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Performance Analysis of OFDM under Rician Fading Channel using Various Digital Modulation Methods

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Abstract:** The widespread use of mobile platforms has resulted in significant challenges related to power constraints and the Quality of Service(QoS) provided by Orthogonal Frequency Division Multiplexing (OFDM) systems. The examination of Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR) is of significant importance in comprehending and enhancing the design of OFDM systems. The utilization of wireless technology in everyday life has experienced a gradual and consistent growth. OFDM is a prevalent technique for multicarrier transmission, which effectively utilizes parallel data streams. OFDM is considered an effective technique for achieving high-speed digital transmission over channels that exhibit time-varying characteristics. OFDM has several advantages compared to single carrier modulation. These include enhanced resistance to impulsive interference, increased spectral density, improved resilience to channel fading, greater tolerance to multipath effects, and reduced computational complexity. Nevertheless, OFDM has some notable challenges that hinder its practical use in telecommunications networks. Several examples of these are packet loss, bit loss, peak-to-average power ratio (PAPR), BER, and SNR. This research aims to investigate the BER and SNR performance of OFDM in the presence of Rician Fading Channel. The study also explores the impact of different modulation techniques on the performance of OFDM.

***Keywords:** BER, Fading, OFDM, PSK, QAM, Rician Channel.*

1. INTRODUCTION

Wireless communication networks have garnered significant attention in academic study over the past few decades. The quick expansion of their popularity has led to the provision of high-speed multimedia services to an exponentially rising number of linked devices.

Therefore, it is imperative to develop novel solutions that can effectively address the increasing traffic needs and accommodate high-speed data rates. The wireless channel poses a significant challenge in the design of effective communication systems due to its inherent characteristic of random fluctuations in the received signal. Various strategies have been presented with the aim of mitigating the adverse attributes associated with a wireless channel [1-2]. Diversity approaches and cooperative relaying have garnered significant attention in the realm of wireless and mobile networks due to their potential to enhance system performance in several aspects like as throughput, diversity, energy efficiency, and cost-effective expansion of coverage. The conventional implementation of macrocell base stations is inadequate in delivering satisfactory QoS, coverage, and capacity for users located inside and at the periphery of cellular networks. This limitation is particularly pronounced when considering the possible utilization of high carrier frequencies in the context of 5G technology [3]. Hence, the tiny cell idea is accorded significant emphasis in 5G mobile networks. The primary advantages of small cell technology are its affordability, energy efficiency, ability to expand the core network, particularly in densely populated urban and indoor regions, enhanced capacity for users in heavily congested macrocells, and better network coverage and data transfer rates in places where buildings provide obstacles [4].

The OFDM transmission technique exhibits potential as a viable option for forthcoming broadband radio systems. The transmission technique mentioned is presently implemented in the widely recognized IEEE 802.16a/d standard [5]. The performance of the system is primarily determined by the integration of dynamic sub-carrier allocation, transmission power allocation, and adaptive modulation. Numerous communication systems need an understanding of the SNR, with efficient signal recognition and connection adaptability being notable illustrations. The SNR is a widely employed metric for assessing the efficacy of a communication channel. In a more precise manner, understanding SNR allows wireless systems to enhance the prediction of propagation channels and serves as a crucial factor in making decisions for adaptive processes including dynamic reconfiguration of cognitive radios, adaptive modulation and coding (AMC), and adaptive power allocation. Frequency division multiplexing (FDM) is an advanced technique that builds upon the principle of single carrier modulation, enabling the use of many subcarriers inside a single channel. The allocation of the overall data rate for transmission inside the channel is distributed across many subcarriers [6]. The baseband signal of OFDM is composed of several orthogonal sub-carriers. Each sub-carrier is modulated individually, utilizing techniques such as Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK), to transmit its own data. Orthogonality enables the concurrent transmission of many sub-carriers within a confined frequency spectrum, ensuring little interference between them. Consequently, they possess the capacity to coexist without causing any disruption. Consequently, OFDM systems provide the capability to optimize spectral efficiency while mitigating the occurrence of neighbouring channel interference [7]. Binary Phase Shift Keying (BPSK) is the most elementary kind of PSK, wherein a digital signal oscillates between two distinct values, namely +1 and -1. This alternating pattern induces phase reversals, characterized by 180^o phase shifts, when the data undergoes state transitions. Quadrature Phase Shift Keying (QPSK) is a digital modulation scheme that In scenarios where enhanced spectral efficiency is desired, higher order modulation methods, such as QPSK, are frequently favoured over BPSK [8]. QPSK use a constellation diagram consisting of four distinct locations. The QPSK modulation scheme consists of four distinct phases, enabling the encoding of two bits per signal. QAM is a modulation scheme that combines both amplitude modulation and QPSK. The proposed approach combines elements of phase modulation and amplitude modulation. QAM is a modulation technique that simultaneously modifies the phase and amplitude of the carrier signal [9-10].

Fading and interference are the primary challenges faced by mobile/wireless communications. The simulation and modeling of communication systems in the presence of fading channels are crucial for enhancing and evaluating the system's ability to withstand fading, with the ultimate goal of achieving optimal performance. Fading channels exhibit a range of properties that are contingent upon the specific propagation environment. Hence, it is imperative to develop appropriate fading models that are grounded in the communication environment [11]. SNR and bit BER are frequently employed as metrics for evaluating the efficacy of communication. The SNR quantifies the level of noise relative to the signal. The use of SNR holds potential for predicting the system's performance in relation to reception accuracy. In the BER analysis, a digital bit is determined to be erroneous or not using a straightforward binary comparison. Contemporary communication systems evaluate their performance by comparing the BER to the SNR [12]. The most often employed fading models in wireless communication include AWGN, Rayleigh fading, and Rician fading. This research aims to examine several modulation methods to assess their performance when utilized in these channels.

System Model

OFDM is a digital modulation technique that employs multiple subcarriers inside a single channel, therefore expanding upon the principle of single subcarrier modulation. In contrast to the transmission of a high-rate data stream using a single subcarrier, OFDM employs a multitude of closely spaced orthogonal subcarriers that are concurrently broadcast [13-14]. Conventional digital modulation schemes, such as QPSK and 16-QAM, are employed to modulate each subcarrier at a low symbol rate. Nevertheless, the use of multiple subcarriers allows for data rates that are comparable to those achieved by traditional single-carrier modulation systems operating within the same bandwidth. OFDM is a modulation scheme that is derived from the widely recognized method of FDM. FDM is a technique that involves the mapping of several streams of information into distinct parallel frequency channels. In order to mitigate interference between neighbouring channels, a frequency guard band is implemented to isolate each FDM channel from one another [25-26].

The figure 1 depicts the fundamental principles of an OFDM signal and the interconnectedness between the frequency and time domains. In the context of the frequency domain, it is common practice to individually modulate complicated data into numerous neighbouring tones or subcarriers. The OFDM symbol in the time-domain is generated by applying an Inverse Fast Fourier Transform (IFFT) on the frequency-domain subcarriers [15]. In the temporal domain, the insertion of guard intervals between symbols serves the purpose of mitigating inter-symbol interference at the receiver, which arises due to the presence of multi-path delay spread in the radio channel. The final OFDM burst signal is formed by concatenating several symbols. The receiver does a Fast Fourier Transform (FFT) operation on the OFDM symbols in order to retrieve the initial data bits [16].

In order to demonstrate the fundamental concepts of creating an OFDM signal, a straightforward analog-based solution will be employed. In the context of this elementary OFDM system, a set of N sinusoidal input signals is present. The transmission of information is achieved by assigning each subcarrier to represent a single bit of data, resulting in a total of N bits. This is determined by the presence or absence of the subcarrier in the output spectrum [17]. The selection of the frequency for each subcarrier is done in order to create a collection of orthogonal signals. The receiver possesses knowledge of these frequencies for the purpose of signal recovery. It should be noted that the output undergoes updates at regular intervals denoted as T, which represents the symbol period. In order to preserve orthogonality, it is necessary for T to be the reciprocal of the subcarrier spacing.

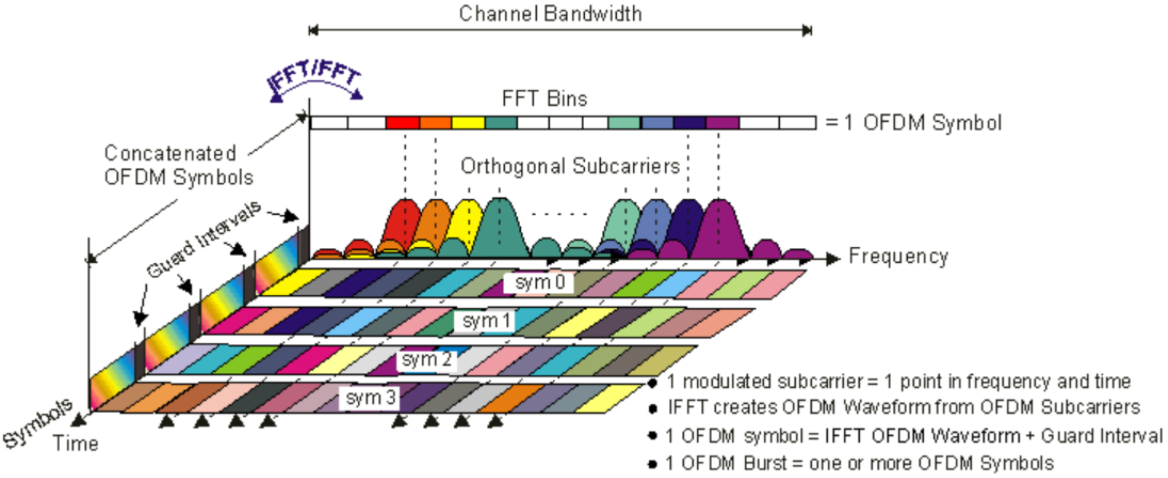

Figure 1. Time - frequency representation of OFDM signal

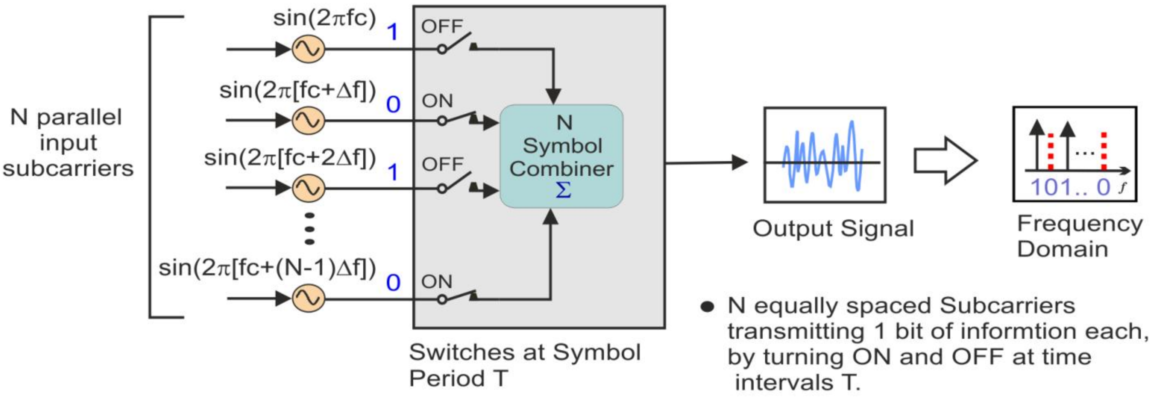

Figure 2. OFDM generation

The principles employed in the straightforward analogue OFDM implementation may be expanded to the digital realm through the utilization of a mix of FFT and IFFT techniques in digital signal processing [18]. The significance of these transformations lies in their relevance to OFDM, since they serve the purpose of transferring digitally modulated input data (data symbols) onto orthogonal subcarriers. The IFFT is a mathematical operation that transforms frequency-domain input data, represented by complex numbers corresponding to modulated subcarriers, into time-domain output data, which is an analogue OFDM symbol waveform [19].

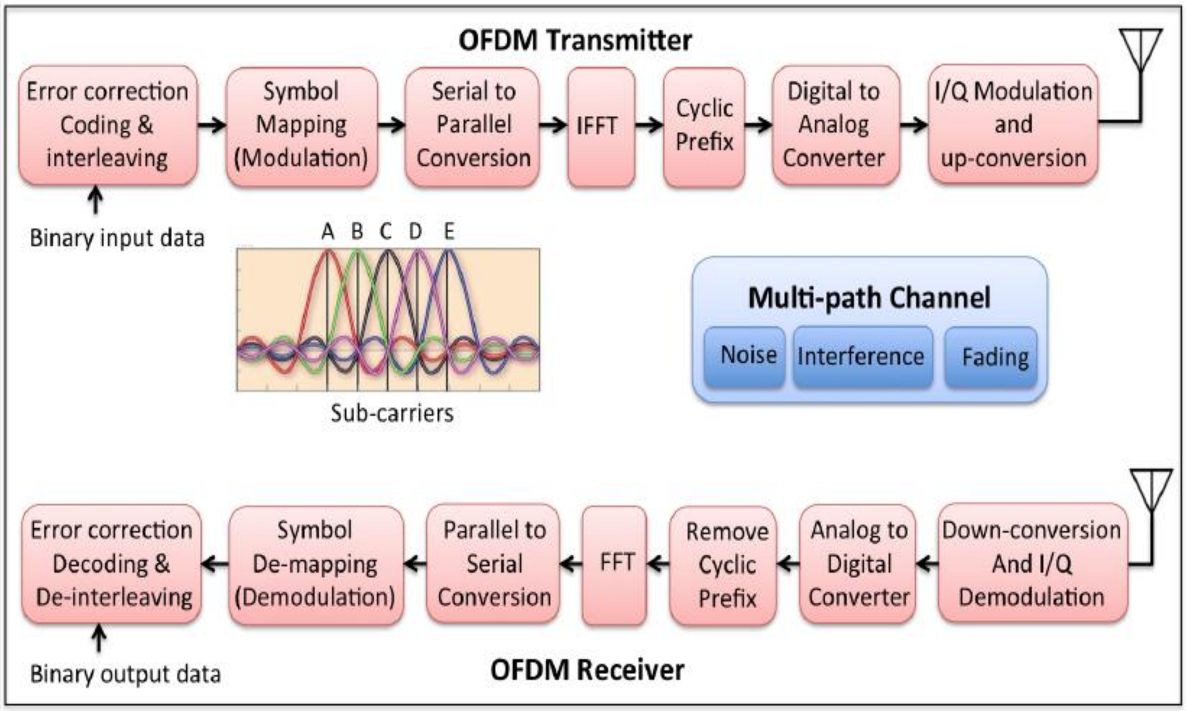

Figure 3. OFDM block diagram

In a digitally implemented OFDM system, the input bits are organized into groups and assigned to source data symbols, which are complex numbers that indicate the modulation constellation point. These symbols correspond to the BPSK or QAM symbols often seen in a single subcarrier system. The transmitter processes the intricate source symbols as though they exist in the frequency-domain. These symbols serve as inputs to an IFFT block, which converts the data into the time-domain. The IFFT is a mathematical operation that processes a set of N source symbols simultaneously, where N represents the total number of subcarriers inside the given system. Each of the N input symbols is characterized by a symbol period of T seconds. It is important to note that the result of the IFFT consists of N orthogonal sinusoids. Each of these sinusoids that are orthogonal to each other have a distinct frequency, with the lowest frequency being direct current (DC). The input symbols consist of complex values that indicate the mapped constellation point. These values determine both the amplitude and phase of the sinusoid associated with the respective subcarrier [20]. The output of the IFFT is obtained by summing all N sinusoidal components. Therefore, the IFFT block

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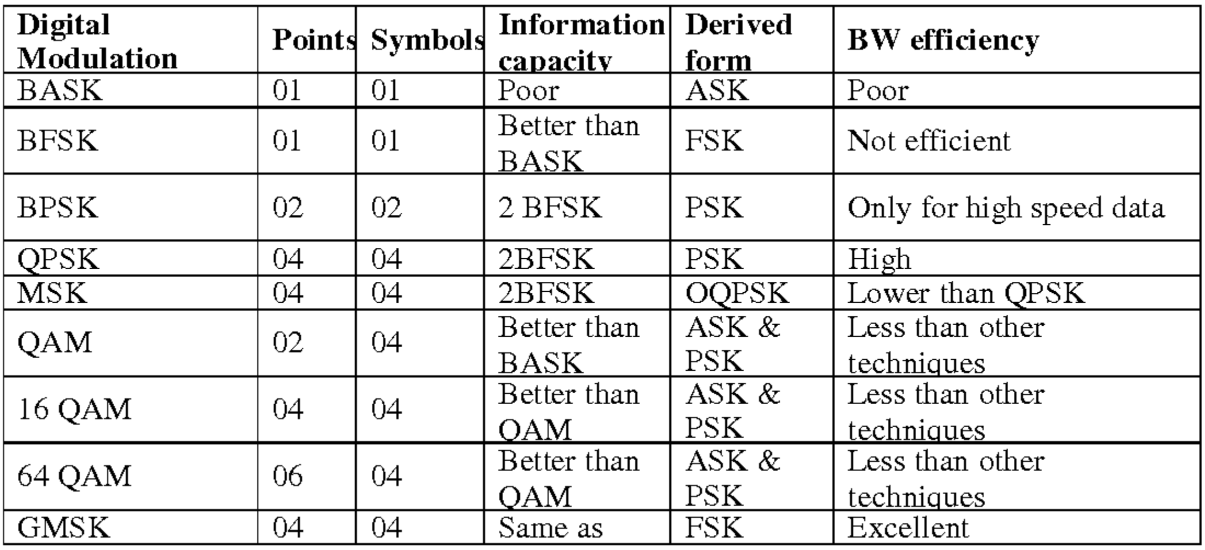
offers a straightforward method for modulating data onto N orthogonal subcarriers. A singular OFDM symbol is composed of a collection of N output samples obtained by the IFFT. Following further processing, the time-domain signal obtained from the IFFT is sent across the radio channel. The received signal is processed at the receiver using an FFT block in order to transform it into the frequency domain, facilitating the recovery of the original data bits [21].

Channel Model & Modulation Techniques

A fading channel refers to a wireless communication channel wherein the signal quality experiences variations over time as a result of fluctuations in the transmission environment. Various variables, including distance, obstructions, and interference, might give rise to these alterations, leading to attenuation and phase shifting. Signal fluctuations have the potential to induce mistakes or result in the loss of information during the process of transmission. Fading channels can be classified into two categories, namely slow fading and fast fading, based on the speed at which the channel characteristics change. Slow fading is a phenomenon that transpires gradually over extended durations, whereas fast fading manifests swiftly during brief time intervals, sometimes attributable to the presence of multipath interference. In order to mitigate the adverse consequences of fading, a range of strategies are employed, encompassing diversity methods, equalization, and channel coding [22].



Digital Modulation	Points	Symbols	Information capacity	Derived form	BW efficiency
BASK	01	01	Poor	ASK	Poor
BFSK	01	01	Better than BASK	FSK	Not efficient
BPSK	02	02	2 BFSK	PSK	Only for high speed data
QPSK	04	04	2BFSK	PSK	High
MSK	04	04	2BFSK	OQPSK	Lower than QPSK
QAM	02	04	Better than BASK	ASK & PSK	Less than other techniques
16 QAM	04	04	Better than QAM	ASK & PSK	Less than other techniques
64 QAM	06	04	Better than QAM	ASK & PSK	Less than other techniques
GMSK	04	04	Same as	FSK	Excellent

Figure 4. Comparison of various digital modulation methods

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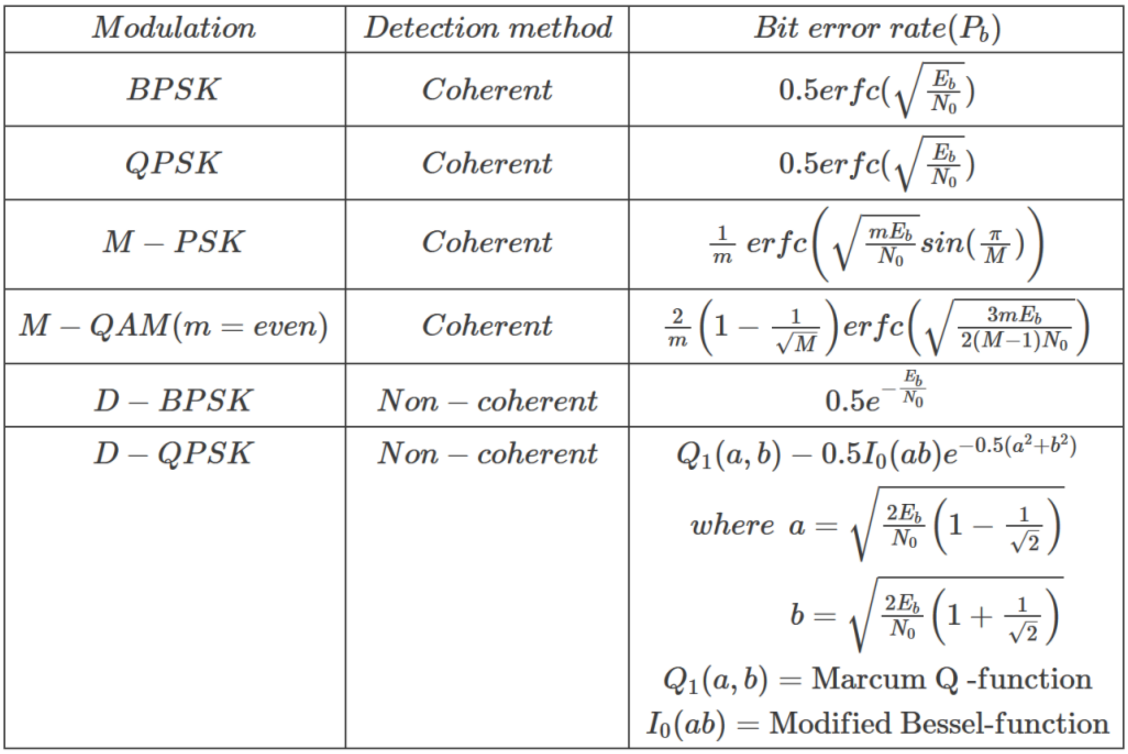

$Modulation$	$Detection\ method$	$Bit\ error\ rate(P_b)$
$BPSK$	$Coherent$	$0.5erfc(\sqrt{\frac{E_b}{N_0}})$
$QPSK$	$Coherent$	$0.5erfc(\sqrt{\frac{E_b}{N_0}})$
$M-PSK$	$Coherent$	$\frac{1}{m}\,erfc\left(\sqrt{\frac{mE_b}{N_0}}sin(\frac{\pi}{M})\right)$
$M-QAM(m=even)$	$Coherent$	$\frac{2}{m}\left(1-\frac{1}{\sqrt{M}}\right)erfc\left(\sqrt{\frac{3mE_b}{2(M-1)N_0}}\right)$
$D-BPSK$	$Non-coherent$	$0.5e^{-\frac{E_b}{N_0}}$
$D-QPSK$	$Non-coherent$	$Q_1(a,b)-0.5I_0(ab)e^{-0.5(a^2+b^2)}$ $where\ \ a=\sqrt{\frac{2E_b}{N_0}\left(1-\frac{1}{\sqrt{2}}\right)}$ $b=\sqrt{\frac{2E_b}{N_0}\left(1+\frac{1}{\sqrt{2}}\right)}$ $Q_1(a,b)=$ Marcum Q -function $I_0(ab)=$ Modified Bessel-function

Figure 5. BER for various modulation methods

In terms of their frequency domain properties, fading channels can be categorized as either frequency selective or frequency-flat fading. A frequency flat fading channel refers to a wireless communication channel characterized by consistent attenuation and phase shift of the signal over the entirety of the frequency spectrum. This implies that the signal encounters uniform fading across all frequencies, hence eliminating any frequency-dependent signal distortion. On the other hand, a frequency selective fading channel refers to a wireless communication channel characterized by variations in signal attenuation and phase shift across different frequencies. This phenomenon entails the signal undergoing varying degrees of fading across different frequencies, leading to a distortion of the signal that is contingent upon frequency [23]. Frequency selective fading can manifest as a result of several reasons, including the interference caused by multipath propagation and the existence of objects that selectively scatter or absorb specific frequencies to a greater extent than others. In order to address the impact of frequency selective fading, a range of strategies can be employed, including equalization and frequency hopping. The phenomenon of channel fading may be represented using several statistical models, such as Rayleigh, Rician, and Nakagami fading. In this part, the fading channel models are employed to produce simulated performance results for different modulations over Rician flat fading channels.

Rician fading is a probabilistic framework utilized to describe irregularities in radio wave propagation resulting from the partial interference of a radio signal with itself. This interference occurs due to the reception of the signal through multiple paths, leading to the phenomenon of multipath interference [24]. Notably, at least one of these paths undergoes dynamic changes, either by increasing or decreasing in length. Rician fading is observed when there exists a significant disparity in signal strength between one of the propagation channels, often associated with a direct line of sight or prominent reflection, and the other paths [25]. The Rician fading phenomenon is associated with a probability distribution that characterizes the amplitude gain. Rayleigh fading is occasionally seen as a specific instance of Rician fading, when the absence of a line of sight signal is assumed. In the scenario described, the Rician distribution, which characterizes the amplitude gain in the presence of Rician fading, simplifies to a Rayleigh distribution. Rician fading may be considered as a specific instance of fading known as two-wave with diffuse power (TWDP) fading [25-26].

2. RESULTS

The MATLAB simulation tool is utilized for the implementation. A comparison of various modulation methods are conducted on the Rician channel utilizing OFDM. The effectiveness of various modulation techniques applied to the Rician channel under OFDM has been observed. The simulation results demonstrate the performance of the Bit Error Rate (BER). The parameters utilized in the simulation are presented in Table 1.

Figure 6 represents the BER performance of various QAM over Rician Fading Channel. As the QAM value decreases, the BER gives better performance. At a CCDF of 10^{-5}, the SNR values are 20dB, 26.2dB and 34.3dB for 16-QAM, 64-QAM and 256-QAM, respectively. The 16-QAM gives lower BER values compared to 64 and 256-QAM.

The BER performance of various PSK modulations over Rician Fading Channel is shown in figure 7. From the results the BPSK provides better BER performance. For the modulation techniques BPSK, DBPSK, QPSK, DQPSK, 8PSK and 8DPSK the SNR values are 22.3dB, 27dB, 30.6dB, 32.9dB, 35dB and 38dB respectively at a CCDF=10^{-3}.

Table 1. Simulation Parameters

Simulation Parameters	**Values**
No. of subcarriers	256
cyclic prefix	32
Max. No. of bit errors	100
Max. No. of bits transmitted	1e7
Modulation alphabet (M)	2, 4, 8
Bits/symbol (K)	1, 2, 3
FFT size	512
No. of data subcarriers	64
No. of OFDM symbols	10^4
Channel model	Rician Channel

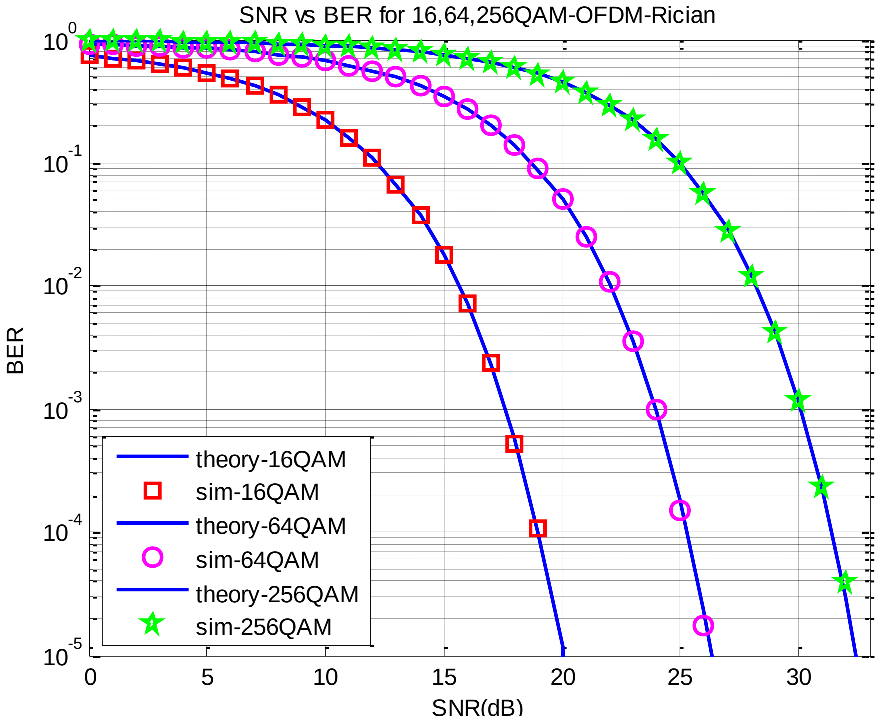

Figure 6: BER performance of various QAM over Rician Fading Channel

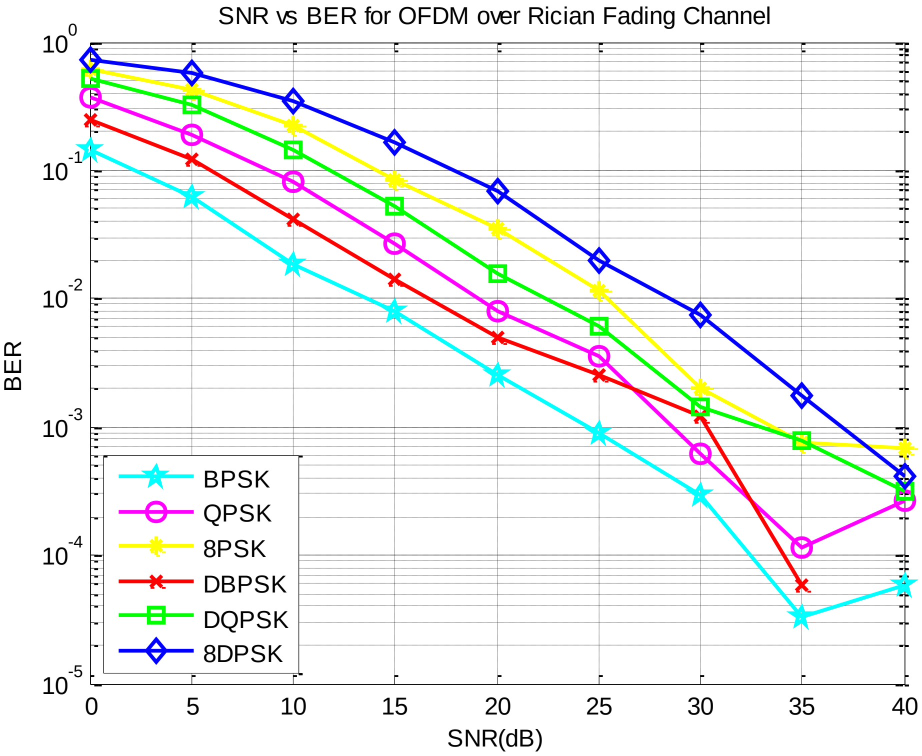

Figure 7: BER performance of various PSK modulations over Rician Fading Channel

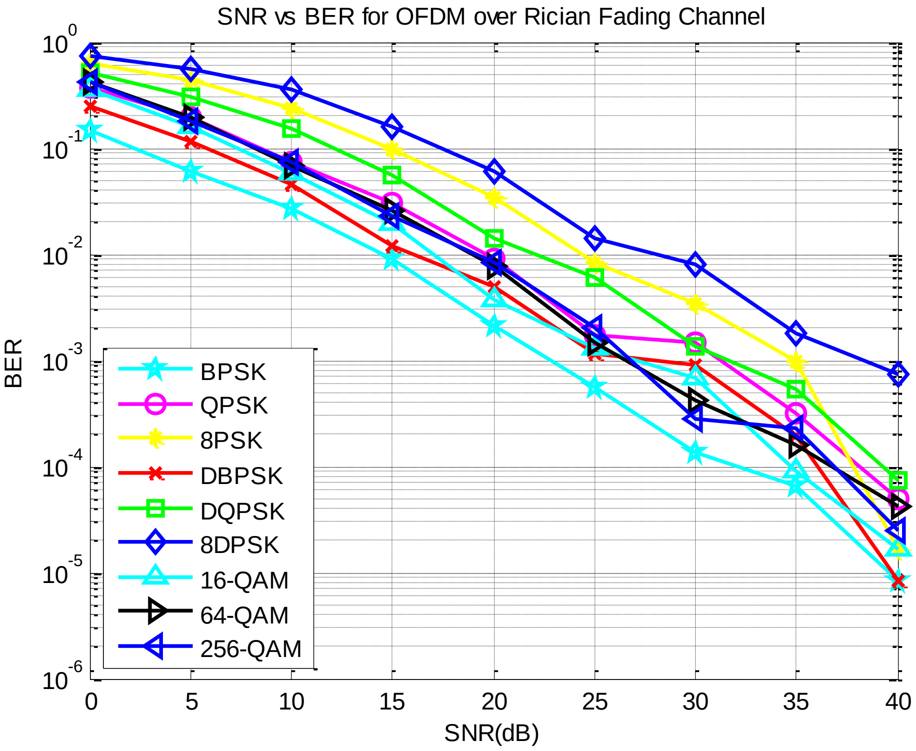

Figure 8: BER performance of various modulations over Rician Fading Channel

3. CONCLUSION

This study investigates several digital modulation schemes, specifically focusing on their performance in Rician fading channel. OFDM systems are capable of effectively managing high data rates. Fading channels are a common phenomenon in wireless communications. Signal losses during transmission can have an influence on the process of signal reception. This research study implements a performance evaluation of several modulation methods in the Rician channel for an OFDM system. The utilization of a graph to depict the Bit Error Rate (BER) as a function of Signal-to-Noise Ratio (SNR) in a certain modulation scheme facilitated the evaluation of the efficacy of the employed modulation techniques in relation to their precision and dependability.

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