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Performance Analysis of 16-FSK Modulator and Demodulator Over Rician Fading Channel by Varying Channel Parameters

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ABSTRACT

This article presents a comprehensive analysis of a 16-FSK modulator and demodulator's performance over a Rician fading channel, which accurately models wireless communication channels with line-of-sight and non-line-of-sight components. The study investigates the impact of various parameters, including the Rician K-factor, Maximum Diffuse Doppler Shift, and Delay Vector, using the MATLAB Simulink communication blockset. The results indicate that increasing the K-factor and delay vector of the channel leads to an improvement in bit error rate. Additionally, it is observed that the maximum diffuse Doppler shift has minimal influence on the bit error rate. These findings provide valuable insights into optimizing the performance of 16-FSK modulation schemes in Rician fading channels, thereby enhancing the design and deployment of wireless communication systems.

Keywords: 16-FSK modulation; Rician fading channel; Wireless communication; Bit error rate; MATLAB Simulink.

1. Introduction

Wireless communication systems play a crucial role in our modern world, enabling seamless connectivity and information exchange. To ensure reliable and efficient communication, it is essential to understand the behavior of wireless channels and their impact on the performance of modulation and demodulation techniques. One prominent channel model used for simulating wireless communication environments is the Rician fading channel [1].

The Rician fading channel incorporates both line-of-sight (LOS) and non-line-of-sight (NLOS) components, making it an effective representation of real-world wireless channels. The performance analysis of modulation schemes over Rician fading channels provides valuable insights into their behavior and aids in designing robust communication systems [2]. In the research conducted by Sadeque [3] (2015) was on evaluating the performance of three fundamental digital modulation techniques: FSK, PSK, and QAM. The study utilized MATLAB Simulink and its relevant toolboxes for system simulation and analysis. Specifically, the research aimed to analyze the bit error rate performance characteristics of the receiver for these modulation schemes when operating over an AWGN channel. While various channel models exist in wireless communication, the AWGN channel was chosen as the target for this study to assess the performance of analog signal waveforms carrying digital information. The objective of this research was to characterize and design these waveforms while examining their performance in the presence of AWGN noise. This study provides valuable insights into the comparative performance of different digital modulation techniques and their suitability for AWGN channel environments. Nikoofard, Zadeh, and Mercier [4] in 2020 presents a significant contribution towards achieving energy-efficient wide area networking through the implementation of a low-power 16-FSK receiver. The receiver leverages the advantages of 16-FSK modulation over BFSK modulation, achieving improved sensitivity compared to prior-art solutions. The integration of a bank of 16 N-path filters enables efficient tone selection for 16-FSK, resulting in a remarkable sensitivity of

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-103dBm at a data rate of 100kbps, while consuming only 0.6mW of power. This study demonstrates the potential for effective and low-power implementation of 16-FSK receivers, paving the way for advancements in energy-efficient wide area networking applications. Again, Nikoofard, Zadeh, and Mercier [5] in 2021 presents a significant advancement in the design of RF receivers for non-coherent 16-FSK modulation. The study demonstrates that 16-FSK offers a 4-dB sensitivity advantage over binary frequency shift keying (BFSK), making it an attractive option for low-power and high-sensitivity applications. The article presents the design of a 16-FSK-compatible receiver front end, incorporating temperature-stabilized phase-locked loops and augmented Miller capacitors for precise filter control, resulting in a receiver with a sensitivity of -103.2 dBm at 100 kb/s while consuming only 0.6 mW of power. This research provides valuable insights and a state-of-the-art benchmark in the field of non-coherent 16-FSK receivers, showcasing the potential for improved performance and power efficiency in wireless communication systems. In the research article by Forkan et al. [6] (2022), the authors conduct a performance analysis of two modulation techniques, BPSK (Binary Phase Shift Keying) and 8-FSK (8-Level Frequency Shift Keying), in the context of wireless communication systems. The study focuses on the impact of these modulation schemes on AWGN (Additive White Gaussian Noise) fading channels, aiming to determine the most suitable technique for implementation in such channels. Using MATLAB Simulink, the researchers analyze the error rate performance and provide a comparative analysis between BPSK and 8-FSK. The findings demonstrate that BPSK outperforms 8-FSK in terms of performance over the AWGN channel. Halder et al. [7] (2023), conducted a MATLAB Simulink study to analyze the performance of the QAM (Quadrature Amplitude Modulation) modulation scheme in various communication channels, including AWGN (Additive White Gaussian Noise), Rayleigh fading, and Rician fading channels. The study addresses the technical challenges faced in wireless communication, such as fading, shadowing, interference, and propagation path loss, with a focus on meeting the demand for high-capacity and high-quality service. The simulation results demonstrate that the QAM scheme performs better in AWGN channels compared to Rayleigh or Rician fading channels, highlighting the potential for improved noise reduction and bit error rate in communication systems.

This article focuses on the comprehensive analysis of a 16-FSK (Frequency Shift Keying) modulator and demodulator's performance over a Rician fading channel. The 16-FSK modulation technique allows the transmission of multiple bits per symbol by varying the frequency of the carrier signal. By investigating various parameters of the Rician fading channel, including the Rician K-factor, Maximum Diffuse Doppler Shift, and Delay Vector, the impact on the bit error rate is evaluated. The study utilizes the MATLAB Simulink communication blockset, which offers a powerful platform for simulating wireless communication systems. Through extensive simulations and analysis, the relationship between the Rician fading channel parameters and the performance of the 16-FSK modulation scheme is investigated. The findings from this research will contribute to the development and deployment of wireless communication systems, enabling better system design, improved performance, and enhanced reliability.

2. Objective of the Study

The primary objective of this research is to understand how different channel parameters influence the bit error rate of the 16-FSK modulator and demodulator. Specifically, the study focuses on the effects of increasing the Rician

K-factor and delay vector, as well as the influence of the maximum diffuse Doppler shift. By quantifying these effects, valuable insights can be gained to optimize the performance of 16-FSK modulation in Rician fading channels.

3. Methodology

The 16-FSK modulator and demodulator system has been implemented using MATLAB Simulink and the Communication Blockset. The system consists of a transmitter, a Rician fading channel model, and a receiver. The transmitter generates a binary data sequence that is converted into 16-FSK symbols. Each symbol represents a unique combination of four bits [8]. The symbols are modulated onto a carrier frequency using 16-FSK modulation scheme. The modulated signal is then passed through the Rician fading channel. The Rician fading channel accurately represents wireless communication channels with both line-of-sight and non-line-of-sight components. The channel model is configured with parameters such as the Rician K-factor, Maximum Diffuse Doppler Shift, and Delay Vector. These parameters are varied during the analysis to investigate their impact on the system performance. The receiver consists of a demodulator that performs 16-FSK demodulation on the received signal. The demodulated symbols are then converted back into binary data. The receiver also incorporates error detection and correction techniques, such as a forward error correction (FEC) code, to improve the system's robustness against channel-induced errors [9].

The performance of the 16-FSK modulator and demodulator system is evaluated based on the bit error rate (BER). The BER is calculated by comparing the received data with the transmitted data. The simulation is run for multiple iterations with different channel conditions and parameter settings to obtain statistically significant results. The Rician K-factor, Maximum Diffuse Doppler Shift, and Delay Vector are varied independently to analyze their impact on the system performance. Different values are selected within a suitable range to cover a wide range of channel conditions. The obtained BER values are statistically analyzed to identify trends and patterns. The relationship between the system performance and the varying parameters is analyzed using graphical representations, such as plots and graphs. The results are interpreted to gain insights into the performance of the 16-FSK modulator and demodulator system over Rician fading channels. The impact of the Rician K-factor, Maximum Diffuse Doppler Shift, and Delay Vector on the system's BER is discussed. Additionally, the relative significance of these parameters in influencing the system performance is determined. Based on the findings, guidelines for optimizing the performance of 16-FSK modulation schemes in Rician fading channels are formulated. These guidelines can assist in enhancing the design and deployment of wireless communication systems by providing insights into parameter selection and system configuration.

4. Numerical Analysis and Discussion

4.1. Basic Block Diagram

The basic block architecture of a 16-FSK modulator and demodulator with a Rician fading channel is shown in Figure 1. The approach entails creating the modulated signal with a 16-FSK modulator, sending it over a Rician fading channel to simulate realistic wireless channel conditions, and then applying 16-FSK demodulation to the received signal to retrieve the transmitted data. The transmission quality is determined by comparing the transmitted and received data, taking into account elements such as bit error rate (BER). Matlab communication blockset Simulink environment was used to develop and simulate the entire system. The simulation and analysis were carried out using the frame-based output of the Bernoulli Binary generator. The setup includes the Bernoulli Binary with the following parameters: The chance of a zero is 0.5, the starting seed is 60, and the sampling duration is 2.5 ms. The 16-FSK modulator and demodulator channel separation was set to 1 KHz, and it would examine 5 samples each symbol. The parameters of the Rician Fading channel were varied as a result of the scenario analysis, and the Doppler shift of the direct path versus bit error rate was derived from each simulation.

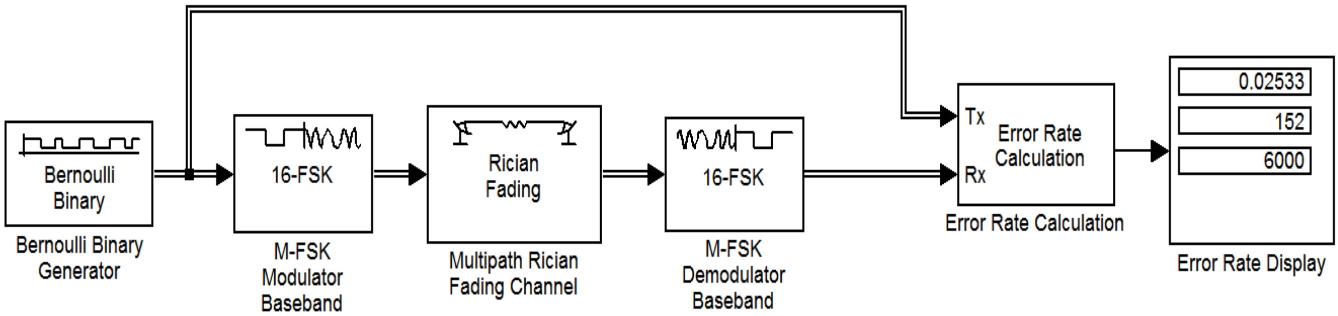

Figure 1. Block diagram of 16-FSK modulator and demodulator setup with Rician Fading Channel

4.2. K-factor Optimization

The Rician fading channel is a wireless communications model that describes the effect of multipath propagation when a dominating line-of-sight (LOS) signal is present alongside dispersed signals. The Rician fading channel is based on the assumption that dispersed signals have a Rician distribution. The K-factor, also known as the Rician factor or Rician K-factor, is a metric used to evaluate the intensity of the LOS signal in a Rician fading channel in comparison to the dispersed signals. It is the power of the LOS component divided by the power of the dispersed multipath components [10].

Mathematically, the K-factor (K) is defined as:

$$K = P_{LOS} / P_{NLOS} \qquad (1)$$

where:

- P_{LOS} is the power of the line-of-sight (LOS) component

- P_{NLOS} is the power of the non-line-of-sight (NLOS) or scattered multipath components

A high K-factor implies a significant LOS component, implying that fading is less severe on the channel. In this scenario, the LOS component dominates the received signal, and the influence of multipath fading is minimal. A low K-factor, on the other hand, suggests a weak LOS component and a greater contribution from dispersed signals, resulting in more severe fading effects [11].

The value of the K-factor is determined by the individual environment and wireless channel parameters. In an open, clear line-of-sight environment, for example, the K-factor can be large (e.g., 10 dB or higher), suggesting a significant LOS component [12]. In contrast, the K-factor may be lower in an urban or interior setting with large obstacles, suggesting a weaker LOS component and higher multipath fading. Understanding the K-factor is

Asian Journal of Basic Science & Research
Volume 5, Issue 2, Pages 97-104, April-June 2023

important in wireless system design and performance evaluation because it helps find effective modulation and coding schemes, diversity techniques, and equalization strategies to mitigate the effects of channel fading.

Figure 2 shows the bit error rate as a function of the Doppler shift of the direct path from 0 to 200 Hz. The plot indicates that when the K factor grows, so does the bit error rate, and vice versa. The lowest bit error rate of 0.0001667 was discovered at 80 Hz and 100 Hz Doppler shift of direct route for K factor of 10. The greatest bit error rate of 0.5258 was discovered at 0 Hz Doppler shift of straight path when K factor was set to 0.25.

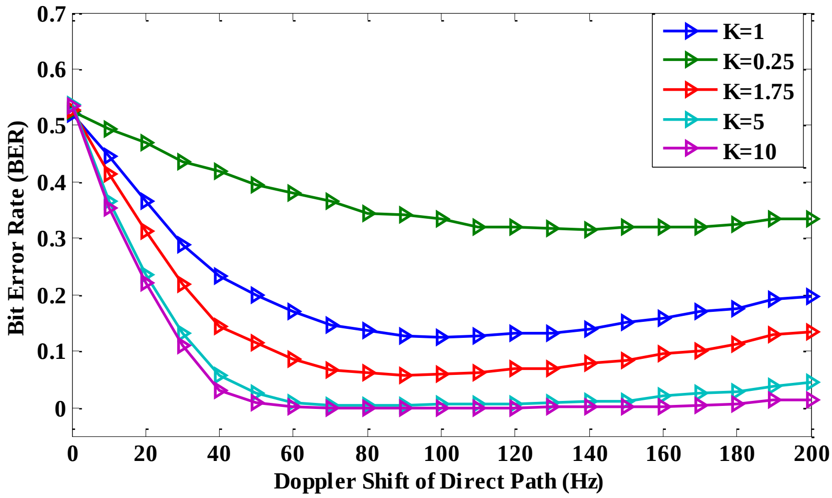

Figure 2. Doppler Shift of Direct Path versus Bit Error Rate plot for K-factor optimization

4.3. Delay Vector Variation

In the context of a Rician fading channel, the delay vector refers to the time delays associated with different multipath components or rays that contribute to the received signal. In a multipath environment, the transmitted signal reaches the receiver through multiple paths due to reflections, diffractions, and scattering. Each of these paths has a different propagation distance, resulting in different arrival times at the receiver. The delay vector provides information about the time delays of these multipath components. It is typically represented as a vector denoted by τ, where each element $\tau[i]$ corresponds to the delay of the i-th multipath component. The delay vector is crucial for understanding the channel impulse response, which describes how the channel responds to an impulse or short-duration pulse [13]. The channel impulse response is directly related to the time delays and magnitudes of the multipath components. By analyzing the delay vector, it is possible to extract important parameters such as delay spread, coherence bandwidth, and channel dispersion, which are useful for designing communication systems and equalization techniques. It's important to note that the delay vector can vary for different scenarios, environments, and propagation conditions. In a Rician fading channel, the delay vector takes into account the line-of-sight (LOS) component and scattered multipath components, where each component has a distinct time delay. The LOS component typically has a delay of zero since it follows the direct path from the transmitter to the receiver. The scattered components have delays corresponding to the additional path lengths they travel due to reflections and scattering. By characterizing the delay vector, one can understand the temporal behavior of the Rician fading channel and design appropriate signal processing algorithms to mitigate the effects of multipath propagation, such as equalization, diversity combining, and channel estimation techniques.

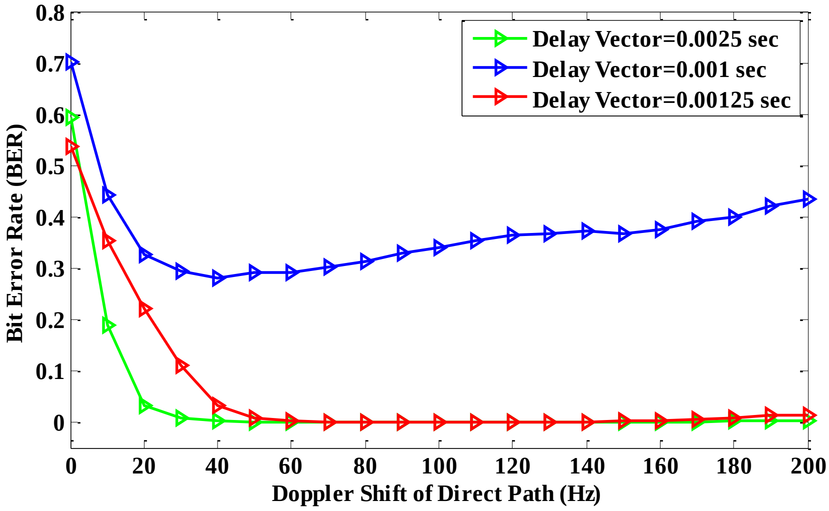

Figure 3. Doppler Shift of Direct Path versus Bit Error Rate plot for varying Delay Vector Parameter

Figure 3 depicts the influence of delay vector on bit error rate by varying the delay vector value by 2.5 ms, 1 ms, and 1.25 ms. It is obvious that increasing the delay vector is appropriate for lowering the bit error rate. For 2.5 ms, the lowest bit error rate was 0.0001667. The k-factor, maximum diffuse Doppler shift, and gain vector were all set to 10, 40 Hz, and 0 dB in each simulation.

4.4. Maximum Diffuse Doppler Shift Variation

The maximum diffuse Doppler shift refers to the highest possible frequency shift that can be observed in the scattered radiation during a Doppler effect experiment. The Doppler effect is a phenomenon in physics that describes the change in frequency of a wave (such as light or sound) when there is relative motion between the source of the wave and the observer [14]. This effect is commonly observed in everyday situations, such as the change in pitch of a siren as it approaches and then passes by. In the context of diffuse scattering, the maximum Doppler shift occurs when the scattering medium (such as a gas or a cloud of particles) is moving directly toward or away from the observer at its maximum velocity. This means that the observer will perceive the scattered radiation at the highest possible frequency shift.

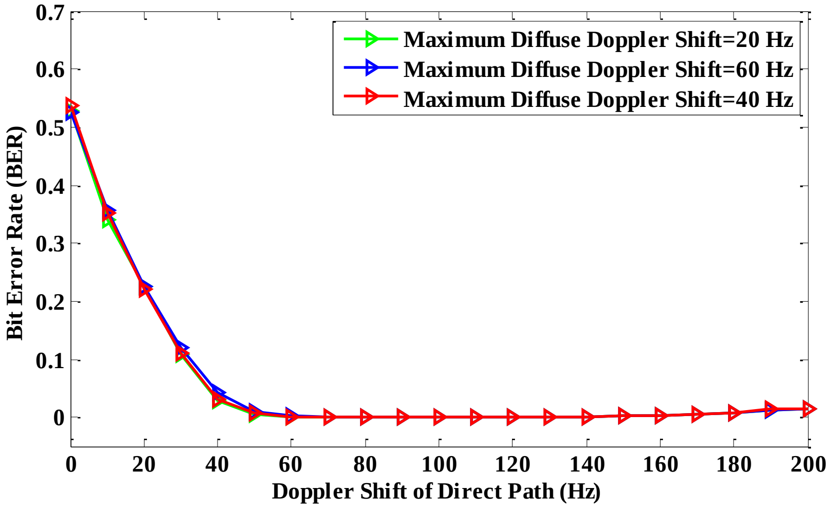

Figure 4. Doppler Shift of Direct Path versus Bit Error Rate plot for varying Maximum Diffuse Doppler Shift

The Maximum Diffuse Doppler Shift was changed by 20 Hz, 40 Hz, and 60 Hz in figure 4. The graphic revealed no significant change in bit error rate with Doppler Shift of Direct Path. The lowest bit error rate was determined to be 0.0003333, 0.0001667, and 0.0001667 for 20Hz, 40Hz, and 60Hz Maximum Diffuse Doppler Shift, respectively, for 90 Hz Doppler Shift of Direct route. The k-factor, delay vector, and gain vector were all set to 10, 0.00125 sec, and 0 dB in each simulation.

5. Conclusion

In conclusion, this study has provided a comprehensive analysis of the performance of a 16-FSK modulator and demodulator over a Rician fading channel. By investigating the impact of key parameters such as the Rician K-factor, Maximum Diffuse Doppler Shift, and Delay Vector, valuable insights have been gained regarding the optimization of wireless communication systems. The results indicate that increasing the K-factor and delay vector of the channel leads to an improved bit error rate, highlighting the significance of these factors in achieving reliable communication. On the other hand, the maximum diffuse Doppler shift was found to have minimal influence on the bit error rate, suggesting that it may not be a critical parameter to consider when designing 16-FSK modulation schemes in Rician fading channels. These findings provide practical guidance for system designers and engineers in optimizing the performance of 16-FSK modulation schemes, particularly in scenarios where Rician fading is present. By considering the appropriate values for the K-factor and delay vector, the overall system performance can be enhanced, leading to more reliable wireless communication. It is worth noting that this study utilized MATLAB Simulink with the communication blockset, demonstrating the effectiveness of simulation tools in analyzing and evaluating communication systems. The simulation platform proved valuable in facilitating a comprehensive performance analysis and enabling a better understanding of the impact of various channel parameters. Overall, this research contributes to the body of knowledge in wireless communication and offers valuable insights for improving the design and deployment of 16-FSK modulation schemes in Rician fading channels. Future work may involve exploring additional modulation schemes or considering other factors that could affect system performance, providing further opportunities for enhancing the efficiency and reliability of wireless communication systems.

Declarations

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This study did not receive any grant from funding agencies in the public or not-for-profit sectors.

Conflict of Interest

The authors declare that they have no conflict of interest.

Consent for Publication

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

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