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Analysis the Performance of OFDM for Different Modulation Techniques with Channels and Image Transmission

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Abstract **– Wireless applications throughput, reliability, and bandwidth needs have grown in recent years. OFDM improves spectrum efficiency, data capacity, and fading resistance. OFDM is used in 3G GSM, WiMAX, and LTE. The OFDM system splits the input data stream into several lower-rate streams, which are concurrently transmitted on orthogonal subcarriers to eliminate Inter Symbol Interference (ISI). This paper's objective is to assess the OFDM system's performance by employing different modulation and channeling methods. Then, after analyzing the performance, we determined the optimal channel for an OFDM communication system. The final step is to transmit an image through the most optimal channel using various modulation techniques. Multiple channels, including AWGN, Rayleigh, and Rician, were utilized over an OFDM system, and M-PSK and M-QAM modulation techniques are used in both OFDM and image transmission. All simulation results are performed in the MATLAB toolbox 2019a.**

Keywords- OFDM, M-PSK, M-QAM, AWGN, BER, SNR

I. INTRODUCTION

In modern communication, there is a need for high-speed data transmission, not just for speech and control data but also for real-time images. To prevent inter-symbol interference (ISI), it is necessary for the symbol duration to surpass the delay time [1]. Long symbol periods reduce the data rate, resulting in inefficient communication. Frequency Division Multiplexing (FDM) divides the available spectrum bandwidth into sub-bands [1] [2]. Closely spacing carriers increase the data rate. Inter-carrier interference results from insufficient carrier spacing. Guard bands must be placed between adjacent carriers to prevent data-lowering inter-carrier interference (ICI). The basic idea behind these systems is to split the entire bandwidth into smaller sub-bands while maintaining orthogonality. Orthogonal Frequency Division Multiplexing (OFDM) divides a channel into many overlapping sub-channels. No sub-channel guard band. OFDM has orthogonal sub-channels. This band split reduces Inter Symbol Interference (ISI) when using wide-band broadcasts in frequency selective channels [3].

The spectrum of OFDM (Orthogonal Frequency Division Multiplexing) signals is characterized by several distinct subcarriers, each carrying a portion of the overall data. These subcarriers are evenly spaced in the frequency domain and are orthogonal to each other, meaning they do not interfere with one another. The spectrum typically exhibits a series of narrow peaks, each corresponding to one of these subcarriers as shown in figure 1.

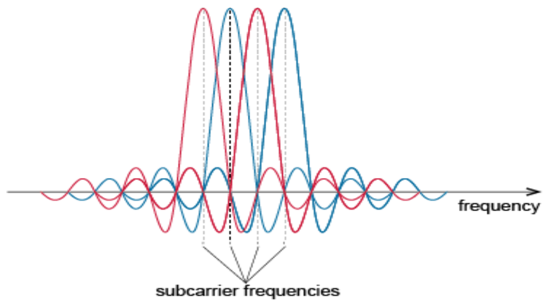


Figure 1. The spectrum of OFDM signals

OFDM is the best solution for 5G mobile communications. WiMAX, DAB, and DVB use it [4]. OFDM provides several advantages, including enhanced data transmission speed, reduced vulnerability to selective fading, simplified channel equalization, and resilience against both co-channel interference and sudden bursts of noise. However, OFDM can be sensitive to co-channel interference and phase instability [2].

Following this, the remaining sections of the paper are structured as follows: Section II contains the description of the channel model, Section III contains modulation techniques, Section IV contains the OFDM system model, Section V describes the flow chart of the working strategy, Section VI covers the presentation of results and discussion, while the final section summarizes the research's conclusions.

II. CHANNEL MODEL

We have employed various channels, including the Additive White Gaussian Noise (AWGN) channel, Rayleigh fading channel, and Rician fading channel. Our analysis involved assessing the performance of the

OFDM system under these different channel conditions to determine the most appropriate one. Below, we provide detailed descriptions of the models for these three channels:

A. AWGN Channel

The AWGN (Additive White Gaussian Noise) channel is widely favored for its non-fading characteristics and straightforward nature. AWGN channel adds White Gaussian noise to the signal [5]. White Gaussian noise values are identically distributed and statistically independent [6]. The Probability density function is always following Gaussian distribution and the equation of Gaussian distribution is expressed as-

$$f_{g(X)} = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \tag{1}$$

Where x = Random variable
μ = Mean value
σ = Standard deviation

Through the AWGN channel, a received signal is expressed as-

$$r(t) = x(t) + n(t) \tag{2}$$

Where $x(t)$ = Transmitted signal
$n(t)$ = Additive White Gaussian noise

B. Rayleigh Fading Channel

Rayleigh fading is a model for multipath fading. In any terrestrial environment, a radio signal travels multiple paths from the transmitter to receiver. The direct path is the most obvious. Rayleigh fading occurs when many objects scatter a signal before it reaches the receiver [5] [7]. In situations where there is a sufficient amount of scattering, it is possible to represent the channel impulse response as a Gaussian process, irrespective of the distribution of its components. The Rayleigh random variable is denoted by the magnitude |Z|, and it possesses a Probability Density Function (PDF) denoted as P(z).

$$P(Z) = \frac{Z}{\sigma^2} e^{\frac{-Z^2}{2\sigma^2}} \tag{3}$$

C. Rician Fading Channel

Rician Fading is a stochastic model that accounts for signal attenuation due to changes in at least one of the signal paths to the receiver. Typically, one of these paths, often representing a direct line-of-sight signal, significantly out-powers the others, leading to the occurrence of Rician fading. This fading is characterized by a Rician gain distribution. In scenarios where there is no direct line of sight between the OFDM transmitter and receiver, Rayleigh Fading comes into play [5] [8]. The Rician Fading channel is defined by two parameters: k and, where k is the Rice Factor, the ratio between direct path and scattered path power, and is the total power from both paths and acts as a scaling factor.

The received signal amplitude not considering the power R is then Rice distributed with parameters:

$$V^2 = \frac{K}{1+K}\Omega$$

$$\sigma^2 = \frac{\Omega}{2(1+K)}$$

The resulting Probability density function is:

$$f(x) = \frac{2(k+1)x}{\Omega} exp\left(-k - \frac{(k+1)x^2}{\Omega}\right) I_0\left(2\sqrt{\frac{k(k+1)}{\Omega}}x\right) \tag{4}$$

III. MODULATION TECHNIQUES

Modulation techniques play a significant role in wireless communication. It is a method of transmitting a message signal to a location that is some distance away. In order to prevent the massage signal from being lost entirely due to its low strength, a robust signal known as the carrier signal is combined with it [9]. M-PSK and M-QAM are the two types of modulation techniques that we apply to this project.

A. M-PSK

M-PSK modulates data by selecting one of the M phase-shifted carriers. M waveforms have the same amplitude, frequency, and phase. PSK can have any number of phases, but more than 8 phases increase the error rate and better, more complex modulations are available, such as QAM [9] [10]. Multilevel modulation allows high data rates with fixed bandwidth. A convenient set of signals for M-ary PSK is

$$\varphi_i(t) = Acos(w_c t + \theta_i) \qquad 0 < t \leq T_s \tag{5}$$

Where the M phase angles are-

$$\theta_i = 0, \frac{2\pi}{M}, \ldots\ldots\ldots\ldots\ldots \frac{2(M-1)\pi}{M}$$

The probability of symbol error-

$$P_{es} \approx 2Q\sqrt{\frac{2E_s}{N_0}} sin\frac{\pi}{M} \tag{6}$$

If a Gray code is used, then the corresponding bit error is approximately

$$P_{be} \approx P_{es}/\log_2 M \tag{7}$$

B. M-QAM

Quadrature Amplitude Modulation modifies both the amplitude and phase of two carriers by 90 degrees. The QAM modulation process changes both the phase and amplitude, like PSK. QAM is used in satellite, cable, modem, and point-to-point wireless systems. [10] [11].

The M-ary QAM modulated signal is expressed as:

$$S_i(t) = \sqrt{\frac{2E_{min}}{T_s}} a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}} b_i \sin(2\pi f_c t, \quad 0 < t < T_s \tag{8}$$

For I = 1, 2 ………… M

If the M-ary QAM is coherently detected then the Probability of Bit Error is expressed as:

$$P_{be,MQAM} \cong 2\left(\frac{\sqrt{M}-1}{\sqrt{M}\log_2 M}\right) erfc\left(\sqrt{\frac{3\log_2 M}{2(M-1)}\frac{E_b}{N_0}}\right) \tag{9}$$

IV. OFDM SYSTEM MODEL

OFDM transmitter sites are crucial components of modern wireless communication networks, as they enable the efficient transmission of data over the airwaves, whether it's for internet connectivity, mobile communications, or broadcasting television signals. The OFDM transmitter splits the data stream into K parallel sub-streams, each modulated on its own subcarrier at frequency [12]. Modulation schemes such as BPSK, QPSK, 4-QAM, 8-QAM, and 16-QAM are employed based on the required data constellation size. The next block in figure 2 is the OFDM transmitter's IFFT part. In OFDM Transmitter, IFFT is used to create OFDM waveform or symbol from modulated data streams. IFFT converts frequency-domain data into discrete time-domain [13].

Multipath propagation results in the delayed arrival and attenuation of OFDM symbols, leading to the occurrence of Inter Symbol Interference (ISI). Cyclic Prefix (CP) counters Inter Carrier Interference (ICI) in GI.

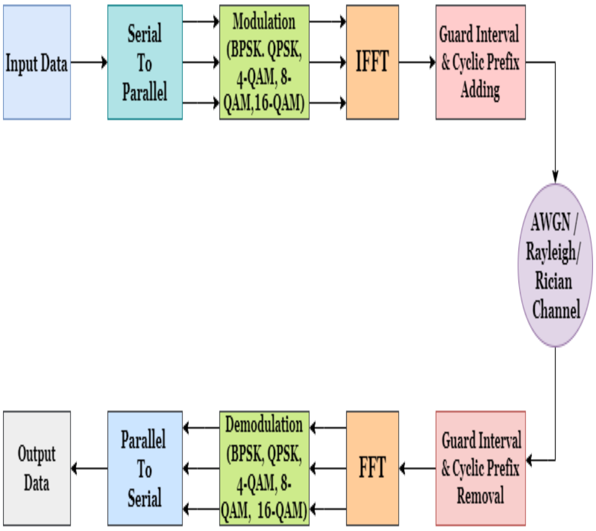


Figure 2. Basic Block Diagram of an OFDM system

At the receiver end, the Cyclic Prefix (CP) is essentially the final symbols of the samples positioned at the beginning, creating the illusion of signal periodicity (figure 2). CP is removed before demodulating OFDM. By using CP. Synchronization is possible.

In the OFDM receiver end, the Fast Fourier Transform (FFT) demodulates data streams as time domains into the frequency domain and takes the opposite operation step by step. Due to carrier orthogonality, DFT and IDFT can be used for signal modulation and demodulation. Different modulation schemes can be used to increase spectral efficiency. BPSK, QPSK, 4-QAM, 8-QAM, and 16-QAM will be used.

The number of N subcarriers can be expressed as

$$f_n = f_c + \frac{n}{T_s} \tag{10}$$

V. WORKING STRATEGY

This section explains our research process. How we worked and simulated the project as shown in the below figure 3. Finally, we discussed OFDM and image transmission simulation parameters.

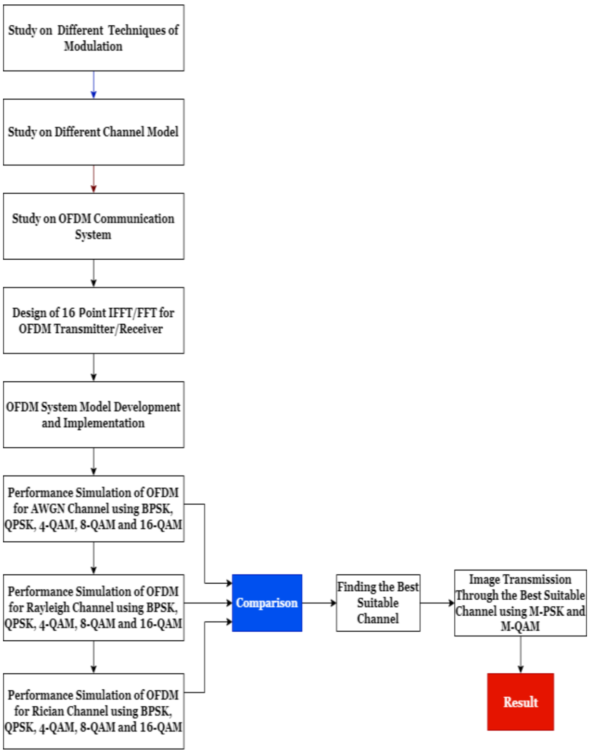


Figure 3. Proposed Flow Chart of the Working Strategy

At the start of the work, we studied different modulation techniques. In the second phase, our aim was to acquire information about various channels. In the third stage, we studied the multicarrier transmission technique OFDM. Then we were able to design a theoretical 16-point IFFT and FFT processor in the OFDM system. Then we compare performance by using different channels and modulation techniques and find the best suitable channel. Finally, we transmit an image through the best suitable channel using different modulation techniques in (figure 3) [14]. Thus we have accomplished our work.

OFDM system parameters used in the simulation are indicated in Table I.

TABLE I. OFDM SYSTEM SIMULATION PARAMETER

Parameters	**Specifications**
Total Number of Data Bits	256
Number of sub-carriers	4
Guard Type	Cyclic Prefix
Guard Length	1
FFT Size	16
Size of each OFDM block	16
Modulation	BPSK, QPSK, 4-QAM, 8-QAM and 16-QAM
Channel	AWGN, Rayleigh and Rician

Table II shows MATLAB simulation parameters for image transmission channels in presence of AWGN channel.

TABLE II. OFDM SYSTEM SIMULATION PARAMETER FOR IMAGE TRANSMISSION

Parameters	Specifications
Guard Type	Cyclic Prefix
Guard Length	20
FFT Size	64
Modulation	BPSK, QPSK, 8-PSK,16QAM
Channel	AWGN
No. of Channel Taps	8
Input image	'boy.bmp'
Image file size	48.7 KB
Resolution	600*400
Total pixels	240000

VI. SIMULATION RESULTS AND DISCUSSION

This section comprehensively covers the entire simulation process of our research. Our research is divided into two main parts. In the first part, we investigate OFDM systems employing various modulation techniques and channels. In the second part, we focus on the analysis of OFDM for image transmission.

A. Simulation Result on the BER vs SNR Ratio

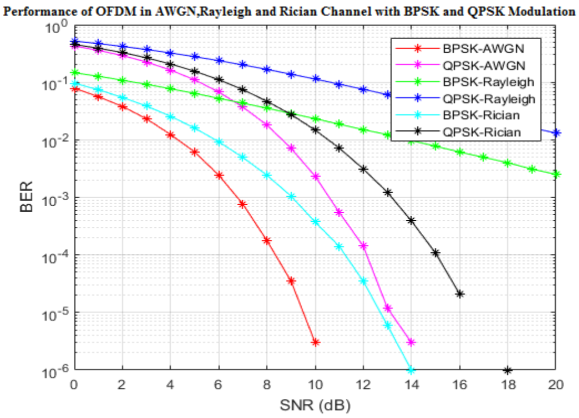


Figure 4. BER performance of AWGN, Rayleigh and Rician channel using BPSK and QPSK Modulation techniques

Figure 4 depicts the performance comparison of AWGN, Rayleigh, and Rician channels when employing BPSK and QPSK modulation. Notably, the combination of AWGN and BPSK modulation yields a lower Bit Error Rate (BER) compared to Rayleigh and Rician channels employing QPSK.

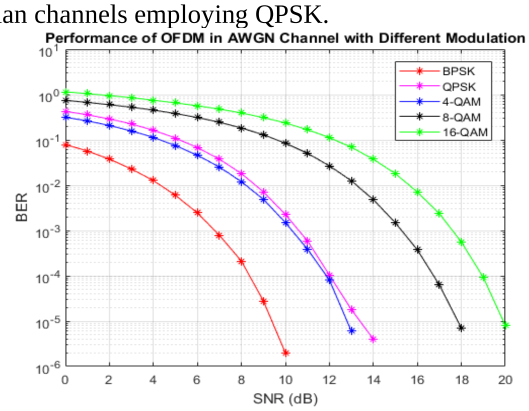


Figure 5. BER performance of AWGN channel using BPSK, QPSK,4-QAM, 8-QAM and 16-QAM modulation techniques

The figure 5 shows AWGN channel bit error rate performance using BPSK, QPSK, 4-QAM, 8-QAM, and 16-QAM modulation. BPSK modulation has a lower BER than other modulation techniques.

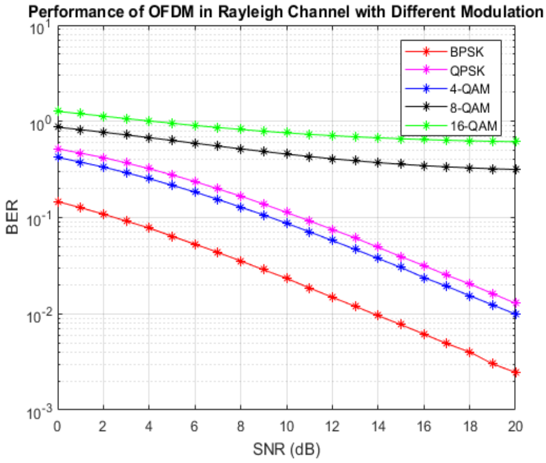


Figure 6. BER performance of Rayleigh channel using BPSK, QPSK,4-QAM, 8-QAM and 16-QAM modulation techniques

The figure 6 shows Rayleigh channel bit error rate performance using BPSK, QPSK, 4-QAM, 8-QAM, and 16-QAM modulation. From here, we see that BPSK modulation has a lower BER than other modulation techniques.

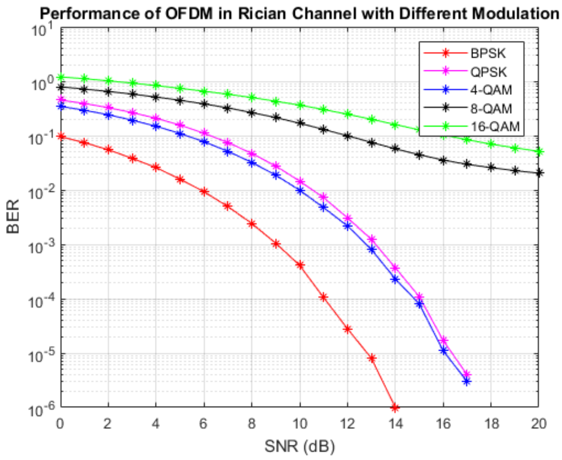


Figure 7. BER performance of Rician channel using BPSK, QPSK,4-QAM, 8-QAM and 16-QAM modulation techniques

The figure 7 shows Rician channel bit error rate performance using BPSK, QPSK, 4-QAM, 8-QAM, and 16-QAM modulation. BPSK modulation has a lower BER than other techniques. Now we compare the OFDM performance using simulated values for different modulation techniques and channels.

From the findings in section A, it becomes apparent that the Bit Error Rate (BER) rises with an increase in modulation levels. Furthermore, we illustrate that the AWGN channel exhibits a lower BER compared to both the Rayleigh and Rician channels. Due to BPSK modulation having the lowest bit error rate among all modulation schemes and considering that AWGN channels are the most favorable, it emerges as an efficient approach for data transmission across the entire network.

B. Effect of different Channels and Modulations of OFDM System using Simulated value

TABLE III. COMPARISON TABLE FOR AWGN CHANNEL USING DIFFERENT MODULATION TECHNIQUES

Signal to Noise Ratio(SNR)	**Bit Error Rate Value (BER) dB**				
	BPSK	QPSK	4-QAM	8-QAM	16-QAM
0	0.0789	0.4241	0.3171	0.7454	1.1502
5	0.0058	0.1098	0.0751	0.3815	0.6553
15	0	0	0	0.0014	0.0180

TABLE IV. COMPARISON TABLE FOR RAYLEIGH CHANNEL USING DIFFERENT MODULATION TECHNIQUES

Signal to Noise Ratio(SNR)	**Bit Error Rate Value (BER) dB**				
	BPSK	QPSK	4-QAM	8-QAM	16-QAM
0	0.1467	0.5189	0.4228	0.8695	1.2693
5	0.0640	0.2772	0.2169	0.6332	0.9556
15	0.0078	0.0392	0.0302	0.3584	0.6595

TABLE V. COMPARISON TABLE FOR RICIAN CHANNEL USING DIFFERENT MODULATION TECHNIQUES

Signal to Noise Ratio(SNR)	**Bit Error Rate Value (BER) dB**				
	BPSK	QPSK	4-QAM	8-QAM	16-QAM
0	0.0956	0.4506	0.3449	0.7872	0.0203
5	0.0158	0.1559	0.1093	0.4462	0.7391
15	0	0.0001	8.0e-05	0.0444	0.1271

From section B, we simulated the BER values and showed that for BPSK, when SNR value is 5 then the BER values are 0.0058 for AWGN channel, 0.0640 for Rayleigh channel, and 0.0158 for Rician channel. At SNR value is 5, 16-QAM BERs are 0.6553 dB for AWGN channel, 0.9556 dB for Rayleigh channel, and 0.7391 dB for Rician channel.

Finally, AWGN and BPSK are the best channels and modulations compared to others.

C. Analyze OFDM for Image Transmission through AWGN Channel under Different Modulation Techniques

Sections A and B consistently affirm that the AWGN (Additive White Gaussian Noise) channel outperforms other channels in terms of performance and reliability. Now we transmit the image through AWGN using different modulation techniques and analyze OFDM's performance [15]. Figure 9 shows the OFDM system test image. This is one of the online default images used by researchers worldwide. It's called 'boy.bmp' 600x400.bmp image. 240000 pixels total. Each pixel is an 8-bit unsigned integer (uint-8). Figure 8 shows the image transmission's block diagram.

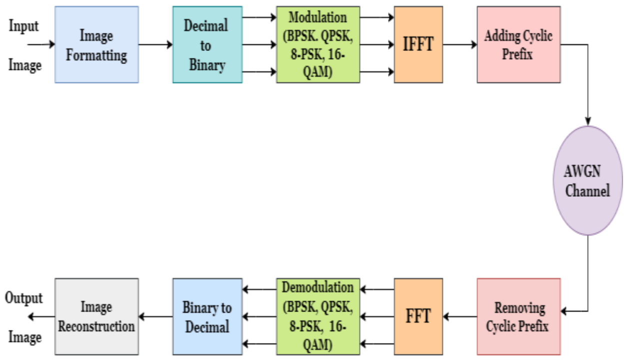


Figure 8. Block Diagram of image transmission system

The original image that we use to analyze the performance of the OFDM system is shown below:

Figure 9. Original Image

Now we compare OFDM system performance for image transmission over the AWGN channel under different modulation techniques.

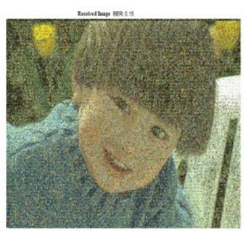
a) BPSK SNR=5 dB

b) BPSK SNR=20 dB

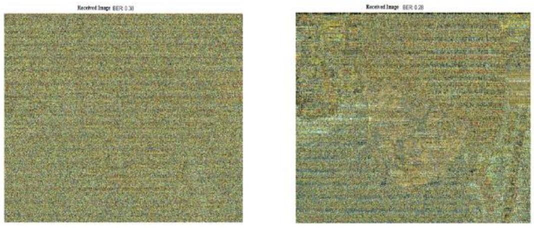
a) QPSK SNR=5 dB

b) QPSK SNR=20 dB

a) 8-PSK SNR=5 dB



b) 8-PSK SNR=20 dB



a) 16-QAM SNR=5 dB b) 16-QAM SNR=20 dB

Figure 10. Received image for different Modulation when SNR=5 dB and SNR=20 dB

Figure 10 shows that BPSK modulation improves image quality and reduces noise. When SNR is 5dB, BPSK BER is 0.057 while QPSK, 8-PSK, and 16-QAM are 0.30, 0.34, and 0.38 respectively. BPSK modulation has a BER of 0.0013 at 15dB SNR, while QPSK, 8-PSK, and 16-QAM modulation have BERs of 0.082, 0.18, and 0.29.

As previously discussed, elevating the Signal-to-Noise Ratio (SNR) leads to a reduction in Bit Error Rate (BER) and noise power. In light of these observations, BPSK modulation consistently exhibits superior image quality and lower noise levels compared to other techniques. Figure 11 clearly illustrates that BPSK is the optimal modulation technique for achieving superior image quality and minimizing noise power.

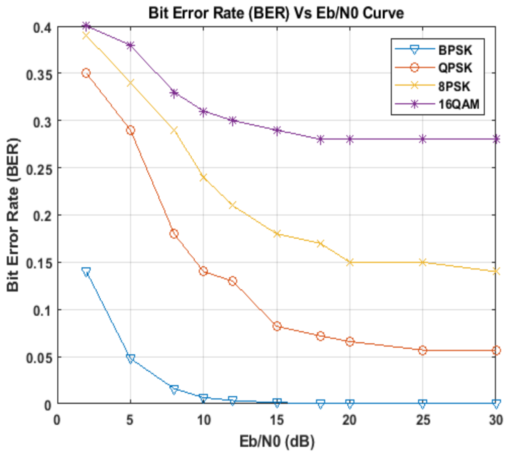


Figure 11. BER performance comparison of different modulation techniques

Figure 11 provides a comparison of the Bit Error Rate (BER) performance for four image modulation techniques: BPSK, QPSK, 8-PSK, and 16-QAM, as a function of Signal-to-Noise Ratio (SNR).The figure shows that for any modulation, increasing SNR reduces BER and noise. BPSK modulation is less noisy than QPSK, 8-PSK, and 16-QAM. QPSK has less noise than 8-PSK and 16-QAM.

TABLE VI. SIMULATED BER VALUE

Signal to Noise Ratio (SNR)	Bit Error Rate Value(BER) dB			
	BPSK	QPSK	8-PSK	16-QAM
2.00	0.14	0.35	0.39	0.40
5.00	0.057	0.30	0.34	0.38
10.00	0.0066	0.14	0.24	0.31
15.00	0.0013	0.082	0.18	0.29

Table VI illustrates the relationships between Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR) for BPSK, QPSK, 8-PSK, and 16-QAM modulations. Across all modulation schemes, it is evident that increasing SNR results in lower BER. Notably, BPSK modulation consistently exhibits lower BER values. Consequently, BPSK emerges as the most suitable modulation technique for image transmission when compared to the other modulation techniques.

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CONCLUSION

This article first briefly introduced the basic ideas of the OFDM system. Then describe different channels and modulation techniques and describe the OFDM system model in figure 2. In this paper we analyzed the performance OFDM system with different modulation techniques and channels and finally analyzed the performance of the OFDM system for image transmission. The AWGN channel consistently exhibits the best performance among all channels, boasting the lowest Bit Error Rate (BER) across various modulation schemes. The noise level present at the BER of this channel is significantly lower than that observed in fading channels. Specifically, Rician fading performs worse than the AWGN channel but better than the Rayleigh channel.

Finally, we transmit an image through the AWGN channel under different modulation techniques and showed that BPSK modulation has lower noise power and better-received image quality than other modulation techniques. BPSK shows the lowest BER among all modulation schemes. Therefore, it can be said that among BPSK, QPSK, 16QAM, and 64QAM, BPSK is the most suitable modulation method for OFDM systems. Overall performance of our research we can conclude that AWGN channel and BPSK modulation are best suitable for both OFDM and image transmission systems.

The author suggests updating the following research. Future FFT/IFFT blocks can be implemented using FPGA devices, and by adding a serial-to-parallel converter, channel coder, and A/D converter, an OFDM modem can be made. The FFT/IFFT block can be implemented to 32/64/128 points, and 32/64/128 QAM modulation techniques must be more accurate.

This article highlights two works that stand out from the crowd and deserve top billing. Because of our extensive investigation, we have uncovered crucial information on the optimal channel for high-quality image transmission and the most effective modulation methods.

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