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Research Article

Study and Analysis of OFDM under Rayleigh fading Channel using Various Modulation Methods

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is well recognized as a very efficient multicarrier technology. OFDM has witnessed a significant increase in its utilization within contemporary wideband digital communication systems. The technology possesses several notable benefits, including its capacity to effectively manage challenging channel circumstances, optimize spectrum utilization, mitigate inter symbol interference (ISI), and support high data transmission rates. Hence, it has been employed in several forthcoming wired and wireless communication systems, such as 4G LTE mobile communications. This work primarily concentrates on the performance assessment and investigation of the OFDM system in the presence of Rayleigh fading channels. By analyzing the outcomes of simulations, we may gain insights into various impacts and signal-to-noise ratios (SNRs). In order to determine their respective signal delivery capabilities, channels are compared and ranked. The evaluation of system performance involves assessing the quality of received signals, including factors like as signal quality, bit-error rates (BERs), and peak signal-to-noise ratios (PSNRs).

1. INTRODUCTION

The radio channel in mobile radio propagation is mostly determined by its multipath characteristics. The receiver receives the broadcast signal by several propagation channels, resulting in many reflections and occasionally a line-of-sight component. These distinct paths introduce variations in time delay and amplitudes. The received signal of Narrow-Band power exhibits significant fluctuations when analyzed in terms of spatial, temporal, and frequency variations. During the earlier stages of mobile systems, the primary focus of communications engineers was on narrowband channels with time-variability [1]. These channels were extensively investigated during that period because to the limited transmission bandwidths. As a result, the assumption of flat-fading was considered significant and justifiable. The increasing deployment of systems has led to a growing demand for greater transmission rates, hence highlighting the critical concern of temporal dispersion in the channel. In the context of modulations, information is sent by alterations in the frequency, phase, or amplitude of a carrier signal. Multiplexing pertains to the allocation of available bandwidth among several users, hence facilitating the distribution of available resources. Orthogonal Frequency Division Multiplexing (OFDM) is a hybrid technique that combines two distinct methods, namely modulation and multiplexing [2-3]. In the context of modulation techniques, the available bandwidth is divided among many sources of modulated data. Various standard modulation techniques, including Frequency Modulation (FM), Phase Modulation (PM), Amplitude Modulation (AM), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM), are examples of single carrier modulation techniques. These techniques include the modulation of information onto a single carrier signal. OFDM is a modulation technique that utilizes a significant number of carriers within a given bandwidth to transmit information from a source to a destination. Each carrier has the option to utilize one of the several digital modulation methods, such as Binary Phase Shift Keying (BPSK), QPSK, and QAM [4]. The issue of inter symbol interference (ISI) in single carrier communication systems is mitigated to a great extent by increasing the symbol duration beyond the time delay. Nevertheless, the utilization of extended symbol periods leads to a significantly reduced data flow, hence diminishing the efficiency of the communication system. Hence, the use of a single carrier for communication purposes is insufficient for achieving high-speed data transfer. The demand for broadband communications is experiencing a steady increase on a daily basis. Multicarrier communication is employed to address the growing demand [5]. Frequency division multiplexing (FDM) is a technology employed in

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telecommunications that involves the subdivision of the spectrum of a communication channel. This subdivision allows for the simultaneous transmission of data over numerous carriers, hence enabling parallel data transmission. Inter-carrier interference (ICI) is a potential issue that arises when carriers are tightly spaced in order to obtain a high data rate. The resolution of this issue is achieved by the implementation of guard bands between carriers, resulting in a reduction of the data rate as a compensatory measure [6]. OFDM is widely employed in many communication systems because to its capacity to achieve high data rates while mitigating the issues of inter-carrier interference (ICI) and inter-symbol interference (ISI) . Indeed, it is widely acknowledged as the prevailing mode of communication capable of effectively managing digital multimedia applications [7]. OFDM is widely recognized as a specific instance of Frequency Division Multiplexing (FDM) . A conceptual grasp of the distinction between Frequency Division Multiplexing (FDM) and Orthogonal Frequency Division Multiplexing (OFDM) channels may be likened to the analogy of water flow. Specifically, the water emanating from a tap represents the FDM channel, while the water originating from a shower symbolizes the OFDM signal. The reduction of ISI and multipath fading phenomena has been achieved by the utilization of parallel subcarriers and the transmission of data at a low rate. Orthogonal Frequency Division Multiplexing (OFDM) is widely employed in several applications, including wireless local area networks (WLAN), fourth generation communications (4G LTE), and digital audio broadcasting (DAB) [8].

This research primarily focuses on the investigation of OFDM performance through the analysis of system performance under Rayleigh fading channels. The performance OFDM is assessed by analyzing the bit-error rates (BERs) and signal-to-noise ratios (SNRs) in the presence of Rayleigh fading channels.

2. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

Orthogonal Frequency Division Multiplexing (OFDM) is a straightforward multicarrier modulation technology that finds extensive use in several domains. In comparison to the data conveyed by single carrier modulations, which has the ability to occupy the whole bandwidth, multicarrier modulation employs orthogonally flat and narrow subcarriers with distinct bandwidths inside the primary bandwidth of the channel. Consequently, a flat fading channel is produced for every subcarrier. In order to enhance the uniformity of the channel across each subcarrier and maintain orthogonality, it is necessary to append an exact replica of the final portion of a sample, known as the cyclic prefix (CP), to the end of each symbol[9-10]. The length of the cyclic prefix is denoted as Lcp. One of the primary benefits of OFDM is its ability to generate several data streams simultaneously by employing overlapping subcarriers. This characteristic enhances its efficiency compared to conventional techniques commonly employed in bandwidths. The orthogonality of the subcarriers is achieved by the use of the fast Fourier transform (FFT), hence mitigating interference. In order to achieve flat fading in Orthogonal Frequency Division Multiplexing (OFDM), a technique involves generating low-rate data streams on subcarriers has been proposed [11]. OFDM transmission is implemented in a sequential fashion, where each symbol is transmitted individually [12]. Hence, the OFDM baseband sign is mathematically represented as.

$$x(n) = \sum_{k=0}^{N-1} S_m e^{\frac{j2\Pi mn}{N}}$$

The variable "Sm" denotes the complex symbols broadcast at a certain subcarrier "m," which has resemblance to constellations used in quadrature amplitude modulation (QAM). The Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) algorithms are capable of performing this operation. In spite of the temporal dispersion characteristics exhibited by the channel, Orthogonal Frequency Division Multiplexing (OFDM) is able to preserve orthogonality due to the use of a straightforward channel equalization and estimation technique at the receiver. Nevertheless, OFDM exhibits many shortcomings due to the use of rectangular pulses. Consequently, the Fourier transform emerges as the inherent solution for pulse shaping [13]. In Orthogonal Frequency Division Multiplexing (OFDM) systems, the encoding of data is accomplished through the use of convolutional codes or other coding methods. These encoded data are then interleaved in the form of bit streams, with the objective of achieving variety. Subsequently, the grouped and mapped data is associated with the corresponding points in the constellation [14]. The data is organized in complex numbers and arranged in a sequential manner. Additionally, known pilot symbols are injected into the data stream to achieve modulation shown in Figure 1. Once the data has been processed by a serial-to-parallel converter, the parallel complex data undergoes the implementation of the Inverse Fast Fourier Transform (IFFT) method. The collected data is further organized into groups according to the required number of subcarriers. Nevertheless, the utilization of the OFDM technology for data modulation necessitates the insertion of a Cyclic Prefix (CP). The CP is included into each block of data in accordance with the system standards, and thereafter transmitted as the data modulated by OFDM [15]. The process of converting digital data into analogue signals is accomplished by a digital-to-analog converter, which operates inside the time domain. In addition, the OFDM signal is delivered at a specific frequency via a radio frequency modulator, thereby bypassing any impairments present in the wireless channel. The process of data transformation is repeated at the receiver through the utilization of an analog-to-digital converter, which is afterwards followed by symbol timing synchronization [16]. In the context of down conversion, it is necessary to take into account the frequency offset in order to successfully restore the carrier frequency.

Following the process of synchronization, the Orthogonal Frequency Division Multiplexing (OFDM) signal is subjected to demodulation using Fast Fourier Transform (FFT). The demodulated pilots are then utilized to conduct channel estimates, resulting in the acquisition of complex data. The acquired data from the transmission constellation diagram are subjected to demapping. The process of recovering the original bit stream that was broadcast involves de-interleaving and decoding, utilizing the forward error correction approach [17].

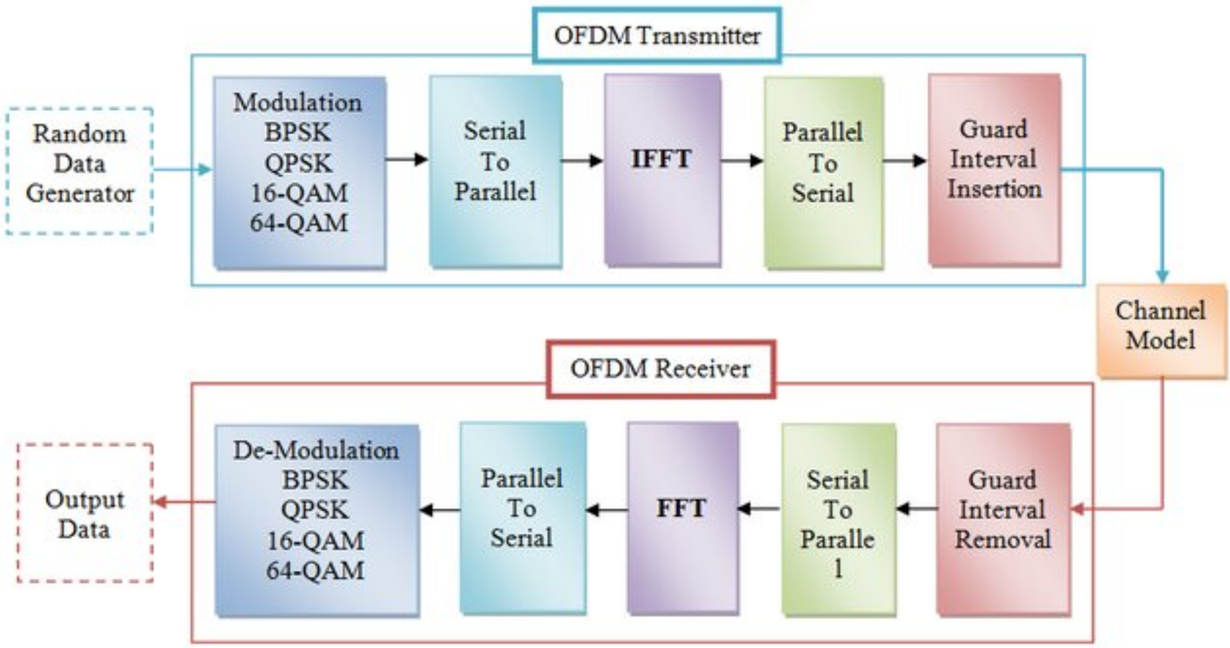

Fig. 1. OFDM scheme.

3. MULTIPATH FADING CHANNELS

The wireless environment exhibits a significant degree of instability, mostly attributed to the phenomenon of fading caused by multipath propagation. The phenomenon of multipath propagation gives rise to fast variations in both the phase and amplitude of the signal. The existence of reflectors within the vicinity of a transmitter and receiver gives rise to several propagation routes over which a sent signal might propagate [18]. Consequently, the recipient perceives the superimposition of several replicas of the transmitted signal, each following a distinct trajectory. During the transmission of each signal copy, several factors like as attenuation, delay, and phase shift will result in changes as the signal travels from the source to the receiver. The outcome of this phenomenon might lead to either constructive or destructive interference, either increasing or decreasing the signal strength observed by the receiver. Fading can manifest as either large-scale fading or small-scale fading. Small scale fading is categorized into two types based on the multipath time delay spread: flat fading and frequency selective fading. In the event that the bandwidth of the signal is less than the bandwidth of the channel and the delay spread is smaller than the relative symbol period, the phenomenon of flat fading is observed [19]. Conversely, if the bandwidth of the signal exceeds the bandwidth of the channel and the delay spread surpasses the relative symbol period, frequency selective fading is encountered. Based on the phenomenon of Doppler spread, small-scale fading can manifest as either rapid fading or slow fading. Slow fading is observed when the coherence time of the channel is greater in comparison to the delay limitation of the channel. The channel's amplitude and phase change can be approximated as being relatively consistent during the duration of its usage. Slow fading can arise due to occurrences such as shadowing, when a substantial object, such as a hill or sizable structure, obstructs the primary signal route connecting the transmitter and the receiver. Fast fading is observed when the coherence time of the channel is comparatively short in relation to the delay limitation of the channel. The channel exhibits significant variations in both amplitude and phase changes over its operational duration. In a rapidly deteriorating channel, the transmitter can exploit the fluctuations in channel conditions by employing temporal diversity, hence enhancing the resilience of the transmission [20]. The Rayleigh fading model incorporates the phenomenon of fading resulting from the reception of multipath signals. The Rayleigh fading model postulates that the amplitude of a signal, after traversing a transmission medium, would undergo random variations, commonly referred to as fading, which can be characterized by a Rayleigh distribution. The Rayleigh fading model is a suitable representation in scenarios where several objects within the environment cause scattering of the radio signal prior to its reception by the receiver. The phenomenon of Rayleigh fading is particularly relevant in scenarios when there is an absence of a prominent direct path for signal transmission between the transmitting and receiving entities [21]. The Rayleigh fading model is a suitable representation in scenarios where several objects within the environment cause scattering of the radio signal prior to its reception by the receiver. The central limit theorem posits that, under conditions of significant dispersion, the channel impulse response may be accurately represented as a Gaussian process, regardless of the distribution of the individual components. In the absence of a prevailing component in the scatter, the aforementioned process will have a mean value of zero and a uniform distribution of phase angles ranging from 0 to 2π radians. Consequently, the probability distribution of the envelope of the channel response will exhibit a Rayleigh distribution [22-23]. The Rayleigh fading model is employed to represent the amplitude of a carrier wave in situations where there is no line-of-sight (LOS) connection between the transmitter and the receiver. The probability density function (PDF) that characterizes the amplitude gain of a channel in Rayleigh fading is determined from empirical observations and is represented by an experimental distribution. Refer to equation 1.

$$P_a(a) = \frac{2a}{\Delta} e^{\frac{-a^2}{\Delta}} ; a \geq 0 \tag{1}$$

The distribution of phase is uniform and may be expressed as in equation 2.

$$P_a(a) = \begin{cases} \frac{1}{2\Pi} ; -\Pi < \phi < \Pi \\ 0; \quad otherwise \end{cases} \tag{2}$$

BER of BPSK Modulation in Rayleigh Fading Channel: In the context of Rayleigh fading channels, the random variable 'a' follows a Rayleigh distribution, whereas the random variable a^2 is characterized by a chi-square distribution with two degrees of freedom. Therefore equation 3 will be:

$$P_{df}(a) = \frac{1}{a} e^{\frac{-a}{b}} \tag{3}$$

Where b is the average SNR, $b = \frac{E_b}{N_o} E\left[a^2\right]$ (4)

$E\left[a^2\right] = 1$ The b represents to the average SNR for the fading channel. Refer to equation 5.

$$BER_{BPSK,Ray} = \frac{\left[1 - \sqrt{\frac{b}{1+b}}\right]}{2} \tag{5}$$

BER Performance of BFSK in Rayleigh Fading Channels: In the BPSK modulation scheme, the receiver utilizes a coherent phase reference in order to demodulate the received signal. However, there are certain applications that employ non-coherent formats, which do not rely on a phase reference [24]. The format characterized by a lack of coherence is commonly referred to as binary frequency-shift keying (BFSK). An analytical equation for slow flat Rayleigh fading channels with non-coherent binary frequency shift keying (BFSK) modulation. Refer to equation 6.

$$Pdf_{BPSK,Ray} = \frac{1}{2+b} \tag{6}$$

4. SIMULATION RESULTS

The MATLAB simulation tool is utilized for the implementation. The project has been successfully executed, whereby a comparative analysis of various modulation schemes in the Rayleigh fading Channel has been conducted utilizing OFDM. The efficiency of the system is evaluated by examining the performance of various modulation schemes when applied to the Rayleigh Fading Channel within the framework of OFDM. The simulation results demonstrate the performance of the BER. Table 1 displays the representation of the simulation settings.

TABLE I. SIMULATION PARAMETERS

Simulation Parameters	Values
subcarriers	128
cyclic prefix	32
bit errors	100
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	Rayleigh Channel

The performance of the OFDM system under various QAM orders is depicted in Figure 2. The simulation was conducted to analyze the Rayleigh Fading Channel model, employing a range of signal-to-noise ratios from 0 to 35 dB. The modulation schemes employed in the simulation were QAM with orders of 16, 64, and 256. Based on the findings of the simulation, it is recommended to utilize lower order QAM schemes over higher order QAM schemes in order to enhance the BER performance.

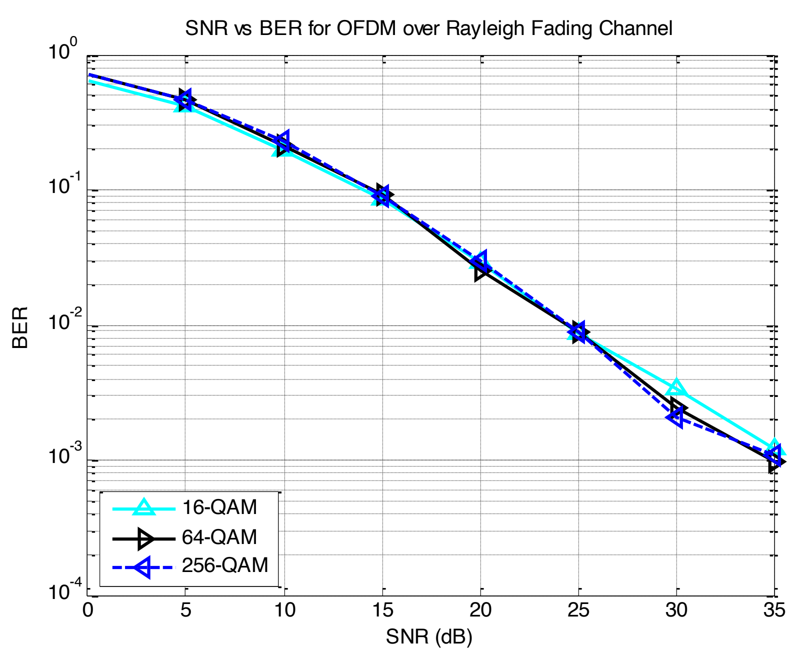

Fig. 2. BER performance of various QAM over Rayleigh Fading Channel

The performance of bit error rate (BER) for different modulation signals across a Rayleigh fading channel is illustrated in Figure 3 and Figure 4. The effectiveness of the system is seen when different modulation methods are applied to the Rayleigh Fading Channel inside the framework of Orthogonal Frequency Division Multiplexing (OFDM). Efficiency is attributed to the system that exhibits the smallest bit error rate, especially in scenarios characterized by low signal-to-noise ratios. The results indicate that at a bit error rate complementary cumulative distribution function (CCDF) of 10^{-2}, the signal-to-noise ratio (SNR) values for BPSK, DBPSK, QPSK, DQPSK, 8PSK, and 8DPSK are 19.1dB, 23.4dB, 26dB, 27.2dB, 31.5dB, and 33.9dB, respectively. The Binary Phase Shift Keying (BPSK) modulation scheme exhibits superior performance.

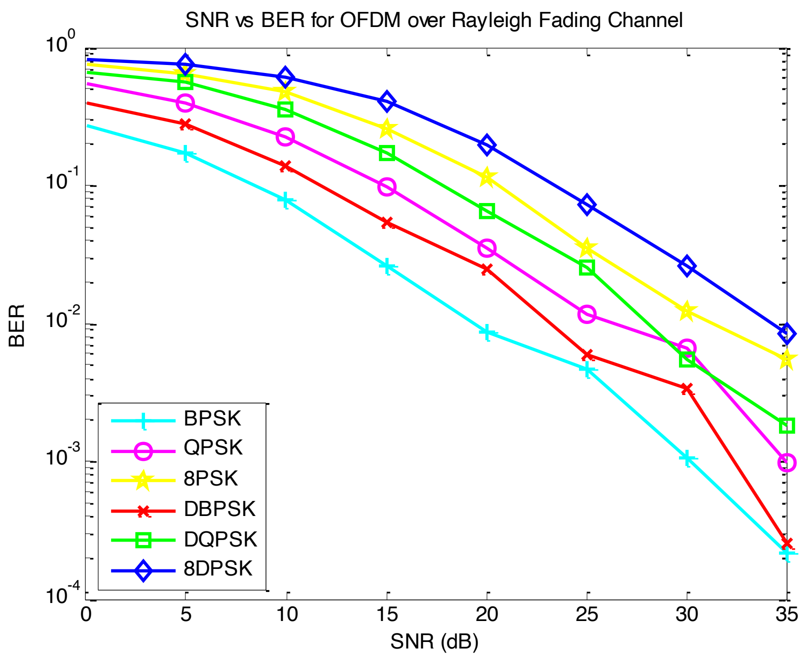

Fig. 3. BER performance of various PSK over Rayleigh Fading Channel

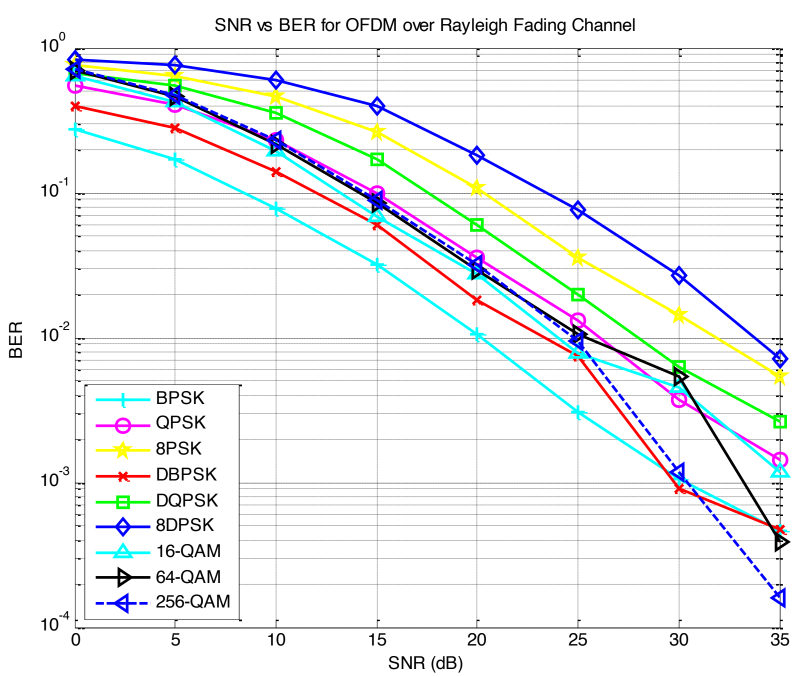

Fig. 4. BER performance of various modulation methods over Rayleigh Fading Channel

Figure 5 displays the power spectrum densities of Orthogonal Frequency Division Multiplexing (OFDM). Orthogonal Frequency Division Multiplexing (OFDM) exhibits a significant expansion in its sideband width. Figure 6 and Figure 7 depict the frequency spectrum of the original OFDM and OFDM baseband signal, respectively. In both figures, it can be observed that there is a presence of zero padding in the center.

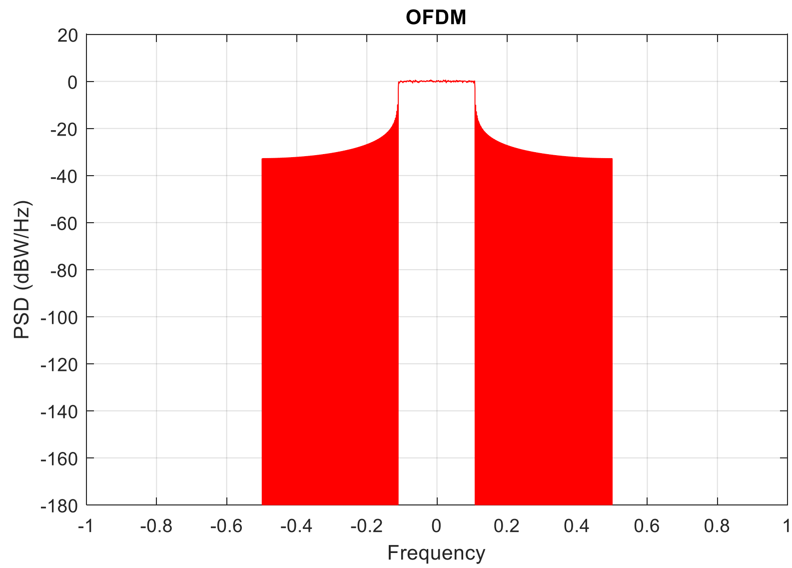

Fig. 5. PSD of OFDM

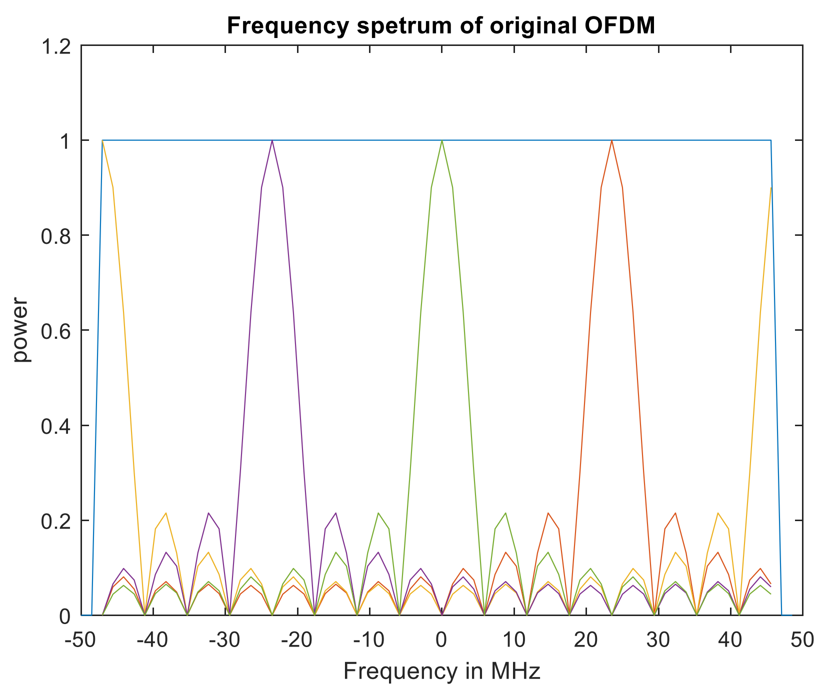

Fig. 6. Original OFDM - Spectrum

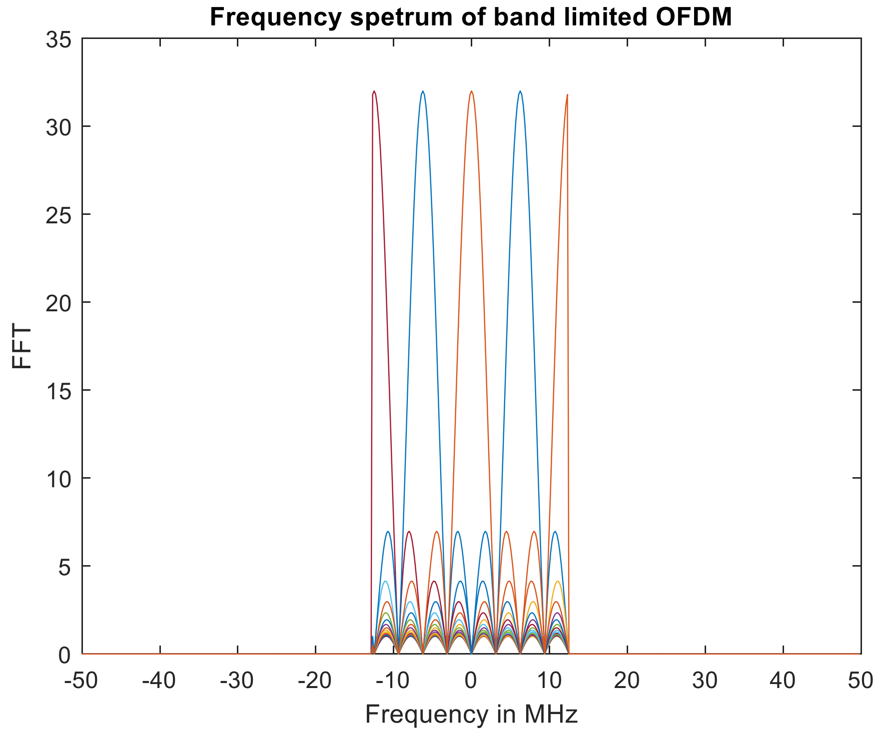

Fig. 7. OFDM baseband signal -Spectrum

5. CONCLUSION

Orthogonal Frequency Division Multiplexing (OFDM) systems have demonstrated remarkable efficiency in effectively managing and accommodating enormous data rates. Fading channels are a common phenomenon in wireless communications. Signal losses during transmission can have a significant influence on the process of signal reception. This project does a performance study of many modulation schemes in the Rayleigh Fading Channel for an OFDM system. The utilization of a graphical representation of the Bit Error Rate (BER) as a function of Signal to Noise Ratio (SNR) facilitated the assessment of the efficacy of modulation schemes in terms of their accuracy and dependability.

Conflicts Of Interest

The author declares no conflicts of interest with regard to the subject matter or findings of the research.

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