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DESIGNING AND SIMULATING THE OFDM TRANSCEIVER

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ABSTRACT

The glittering progress and usage of Wireless Communication in the past few years upraise some core challenges and problems which need to be conquered. Providing the higher data rates to confront the user demands, forced the researchers to develop new methods and techniques to fulfill the demand of high capacity wireless system. In this regard the Orthogonal Frequency Division Multiplexing (OFDM) technology for Wireless Local Area Networks (WLAN) promises a much improved and higher data rates (up to 100 Mbps). It also have a strong capability of taking over other technologies for the enhancements in mobile and wireless technology for the 4th generation (4G) systems. In this paper we attempt to design and simulate the OFDM transceiver using MATLAB. The three simulations with different conditions are enlightened and performed which includes the simple transceiver simulation, simulation considering the channel effects (AWGN channel) and lastly the simulation including coding, interleaving and pilot insertion to reduce channel effects (AWGN channel). Bit Error Rate (BER) is found in these simulations and special measures are taken to reduce BER due to channel effects. The simulation results shows that OFDM is more appropriate and is capable for the high frequency Wireless systems and is more robust to noise, channel effects and interference.

KEYWORDS: *Wireless Communication, Orthogonal Frequency Division Multiplexing, Transceiver, Bit Error Rate*

I. INTRODUCTION

As the field of wireless communication is evolving, huge progress has been achieved in this field over the past few years. A demand of high capacity wireless networks was felt, either by upgrading present technology or by devising new methods and techniques. The change was considered because of the interest of people in the cellular technology and wireless technology (like Wireless Local Area Networks) as a result of exponential growth of the internet.

The use of Orthogonal Frequency Division Multiplexing (OFDM) technology in the newer WLAN technologies promises a much improved and higher data rate of almost 54 Mbps and with further improvements, higher data rates can be achieved (up to 100 Mbps). The use of OFDM in LTE offers peak data rates of 100 Mbps for the cellular purposes.

The main goal of 3rd and 4th generation wireless technologies is to entertain people with higher data rates along with the provision of wide range of services, like voice communication, video services (e.g. video call) and internet services, over the same platform. The use of OFDM in LTE has provided a complete convergence of cellular technology, multimedia applications such as video and high quality audio and high speed internet. Thus OFDM has a strong capability of taking over other technologies for the enhancements in mobile and wireless technology for the 4th generation (4G) systems.

Orthogonal Frequency Division Multiplexing (OFDM) is a mixture of modulation and multiplexing. The carrier signal is split into independent fragments. These fragments are called sub-carriers and they are orthogonal to each other. The data is modulated with these signals and then the modulated data is multiplexed to create the composite OFDM signal. Thus it is a multi-carrier modulation scheme.

'OFDM is a special case of Frequency Division Multiplexing (FDM). As an analogy, a FDM channel is like the water flow out of a faucet, in contrast the OFDM signal is like a shower. In faucet all water comes in one big stream and cannot be divided. OFDM shower is made up of a lot of little streams.' [1].

OFDM is a substitute of Code Division Multiple Access (CDMA). It can easily exceed the capacity of CDMA systems. The work on the development for the commercial use of it, started with the introduction of Digital Audio Broadcasting (DAB) system, in late 1980s. Since then this technique had development and is being used in applications these days. Its implementation is making progress day by day.

The rest of the paper is organised as follows: Related Work is discussed in Section 2. Section 3 enlightens the basic principles of OFDM. OFDM design and simulation is given in Section 4. Lastly conclusion is drawn in Section 5.

II. RELATED WORK

A wide range of contribution has been done by the researchers in context of OFDM technology and the analysis of OFDM's past and future. Time to time different ideas were proposed and different modulation schemes were developed in order to get higher data rates. An effort has been done in this section to summarize the research related to OFDM technology.

Chang [3] proposed the idea of OFDM in mid-60's by proposing a new method to synthesize the band limited signals for the multi-channel transmission. Basically the core idea behind it was to transmit the signals simultaneously without Inter-Channel (ICI) and Inter-Symbol Interference (ISI) through a linear band limited channel.

An analysis was performed by Saltzberg [4] which was based on Chang's work. To concentrate and focus on reducing the crosstalk between the adjacent channels rather than improving the individual signals should be the main focus to design the multi-channel transmission was the main conclusion of Saltzberg's work.

Weinstein and Ebert [5] made a significant contribution to the OFDM technology in 1971 by proposing the method of Discrete Fourier Transform (DFT) in order to execute the base band modulation and demodulation. DFT is a very effective and efficient algorithm for signal processing and also eliminates and reduces the banks of sub carrier oscillations. To combat the problems of ICI and ISI, it uses the guard space between the symbols. One of the loophole in this system was that it can solve the ISI and ICI issues up to some extent but over a dispersive channel it can't achieve perfect orthogonality between the sub-carriers.

Peled and Ruiz [6] in 1980 introduced the Cyclic Prefix (CP) that solved orthogonality issue by filling the guard space of the OFDM symbol with a cyclic extension and is assumed that the impulse response of the channel is shorter than the cyclic prefix.

Chang and Iwao [7] in 2002 worked on increasing the throughput performance by considering the effect of Doppler frequency for adaptive modulation, target BER and various other modulation combinations and also evaluated the performance of adaptive and fixed modulation. So they come to the conclusion that the better throughput performance can be achieved by QPSK as compared to the adaptive modulation by increasing the Doppler frequency. To reduce the transmission time, they also proposed the predicted feedback information method.

In 2005, Xiadong [8] gave his ideas on OFDM in his research paper entitled "OFDM and Its Application to 4-G". With the development of modern digital signal processing technology, OFDM has become more applied or practical to implement and has been proposed as an efficient modulation scheme for applications ranging from modems, digital audio broadcast, to the next-generation high-speed wireless data communications.

DARREN MCQUEEN [9] discussed the future of OFDM and Long Term Evolution (LTE). LTE is popularly known as the 4th Generation technology. It is an all IP technology based on Orthogonal Frequency Division Multiplexing. OFDM is more spectrally efficient–meaning it can deliver more bits/Hz. In the future, LTE will be the technology of choice for most existing Third Generation Partnership Project (3GPP) and 3GPP2 mobile operators i.e. all the mobile operators will shift their network to 4-G. LTE also brings subscribers a "true" mobile broadband that enables a quality video experience and media mobility. LTE will enable a wealth of new applications previously available only on a wired Internet connection (such as ADSL or Cable Internet).

A need for a new modulation scheme was felt to reduce the effects of Inter-Channel Interference (ICI), Inter Symbol Interference (ISI) and crosstalk between adjacent channels. There was also a need for higher data rates. OFDM has been previously used in Wireless Local Area Networks (WLANs), Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB). The higher data rates have been made possible in WiMAX by the use of OFDM and it is in use all over the world now a days. The latest work is on LTE, the first use of OFDM in cellular technology. LTE systems have been implemented in some countries and it has a bright future.

III. BASIC PRINCIPLES OF OFDM

As the "Orthogonal Frequency Division Multiplexing (OFDM)" is the process of transmitting the data using quite a huge quantity of modulated sub-carriers, additionally this data is directed in the parallel form. The offered bandwidth is divided by the sub-carriers and they have a separation among them to avoid interference i.e. they are orthogonal to each other. Defining the carrier orthogonality over a symbol period in which each carrier has an integer number of cycles over that period. No interference is achieved because each carrier's spectrum contains a null at the center frequencies of all other carriers of the system and this is due to orthogonality. This escalates the spectral efficiency in OFDM. Spectral Efficiency is a measure of how proficiently the bandwidth is being utilized.

The conventional method of frequency was "Frequency Division Multiplexing (FDM)". Frequency modulated radio stations is an example of this technique. For transmission and reception these radio signals utilize different carrier frequencies. In Addition to it, in order to guarantee that there spectra do not overlap each other they are sufficiently spaced far apart in frequency domain. By using the band pass filters every signal is received individually at the receiver end. Lastly to recover the original signal, the filtered signal is demodulated.

There is a major difference between OFDM and FDM. In conventional broadcasting the radio stations use different frequencies for transmission and separation between the stations, and this is maintained and done by the effective use of FDM but no synchronization is carried out among these stations. In OFDM transmissions, to form a single multiplexed stream of data the signals of different stations are merged. An OFDM group is used for the broadcast of this data. A compacted settlement of many sub-carriers makes up the OFDM cooperative.

By maintaining the time and frequency synchronization of the sub-carriers with each other, the interference between the subcarriers is controlled. Because of the orthogonal nature of the modulation, the overlap of the spectra of these sub-carriers occurs, but do not cause "Inter-Carrier Interference (ICI)".

A pulse in the time domain corresponds to the "sinc" in the frequency domain. The "sinc" is of infinite length there is an interference between them in frequency domain. As these carriers are orthogonal in nature this indicates that the interference will not affect the message signal. Fig.1 and Fig.2 shows the sub-carries in time and frequency domain.

Talking about the situation with FDM, to prevent the interference the transmission signals need to have a large frequency guard-band between channels. So as a result this lowers the overall spectral efficiency. In OFDM the guard band is provided by the orthogonal packing of sub-carriers, which increases the spectral efficiency.

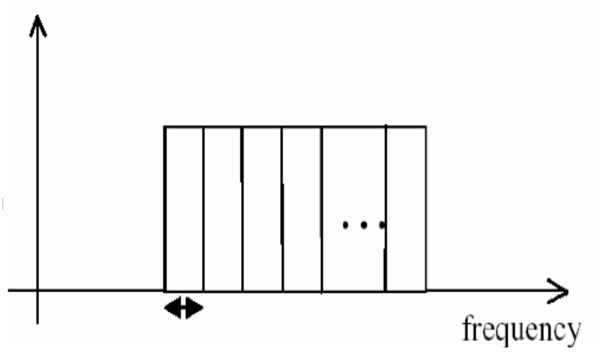

Fig.1 Sub-carriers (Time Domain) [10]

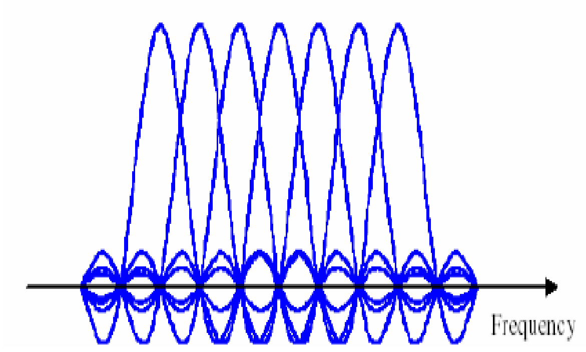

Fig.2 Sub-carriers (Frequency Domain) [10]

To effectively and efficiently transmit the signal on to the channel the communication system needs modulation.

The carriers in the FDM transmission can use a digital or an analog modulation scheme. All the sub-carriers are synchronized to each other in a single OFDM transmission and restricting the transmission to digital modulation schemes. Quadrature Amplitude Modulation (QAM), Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) are the common modulation schemes for the digital communication.

All the carriers in OFDM transmit in unison using the synchronized frequency and time, forming a single block of spectrum. This is to guarantee that the orthogonal nature of the structure is maintained. As these multiple carriers form a single OFDM transmission, so they are commonly referred as 'sub-carriers', with the term of a 'carrier' reserved for describing the RF carrier mixing the signal from base band.

3.1. Principles of OFDM

The practical OFDM system have the following main features [11]:

- On the source data some of the processing is done, such as the coding for correcting the errors, mapping and interleaving of bits onto the symbols. Quadrature Amplitude Modulation is an example of the mapping used.
- Onto the orthogonal sub-carriers the symbols are modulated. This is done by using the IFFT.
- Orthogonality is maintained during the channel transmission. This is accomplished by adding a cyclic prefix to OFDM frame to be sent.
- Synchronization: To detect the start of each frame the introduced cyclic prefix can be used.
- Received signal Demodulation by using the FFT.
- Channel equalization
- De-interleaving and the Decoding.

Fig. 3 and Fig. 4 is showing the simplified configuration for an OFDM transmitter and receiver respectively.

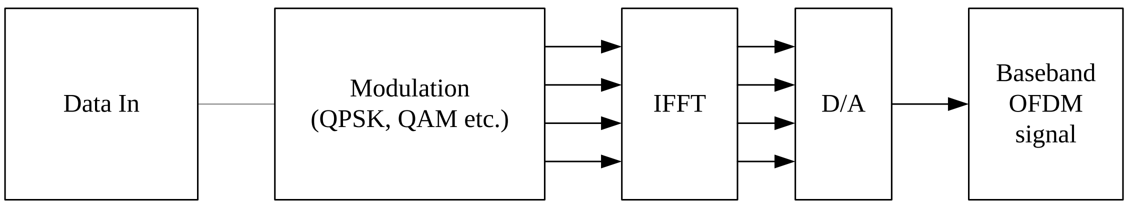

Fig. 3 OFDM Transmitter [11]

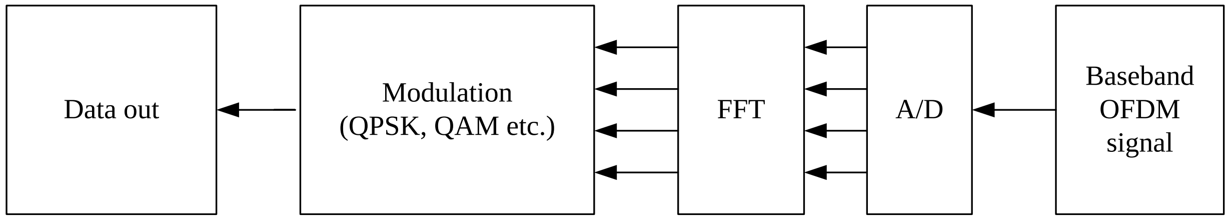

Fig. 4 OFDM Receiver [11]

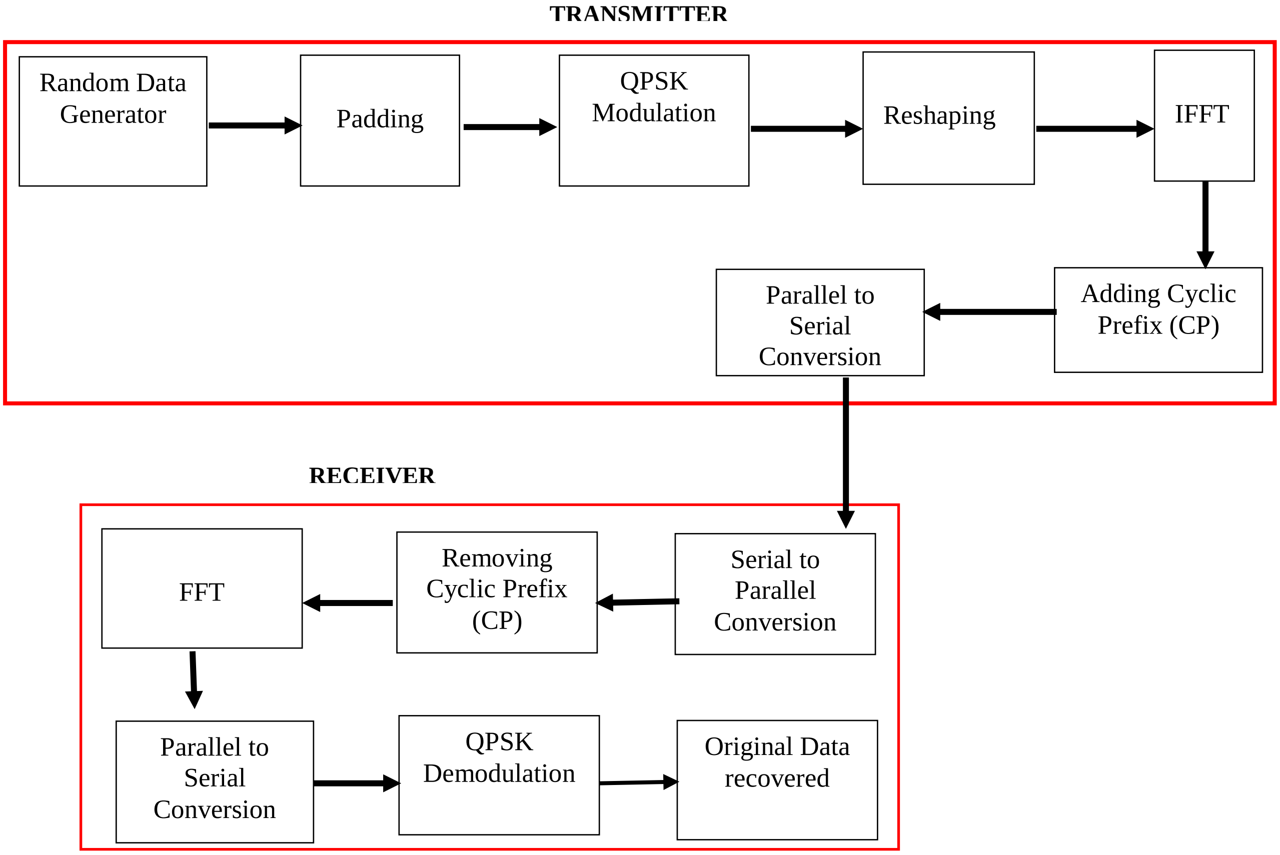

Fig. 5 Simple OFDM Model Block Diagram

IV. OFDM DESIGN AND SIMULATION

The basic simulation of the OFDM transceiver, without any channel effects, is discussed and its code is also given in this section. Then simulation with channel effects using QPSK is reviewed and the Bit Error Rate (BER) has been discussed. Another simulation is provided which includes convolutional encoding, interleaving and pilot insertion to minimize the channel effects.

We performed a number of simulations, each with different conditions. We then examined the different results obtained from these simulations. We start off with a simple model simulation that involves only transmission and reception of the OFDM signal, no channel effects are imposed. The data is received with accuracy. The digital modulation technique used is Quadrature Phase Shift Keying (QPSK). The block diagram of the simulation model is given in Fig. 5.

We now improved the simulation by introducing the Additive White Gaussian Noise (AWGN) channel. The channel effects are implied on the transmitted signal. We use the built-in MATLAB function "awgn" which adds AWGN to the signal. The signal gets distorted and the original signal does not get fully recovered. We then calculate the Bit Error Rate (BER) which is on the higher side indicating extensive distortion in the received signal. The block diagram of the model is given below in Fig. 6.

Our next step was to take measures to reduce the AWGN channel effects. We had a deep study on it and in the end we came up with the conclusion of adding some extra parameters to the signal before transmission. Convolutional encoding is performed on the input data to make it secure and then we introduce the concept of interleaving to avoid burst error. We insert 4 pilots in between the data points to make data secure.

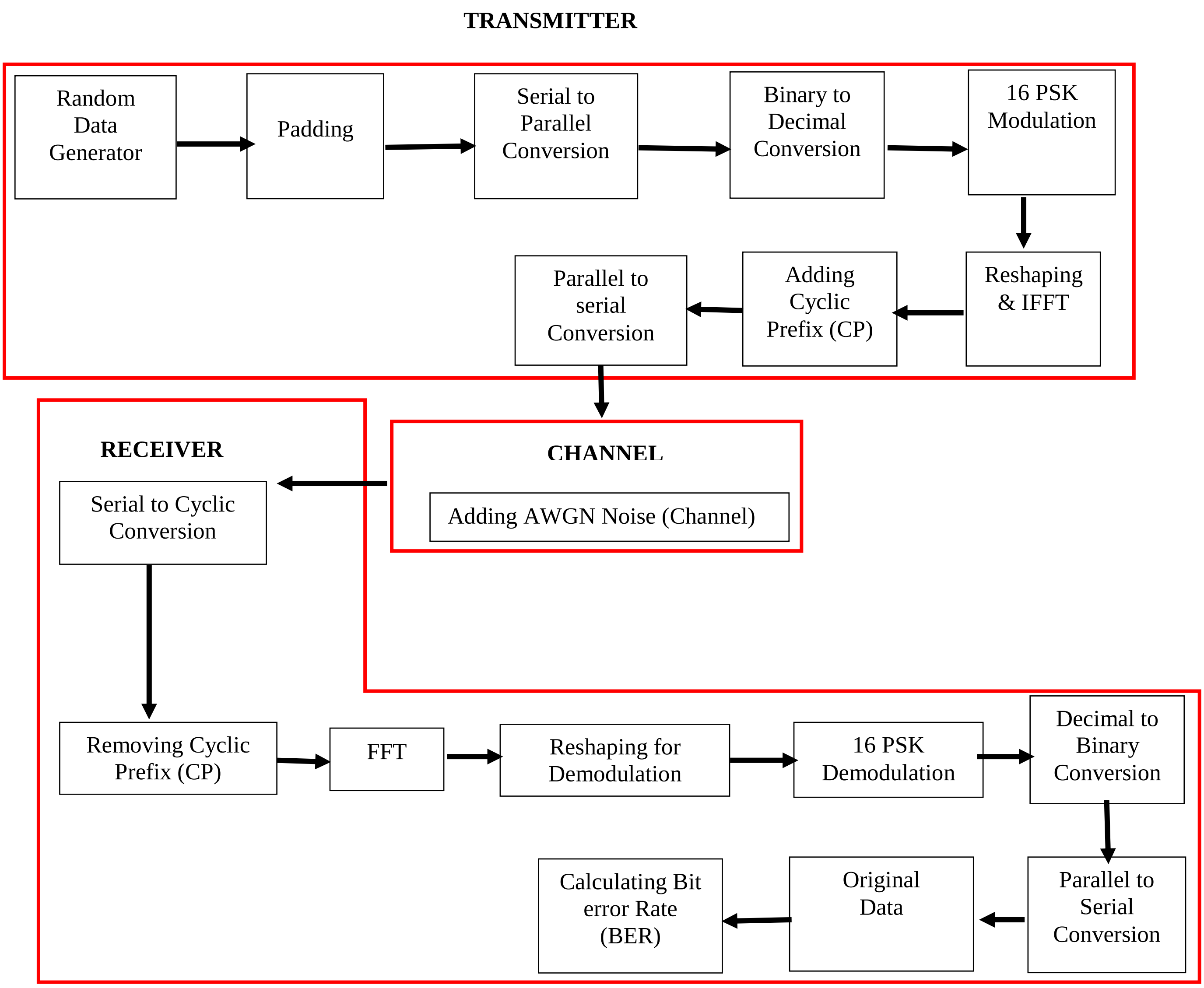

Fig. 6 OFDM Model with AWGN Channel

This work of coding and interleaving is done before the modulation. After performing 16QAM modulation, 4 pilots are inserted in between data points to ensure more robustness to noise inserted by the AWGN channel. The Bit Error Rate (BER) gets improved a lot, the errors are negligible. The block diagram of the model is given on the next page in Fig. 7.

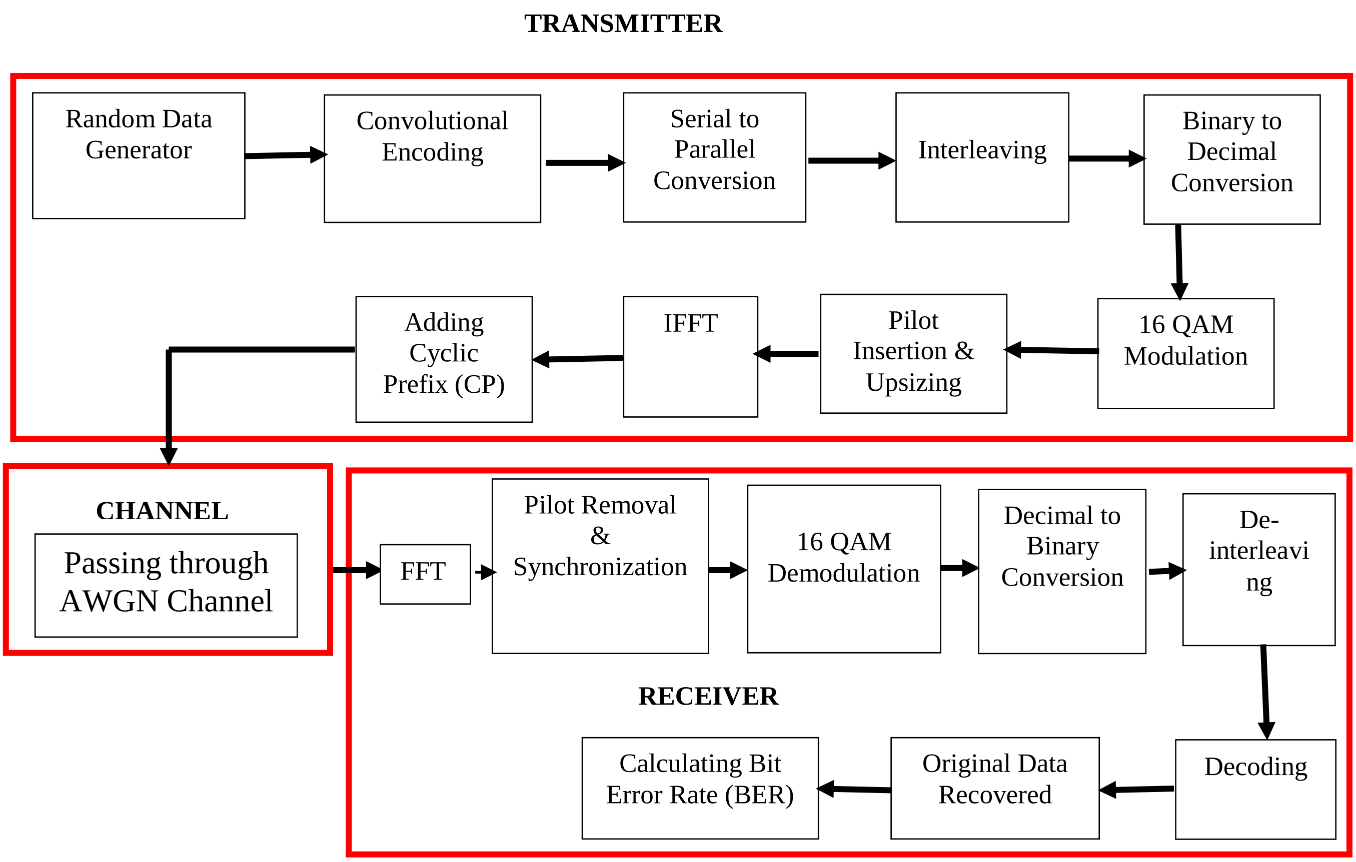

Fig. 7 OFDM Model with Coding, Interleaving and Pilots

The convolutional that we use in our simulation is given below in Fig. 8.

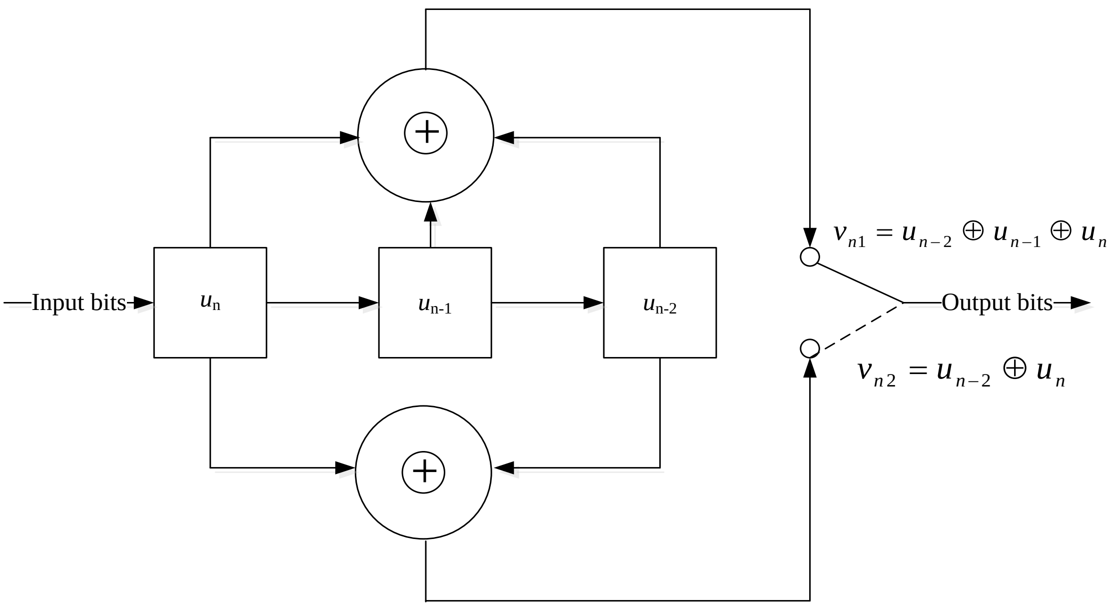

Fig. 8 Convolutional Coder [14]

4.1. Experimental Results of Simulations

The Experimental results of our simulations are as follows:

4.1.1 Results of Simulation 1: OFDM Basic Code

We use different set of inputs and observe the results. Those results are given below in Table. 1.

Table 1. Heading and text fonts.

Sr. No.	Data Rate (bits per second)	Input	Number of Errors	Bit Error Rate (BER)
1	64	1x64 vector	0	0
2	128	1x128 vector	0	0
3	256	1x256 vector	0	0
4	512	1x512 vector	0	0
5	1024	1x1024 vector	0	0

The graphical results for the input '1x64 vector' are as follows:
The data that has to be sent is shown in the Fig. 9 and the constellation diagram of QPSK modulation is given in Fig. 10.

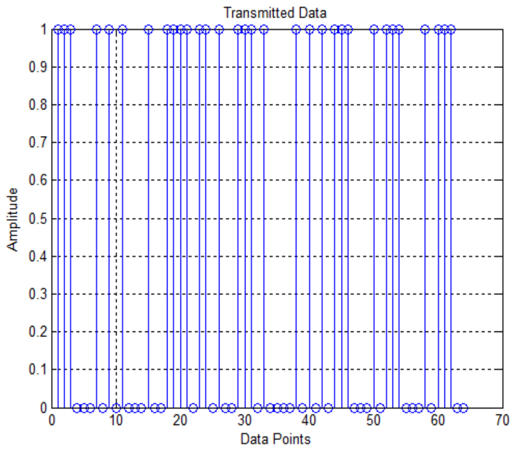

Fig. 9 Transmitted Data

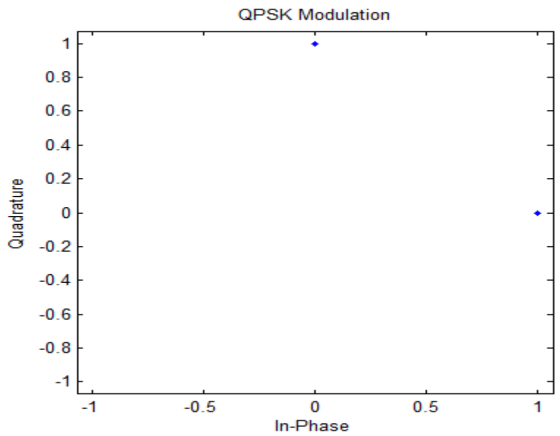

Fig. 10 Constellation Diagram

The OFDM signal to be sent is shown in Fig. 11 and Fig. 12 shows sent data (represented by 'o') and received data (represented by 'x').

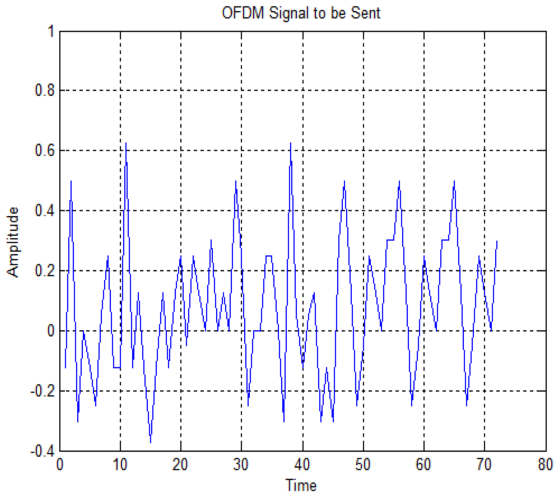

Fig. 11 OFDM Signal

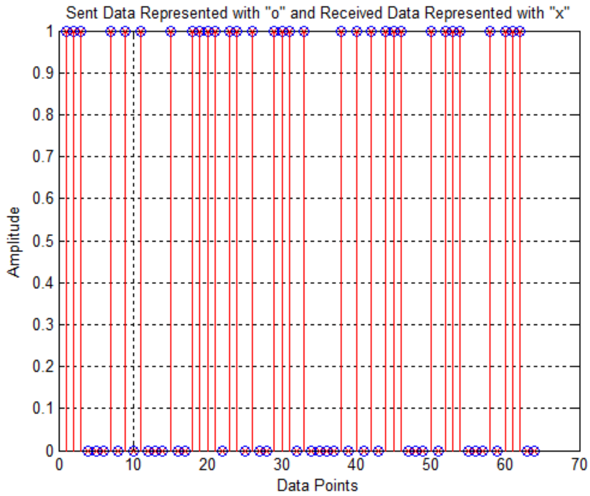

Fig. 12 Sent and Received Data

The difference between the transmitted and the received data is shown in the Fig. 13.

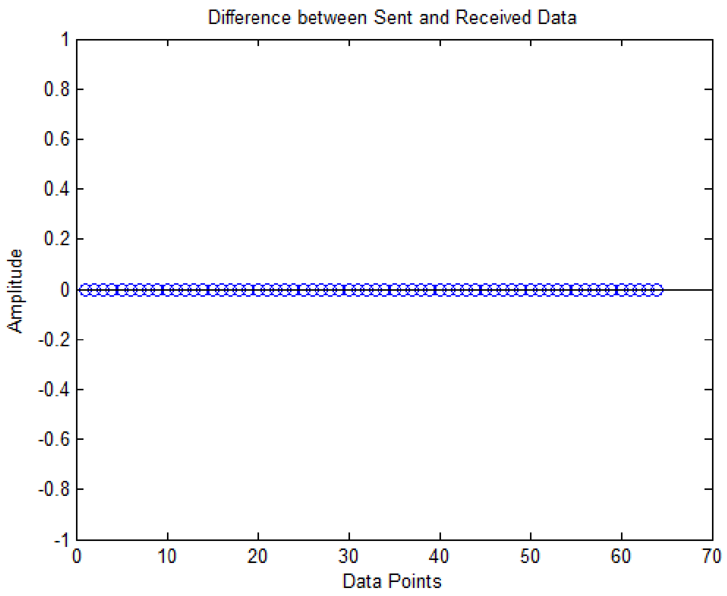

Fig. 13 Difference between Sent and Received Data

We can see from Fig. 13 that the data has remained intact because the error between the sent and received data is zero. The same data, as transmitted, is received and there is no error. Thus the Bit Error Rate (BER) is zero. It is so because the simulation includes only the transceiver, the channel has not been taken into account whose effects can result in signal distortion.

4.1.2 Simulation 2: OFDM with Channel Effects

The results are observed for different inputs for this simulation and are transformed in the shape of a Table. 2.

Table. 2 Results of OFDM with Channel Effects

Sr. No.	Data Rate (bits per second)	Number of Sub-carriers	Input	Number of Errors	Bit Error Rate (BER)
1	64	16	1x64 vector	105	0.4102
2	128	32	1x128 vector	223	0.4355
3	256	64	1x256 vector	457	0.4463
4	512	128	1x512 vector	901	0.4399
5	1024	256	1x1024 vector	1798	0.4390

The results for the input '1x64 vector' are given in the graphical form on the following pages.

Fig. 14 represents the data to be sent via OFDM technique and the constellation diagram of 16PSK modulation is shown in Fig. 15.

The OFDM signal to be sent over the channel is shown in Fig. 16 and Fig. 17 shows the sent data (represented by 'o') and received data (represented by 'x').

The Fig. 18 shows the difference between the transmitted and the received data.

We introduce the AWGN channel in this simulation and the effects can be seen in the figure 4.22 as the difference between the transmitted and received data is not zero. The sent data is not received with accuracy and some errors are introduced by the channel. This results in some BER even though we have inserted the cyclic prefix for safety purposes. These channel effects can be minimized taking measures such as coding, interleaving, pilot insertion, etc.

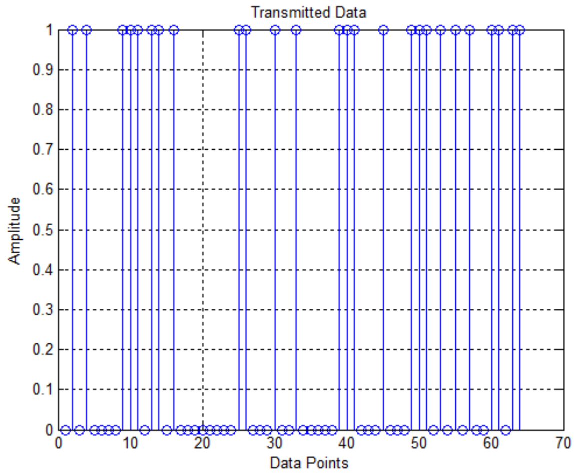

Fig. 14 Transmitted Data

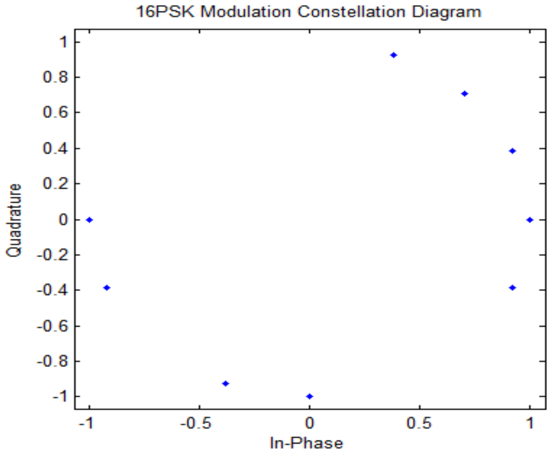

Fig. 15 Constellation Diagram

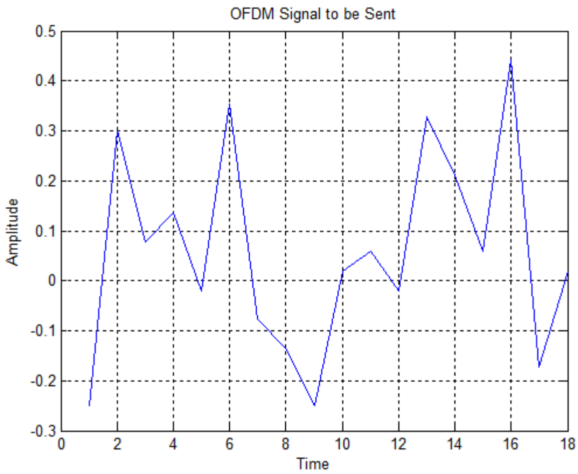

Fig. 16 OFDM Signal

Fig. 17 Sent and Received Data

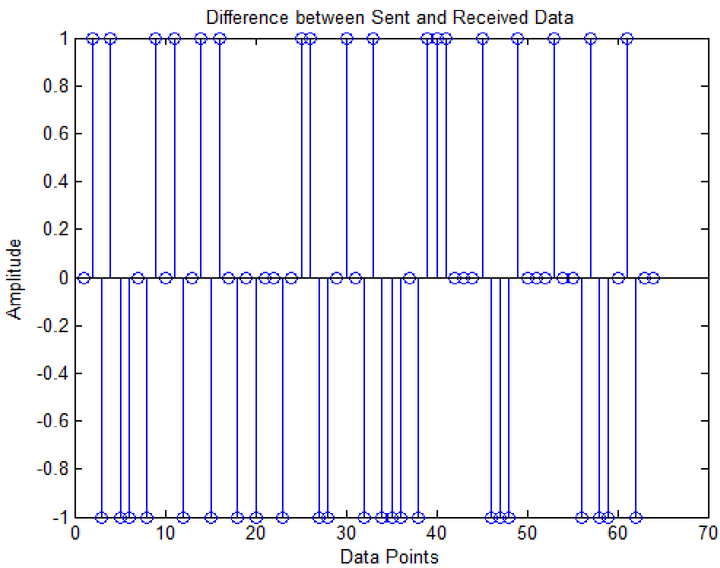

Fig. 18 Difference between Sent and Received Data

4.1.3 Experimental Results of Simulation 3: OFDM with Coding, Interleaving and Pilots

We use different inputs for this simulation and observed the results. The results are given in Table. 3.

Table. 3 Results of OFDM with Coding, Interleaving and Pilots

Sr. No.	Data Rate (bits per second)	Input	Number of Sub-carriers	Frame Size	Number of Errors		Bit Error Rate (BER)	
					16PSK	16QAM	16PSK	16QAM
1	1600	1x1600 vector	800	50	0	0	0.0041 to 0 ('o' after 8 iterations)	0.0047 to 0 ('o' after 12 iterations)
2	3200	1x3200 vector	1600	100	0	0	0.0041 to 0 ('0' after 8 iterations)	0.0047 to 0 ('0' after 12 iterations)
3	6400	1x6400 vector	3200	200	0	0	0.0040 to 0 ('0' after 8 iterations)	0.0047 to 0 ('0' after 13 iterations)
4	9600	1x9600 vector	4800	300	0	0	0.0041 to 0 ('0' after 8 iterations)	0.0049 to 0 ('0' after 12 iterations)
5	12,800	1x12,800 vector	6400	400	0	0	0.0040 to 0 ('0' after 8 iterations)	0.0048 to 0 ('0' after 12 iterations)

The graphical results for the input '1x3200' vector are as follows:
The data to be transmitted is shown in the Fig. 19 and the constellation diagram of 16QAM modulation is shown in the Fig. 20.

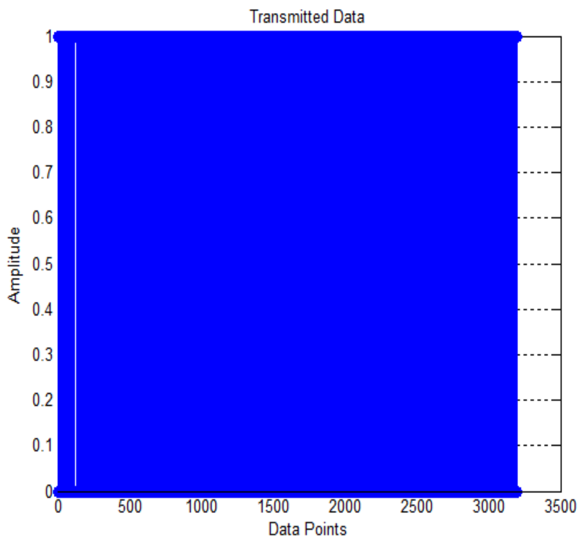

Fig. 19 Transmitted Data

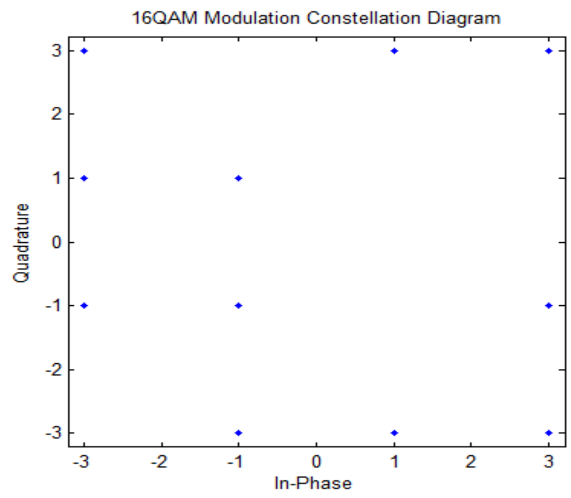

Fig. 20 16QAM Constellation Diagram

The constellation diagram of 16PSK modulation is shown in the Fig. 21 and Fig. 22 shows the OFDM signal to be sent.

Fig. 23 is showing the received data and the BER vs. SNR graph is shown in Fig. 24.

The difference between the sent and received data is shown in Fig. 25, given below.

The sent is received with precision in this simulation despite the channel effects because we have taken the measure to minimize them. For this purpose we first convolutionally encode the data, then perform interleaving and in the end we insert 4 pilots make data secure. We also add the cyclic prefix. It can be seen in figure 4.28 that the BER reduces with the increase in SNR, it almost becomes zero in the end. Figure 4.29 also shows that the difference between the sent and the received data is zero.

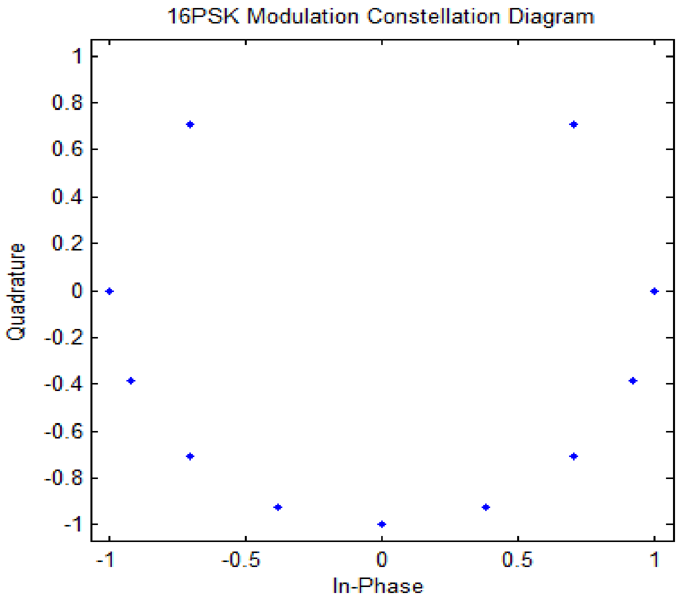

Fig. 21 16PSK Constellation Diagram

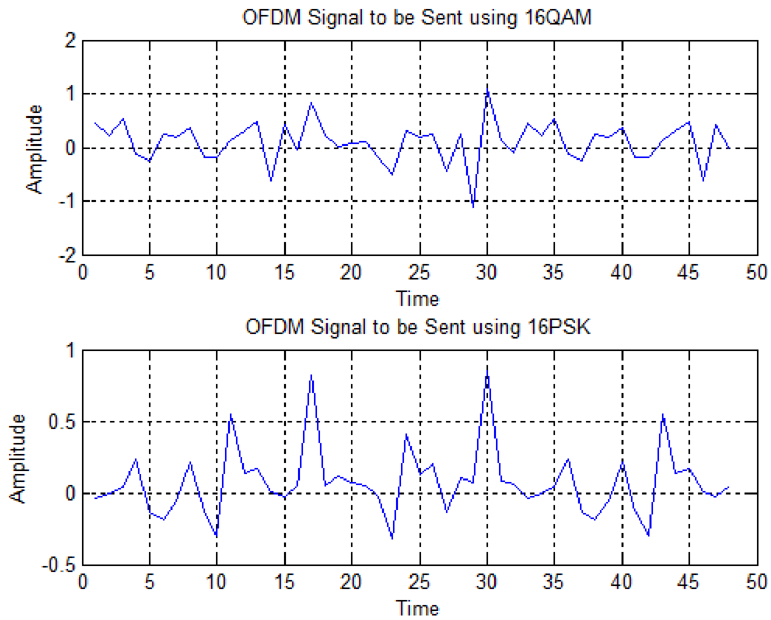

Fig. 22 16QAM and 16PSK OFDM Signal

We observed the results of our simulations and studied them deeply. We concluded that measures like "coding, interleaving and pilot insertion" to make the data more secure. They save the data from being effected by channel effects and other distortions during transmission. As discussed earlier it is more robust to noise, channel effects, ISI, etc. and it is proved from our simulations too.

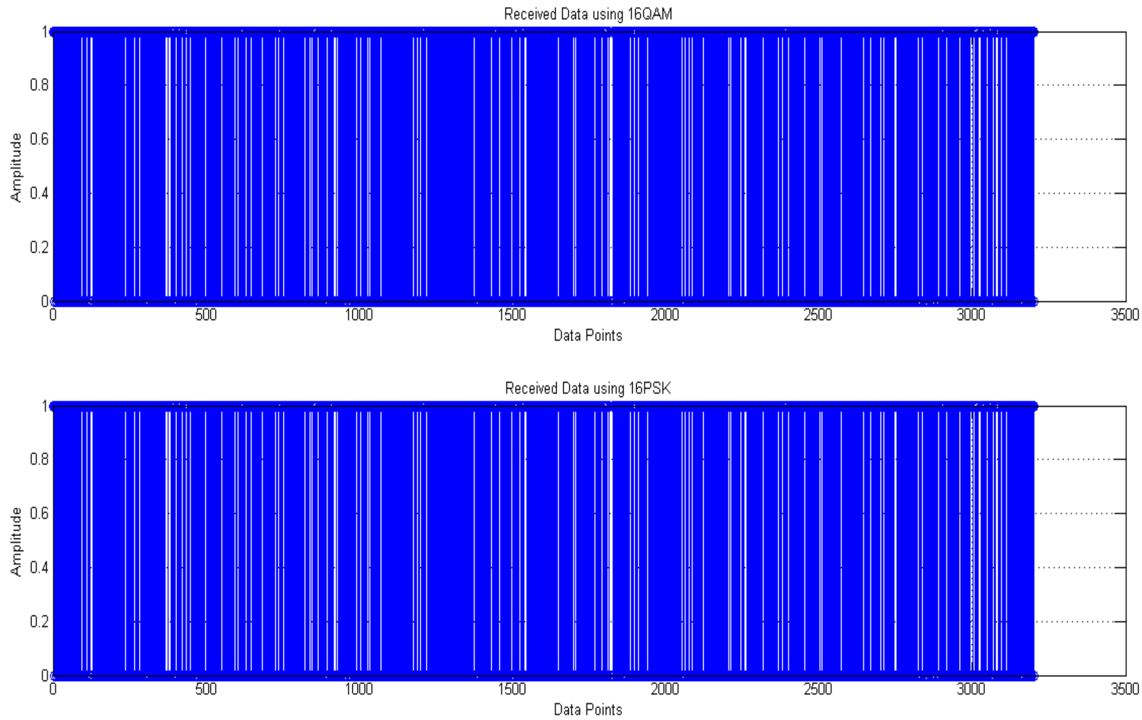

Fig. 23 16QAM and 16PSK Received Data

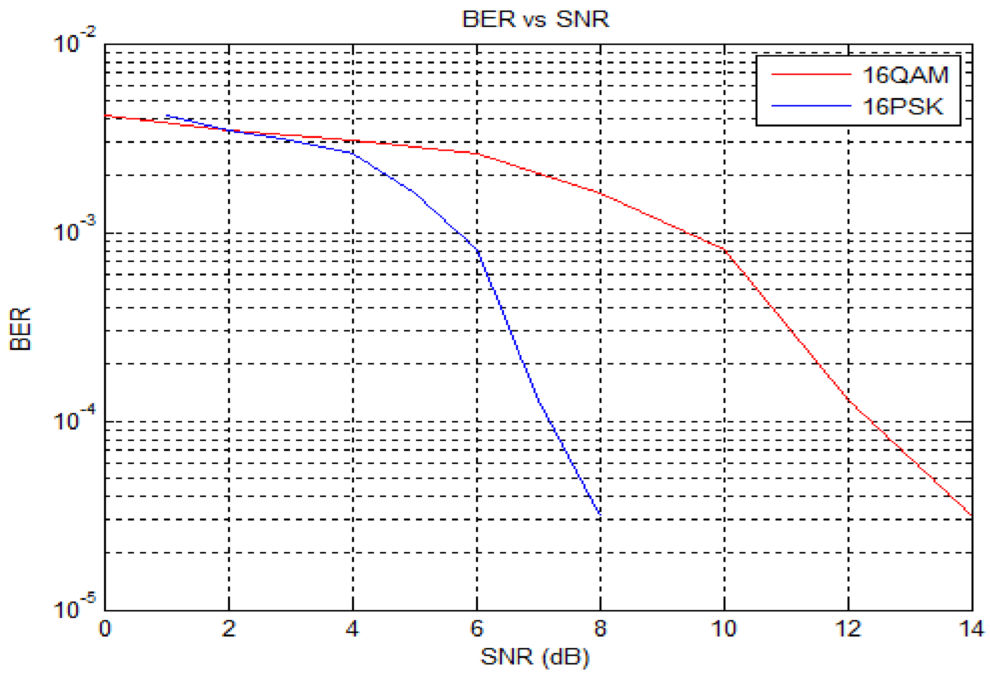

Fig. 24 BER vs. SNR of 16QAM and 16PSK

V. CONCLUSIONS

The aim of our research was to learn about the OFDM comprehensively and also understand the process of this modulation scheme along with transmission, reception and channel impacts. In order to achieve it, simulations of the whole process were performed in MATLAB and we can say that OFDM is more appropriate and capable for high capacity wireless systems.

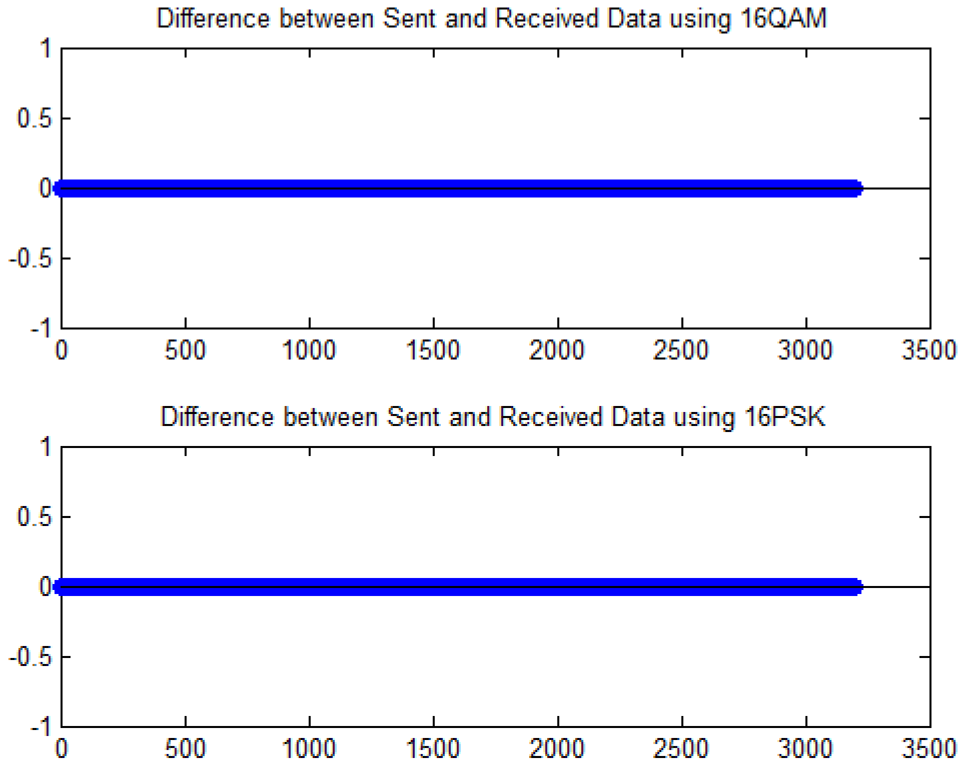

Fig. 25 Difference between 16QAM and 16PSK Sent and Received Data

Each and every step of the simulations was assessed. The Bit Error Rate (BER) was calculated for each simulation, which is vital for design a system based on any of the modulation techniques.

We were successful in the implementation of OFDM transceiver in MATLAB. Some improvements like equalization, multi-path effects, and the application of channel models other than AWGN can be made. It is very important technique and its use in 4th generation systems is going to revolutionize the telecom world in the near future.

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