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A MATLAB Simulink Study on the Performance of QAM Modulation Scheme in AWGN, Rayleigh, and Rician Fading Channels: BER Analysis

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ABSTRACT

Wireless communication is the fastest-growing segment in the communication industry, with mobile communication being the most widely used. However, it faces several technical challenges, such as Fading, Shadowing, Interference, and Propagation path loss. Meeting the higher demand for capacity with high-quality service is crucial. Orthogonal Frequency Division Multiplexing (OFDM) is a technique that converts wideband signals into narrowband signals for transmission, making it a suitable option for high bandwidth data transmission. The transmission of these narrowband signals is executed with an orthogonal carrier. This paper focuses on building a QAM model using MATLAB to simulate Bit Error Rate (BER) performance for real data communication under different communication channels, including AWGN and fading channels (Rayleigh and Rician). The aim is to investigate the reduction of noise and bit error rate in communication channels. The simulation model built for this research work demonstrates that QAM scheme performs better in AWGN channels than Rayleigh or Rician fading channels.

Keywords: Digital modulation; Quadrature Amplitude Modulation (QAM); AWGN; Rayleigh fading; Rician fading.

1. Introduction

Wireless communication has witnessed significant growth over the past few years, with mobile communication being the most widely used [1]. However, the transmission of wireless signals is prone to various technical challenges such as fading, shadowing, interference, and propagation path loss, which have a detrimental impact on signal quality [2]. To address these challenges and ensure high-quality service, orthogonal frequency division multiplexing (OFDM) has emerged as a suitable technique for high-bandwidth data transmission. OFDM converts wideband signals into narrowband signals for transmission using orthogonal carriers. One critical aspect of wireless communication is bit error rate (BER) performance [3]. In this context, this paper presents a study on BER performance using Quadrature Amplitude Modulation (QAM) model under different communication channels, including additive white Gaussian noise (AWGN) and fading channels (Rayleigh and Rician), using MATLAB. The study aimed to investigate the reduction of noise and bit error rate in communication channels.

In 2012, Vineet Sharma et al., conducted a study to determine the performance of OFDM-8PSK and QAM systems using direct error correction codes in the AWGN channel. The study aimed to encode the data stream for wireless communication without wire [4]. In 2013, Sharif Nasr Abdel-Razek et al., modelled the QAM modulator and demodulator using MATLAB Simulink. They highlighted the widespread use of QAM modulation in digital communication systems due to its high bandwidth utilization [5].

Sanjeev Kumar et al. (2013) compared the performance of Rayleigh and Rician channel models using MATLAB modelling. They developed algorithms to calculate the envelope and the likelihood of failure in the fading channels, considering parameters such as source speed and interruption probability. This analysis is crucial in designing efficient digital communication systems that can withstand multipath blurring [6]. Singya et al. (2020) analyzed the performance of a dual-hop variable gain AF mixed RF/FSO system with outdated channel state information. They model the RF link with the generalized Nakagami-m fading and the FSO link with the Gamma-Gamma distribution affected by atmospheric turbulence and pointing error impairments. They derive analytical expressions of outage probability, ergodic capacity, and generalized average symbol error rate for various QAM schemes, and present a comparative study highlighting the impact of various impairments on system performance [7]. Forkan et al. (2022) provides a comparative analysis of the performance of two widely used modulation techniques, BPSK and 8-FSK, over an AWGN fading channel in wireless communication systems. The authors use MATLAB Simulink software to synthesize the design and analyze the error rate quantity of each technique. The findings indicate that BPSK outperforms 8-FSK modulation in terms of error rate, which can be useful in determining the best technique for implementing in an AWGN fading channel [8]. Farzamnia et al. (2022) present a study on the bit error rate (BER) performance of M-PSK and M-QAM schemes in AWGN, Rayleigh, and Rician fading channels. The authors investigate the impact of channel fading on the performance of these modulation schemes and analyze the BER for different values of signal-to-noise ratio (SNR). The study highlights the importance of choosing an appropriate modulation scheme for different channel conditions in order to ensure reliable communication [9].

The proposed QAM model is an effective tool for evaluating BER performance in real-world data transfer settings. The results show that the QAM modulation method outperforms Rayleigh and Rician fading channels in AWGN fading channels. The contribution of this work is noteworthy because it provides insights into the performance of QAM in different fading channels, which can be used to design better wireless communication systems.

2. Design Methodology

The MATLAB environment was used to analyze QAM modulations, and the effects of various types of noise on QAM were studied by adding them and analyzing the results using the Communication blockset in MATLAB Simulink. The methodology used in this research work involved building a QAM model using MATLAB to simulate Bit Error Rate (BER) performance for real data communication under different communication channels, including AWGN and fading channels (Rayleigh and Rician). The QAM model was constructed by implementing orthogonal frequency division multiplexing (OFDM) technique which converts wideband signals into narrowband signals for transmission. The transmission of these narrowband signals was executed with an orthogonal carrier. The simulation model was used to investigate the reduction of noise and bit error rate in communication channels. The performance of the QAM model was evaluated by analyzing the BER performance under different communication channels, including AWGN and fading channels (Rayleigh and Rician). The results obtained were then compared and analyzed to determine the best performing channel for QAM communication.

2.1. Numerical Equations

Quadrature Amplitude Modulation (QAM) is a modulation scheme that transmits digital data by simultaneously varying the amplitude and phase of the carrier signal. The mathematical equation for a QAM signal is [10]:

$$s(t) = \mathrm{Re}\{A[m]e^{j2\pi f_m t} + \theta[m]\} \qquad (1)$$

Where *s(t)* is the QAM signal, A[m] is the amplitude of the m^{th} symbol, f_m is the frequency of the carrier signal, $\theta[m]$ is the phase of the m^{th} symbol, and Re{} denotes the real part of the complex signal. The symbol rate is given by $1/T_s$, where T_s is the symbol period. The number of bits that can be transmitted per symbol depends on the number of points in the QAM constellation, which determines the amplitude and phase combinations used for each symbol. For example, a 16-QAM constellation has 16 points and can represent 4 bits per symbol.

The equation for the additive white Gaussian noise (AWGN) channel is given by [11]:

$$y(t) = s(t) + n(t) \qquad (2)$$

Where $y(t)$ is the received signal, $s(t)$ is the transmitted signal, and $n(t)$ is the noise introduced by the channel. The noise $n(t)$ is modeled as a Gaussian process with zero mean and a power spectral density of $N_0/2$, where N_0 is the noise power.

The equation for Rayleigh fading channel can be represented as follows [12]:

$$h = \sqrt{2}(randn(1, L) + irandn(1, L)) \qquad (3)$$

Where:

- h is the complex fading coefficient representing the channel response;
- L is the length of the channel;
- $randn(1,L)$ is a Gaussian random variable with mean 0 and variance 1;
- i is the imaginary unit;
- $\sqrt{2}$ is a normalization factor to ensure that the average power of the channel is 1/2.

The fading channel response h varies randomly with time and position, and represents the attenuation and phase shift experienced by the transmitted signal.

The equations for the Rician fading channel [13]:

$$H = (\sqrt{\frac{k}{1+k}})e^{j\theta} \qquad (4)$$

Where H is the complex gain of the channel, K is the Rician factor, and Theta is a random phase uniformly distributed between 0 and 2π.

The power of the Rician channel can be expressed as:

$$P_{ric} = \frac{P_{dir}}{(1+k)} \qquad (5)$$

Where, P_{dir} is the power of the direct path and P_{ric} is the total power of the Rician channel.

2.2. Block Set Configuration

This study presents simulation models for different digital modulation techniques, with a focus on Quadrature Amplitude Modulation (QAM) as one of the most widely used techniques. The simulation involves feeding a

Bernoulli Binary Generator into the QAM modulation scheme and evaluating its performance under various noise conditions such as AWGN, Rayleigh, and Rician fading channels. The Bit Error Rate (BER) is calculated through adaptive filter simulations using MATLAB.

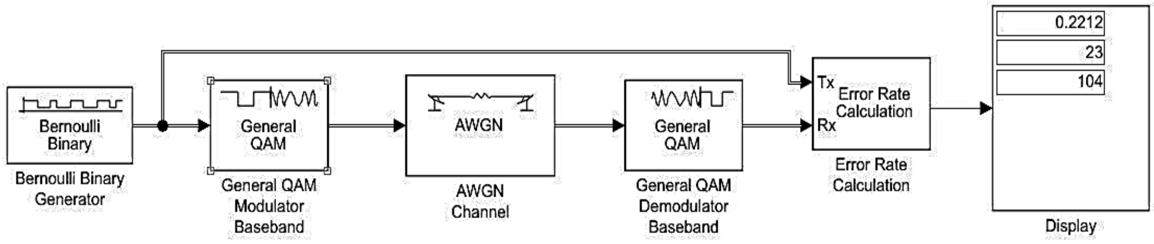

Figure 1. Block diagram of AWGN Fading channel on QAM modulation scheme

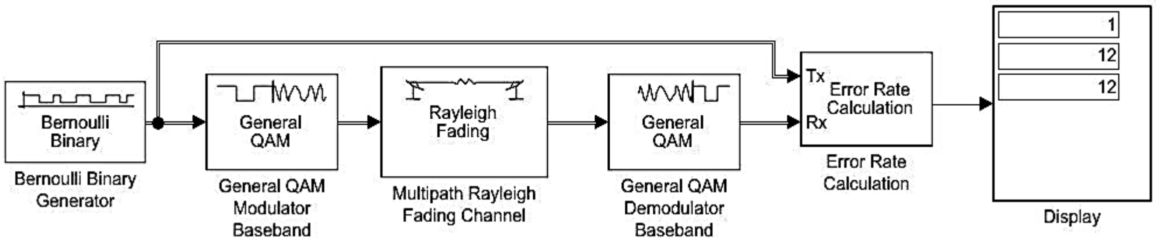

Figure 2. Block diagram of Rayleigh Fading channel on QAM modulation scheme

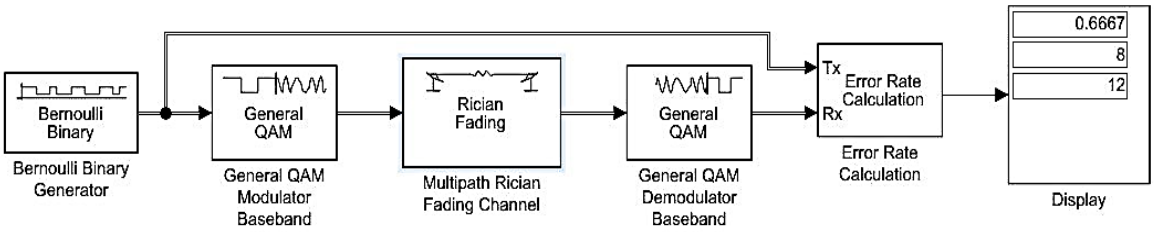

Figure 3. Block diagram of Rician Fading channel on QAM modulation scheme

In this research, the impact of AWGN, Rayleigh, and Rician fading channels on the Bit Error Rate (BER) of Quadrature Amplitude Modulation (QAM) schemes is studied through MATLAB simulations. The effects of varying parameters such as sample time, signal power, initial seed, sample period, maximum Doppler shift, k-factor, and average path gain on the QAM technique are investigated.

3. Numerical Outcomes and Discussion

By using the MATLAB Communication Blockset and Simulink the following effects of different fading channels were observed.

3.1. Effect of AWGN fading channel on QAM Modulation Scheme

The impact of an AWGN channel on the performance of the QAM modulation scheme was examined by analyzing the bit error rate (BER) relative to the signal-to-noise ratio (SNR) of the fading channel. The analysis of the AWGN fading channel involved assessing two parameters: the input or transmitted signal power and the SNR. The variation of the BER with respect to the SNR of the channel for different input or transmitted signal powers was plotted in Figure 4. The results showed that the BER decreased gradually as the SNR increased, and the lowest BER was observed for low transmitted power. For input signal powers of 200mW, 2000mW, and 100mW, the BER was recorded as 0.1818 from 20 dB to 55 dB, while from 65 dB to 90 dB, the BER was recorded as 0.09091 for the same input signal powers. The observation was conducted using an initial seed of 100 and a sample time of 1 second.

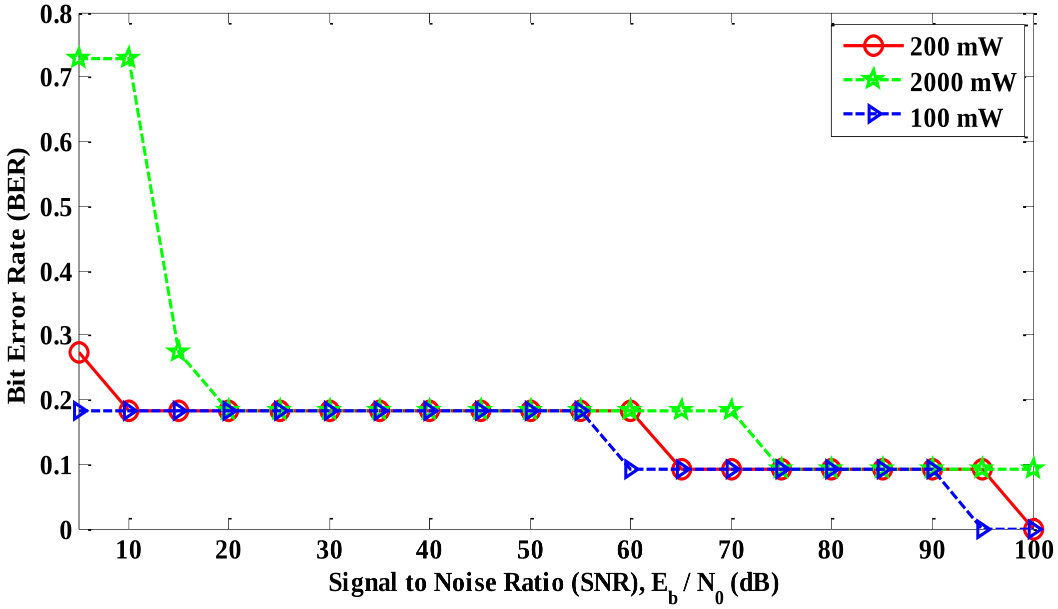

Figure 4. Plot of SNR vs. BER for AWGN fading channel

3.2. Effect of Rayleigh fading channel on QAM Modulation Scheme

In this analysis, as shown in Figure 5, the impact of the multipath delay vector on the BER performance of QAM modulation in the Rayleigh fading channel was studied. The multipath delay vector was varied from [0 1e-3] seconds to [0 9e-3] seconds, while the multipath gain vector was changed with three different reference values: [0 0], [0 2], and [0 -2] dB.

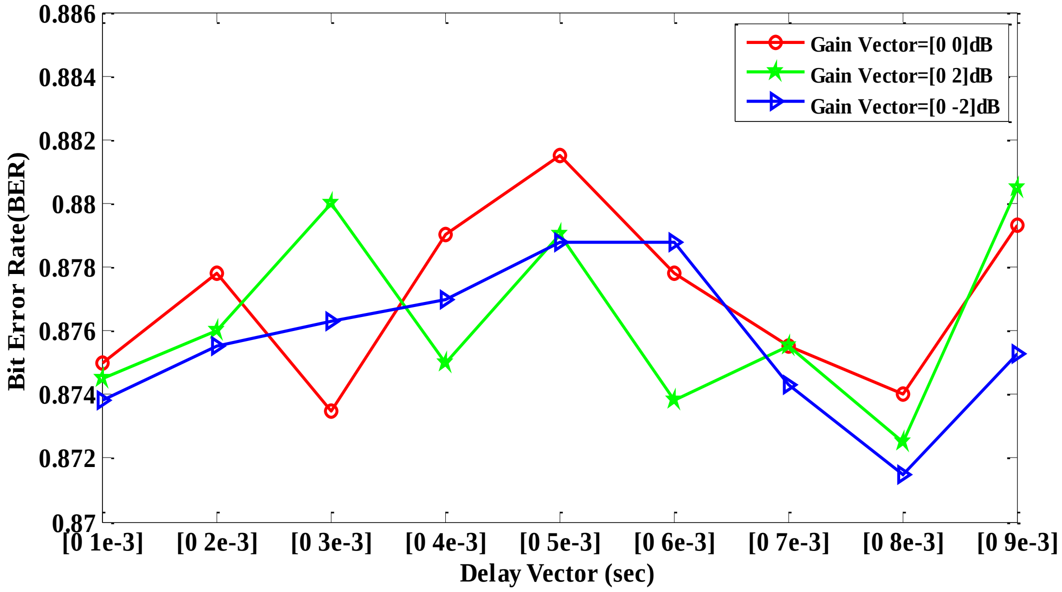

Figure 5. Plot of Delay Vector vs. BER for Rayleigh fading channel

The maximum Doppler shift was set to 40 Hz, with an initial seed of 100 and a sample time of 0.0025 seconds. The results showed that the BER was higher in the Rayleigh fading channel compared to the AWGN fading channel.

Additionally, setting the multipath gain vector to [0 -2] dB resulted in better performance than the other two values. The findings of this analysis highlight the importance of understanding the effects of various parameters on the performance of wireless communication systems, particularly in a fading channel such as the Rayleigh fading channel.

3.3. Effect of Rician fading channel on QAM Modulation Scheme

This study investigates the impact of various parameters on the performance of Quadrature Amplitude Modulation (QAM) in the Rician fading channel. Unlike the Rayleigh and Additive White Gaussian Noise (AWGN) fading channels, the Rician fading channel involves more parameters for evaluation. These parameters include the K factor, multipath gain vector, delay vector, maximum diffuse Doppler shift, and Doppler shift of the direct path. For this study, the K factor was set to 1, the Doppler shift of the direct path was set to 0 Hz, and the maximum diffuse Doppler shift was set to 40 Hz.

The observation was carried out for the Bit Error Rate (BER) performance of QAM with respect to the delay vector, which was varied from [0 1e-3] to [0 9e-3] seconds. Additionally, the multipath gain vector was changed with three different reference values: [0 0], [0 2], and [0 -2] dB. The results showed that the BER performance in the Rician fading channel was lower than that of the Rayleigh fading channel but still higher than that of the AWGN fading channel. Figure 6 displays the lowest BER recorded for the different multipath gain vectors. The results indicate that the QAM performance was much better when the multipath gain vector was set to [0 -2] dB. The trajectories of the curve were quite similar in the delay vector range, with optimal BER at [0 0] dB, lower BER at [0 -2] dB, and higher BER at [0 2] dB. These findings suggest that setting the multipath gain vector to a negative value results in better QAM performance than setting it to a positive value.

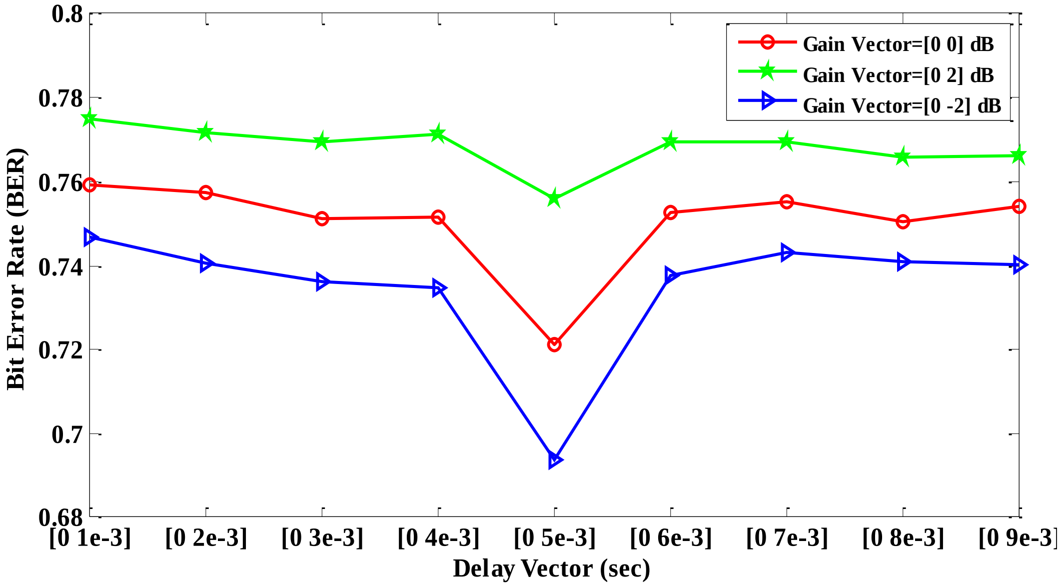

Figure 6. Plot of Delay Vector vs. BER for Rician fading channel

Based on the findings of this outcome, it is recommended that wireless communication systems be optimized for performance in the Rician fading channel by setting the multipath gain vector to a negative value. This optimization could lead to improved reliability and performance of wireless communication systems in real-world scenarios.

4. Conclusion and Future Recommendation

In conclusion, this study aimed to investigate the performance of Quadrature Amplitude Modulation (QAM) in different wireless communication channels, including the additive white Gaussian noise (AWGN) channel and fading channels (Rayleigh and Rician). The simulation model built for this research demonstrated that the QAM scheme performs better in AWGN channels than in Rayleigh or Rician fading channels. The study highlights the importance of addressing technical challenges, such as fading, shadowing, interference, and propagation path loss, in wireless communication to meet the increasing demand for high-capacity and high-quality service. The use of techniques such as Orthogonal Frequency Division Multiplexing (OFDM) can be a suitable option for high-bandwidth data transmission in wireless communication systems. Future research could explore the impact of other parameters on the performance of wireless communication systems in different fading channels, such as the effects of channel coding, modulation schemes, and multiple antenna techniques. Additionally, researchers could investigate the use of machine learning and artificial intelligence techniques to optimize the performance of wireless communication systems in fading channels.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this research work.

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