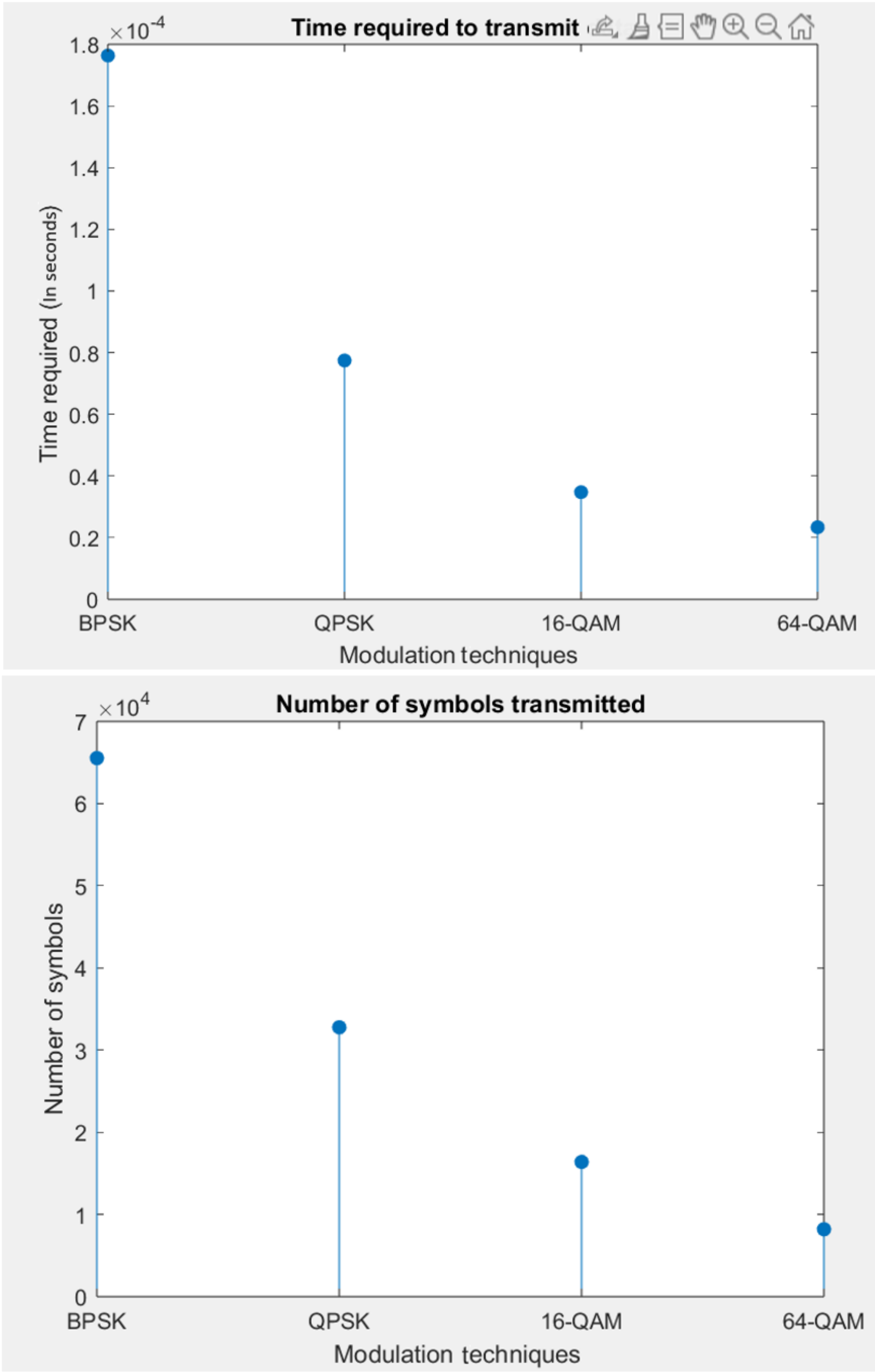


Figure 11. Number of symbols transmitted and time required by each modulation technique to transmit data.

Figure 11 shows that 64-QAM performs better in speed and number of symbols transmitted. Here, the 64-QAM modulation technique sends data in smaller number of characters and in less time.

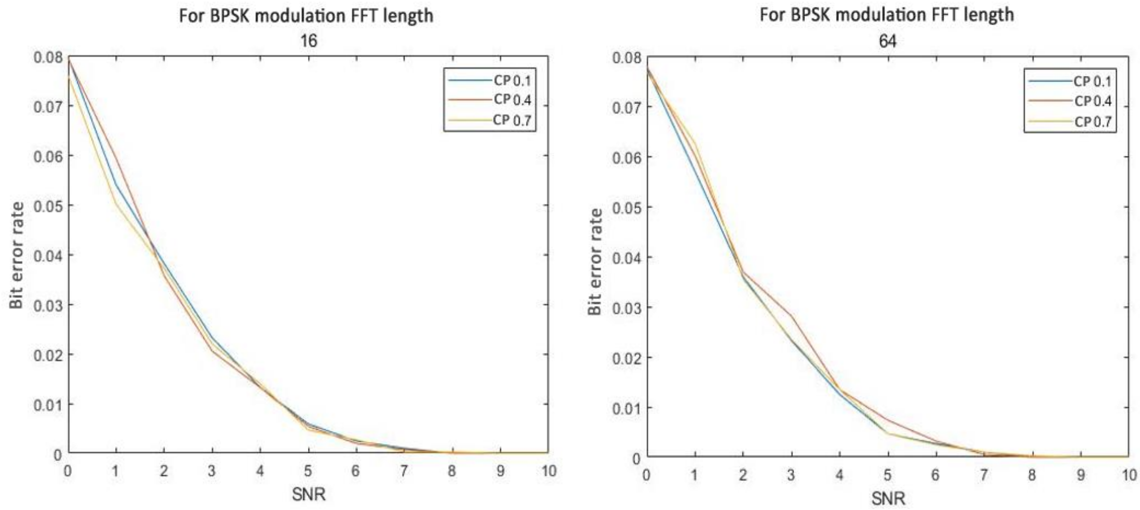


Figure 12. BER versus SNR for BPSK modulation of FFT length 16 and 64 for different C.P. length.

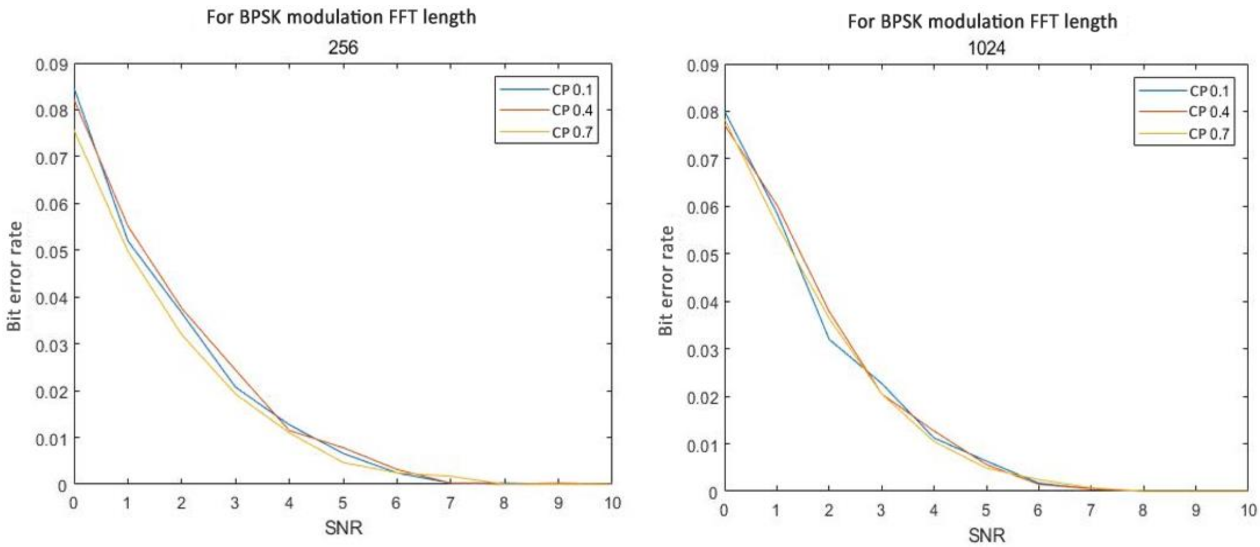


Figure 13. BER versus SNR for BPSK modulation of FFT length 256 and 1024 for various CP lengths.

Figure 12,13 shows graphs for BER versus SNR for BPSK modulation technique for various FFT lengths, i.e., 16, 64, 256, and 1024, for different CP lengths, i.e., 10% (blue), 40% (red), and 70% (yellow) of total data length.

Table 2. 16-QAM modulation, BER with a more extended cyclic prefix for FFT length 16, 64, 256 and 1024.

FFT length	Cyclic prefix	BER
16	0.1	0.080
	0.4	0.079
	0.7	0.076
64	0.1	0.077
	0.4	0.077
	0.7	0.076
256	0.1	0.085
	0.4	0.082
	0.7	0.076
1024	0.1	0.080
	0.4	0.077
	0.7	0.078

Hence, here BER with a more extended cyclic prefix comes out as low, so we can opt for the optimal cyclic prefix length. Similarly, for 16-QAM modulation, we experimented with various cyclic and FFT lengths. The 16 QAM of BER is given in Table 2.

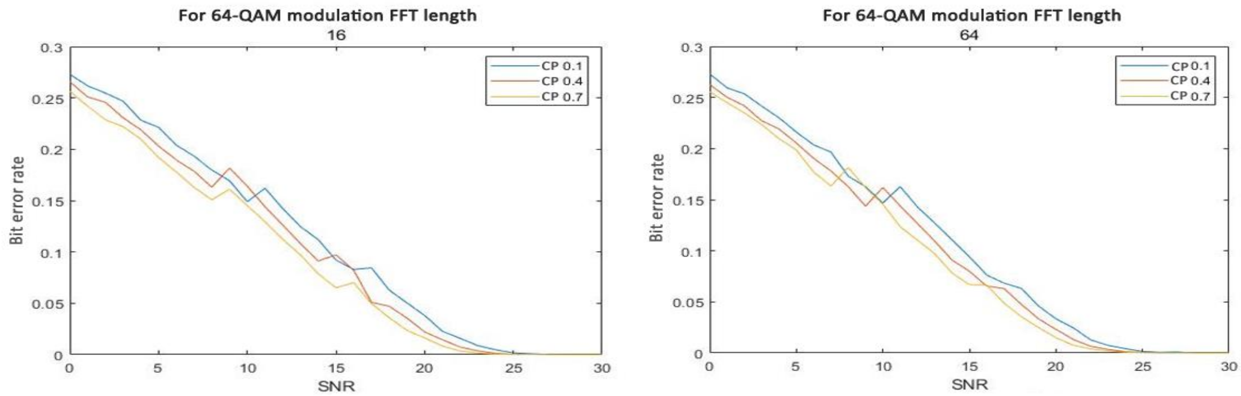


Figure 14. BER versus SNR for 64-QAM Modulation of FFT length 16 and 64 for various C.P. lengths.

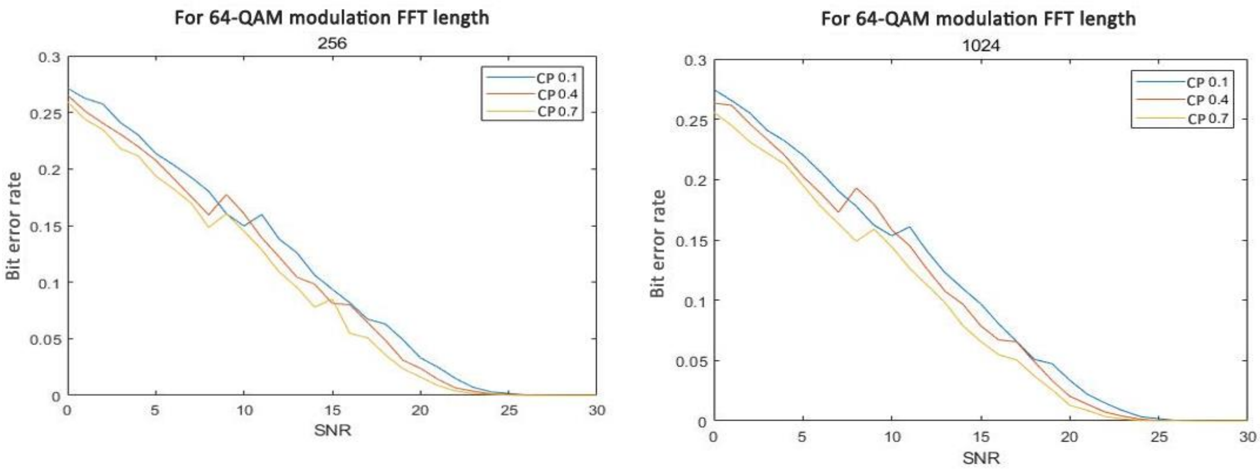


Figure 15. BER versus SNR for 64-QAM Modulation of FFT length 256 and 1024 for various C.P. lengths.

Figure 14, and 15 shows graphs for BER versus SNR for 64-QAM modulation technique for various FFT lengths i.e., 16, 64, 256, and 1024 for different CP lengths, i.e., 10% (blue), 40% (red), and 70% (yellow) of total data length.

Table 3. 64-QAM modulation, BER with a more extended cyclic prefix for FFT length 16, 64, 256 and 1024.

FFT length	Cyclic prefix	BER
16	0.1	0.2730
	0.4	0.2657
	0.7	0.2565
64	0.1	0.2726
	0.4	0.2627
	0.7	0.2556
256	0.1	0.2713
	0.4	0.2653
	0.7	0.2592
1024	0.1	0.2747
	0.4	0.2634
	0.7	0.2557

In the case of 64-QAM modulation in Table 3, BER with a more extended cyclic prefix comes out as low, so we can opt for the optimal cyclic prefix length.

5. CONCLUSION

The results of BER versus SNR graphs are plotted for different FFT lengths and different modulation techniques. The use of the BPSK scheme in OFDM provides a lower Bit Error Rate than other modulation techniques and for FFT length 1024 as compared to different FFT lengths. The 64-QAM modulation technique transmits the same amount of data in less time and with fewer symbols than other modulation techniques. Therefore, the 64-QAM modulation technique is proposed. The results of BER versus SNR graphs are plotted for OFDM using the BPSK modulation scheme for different FFT lengths for various CP lengths. As CP length increases, BER decreases, but the Bit rate rises with the CP length. So, there is a trade-off between CP length and BER. So, if the application requires higher accuracy, the CP length can be increased, and if the application doesn't require much accuracy but faster data, then the CP length can be kept lower.

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Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study. Both authors have read and agreed to the published version of the manuscript.

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