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Error Rate Analysis of 32-FSK Modulation in Wireless Fading Channels using MATLAB: Impact of Delay Vector and K-Factor

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ABSTRACT

This paper investigates the error rate performance of wireless communication systems employing 32-Frequency Shift Keying (32-FSK) modulation in fading environments, using MATLAB as the simulation platform. Key parameters such as delay vector, Doppler shift, K-factor, and diffuse Doppler shift are systematically varied to analyze their effects on system performance. Results demonstrate that error rates increase with larger delay vectors but are significantly mitigated by higher K-factor values, reflecting the influence of a stronger Line-of-Sight (LOS) component. The study underscores the effectiveness of 32-FSK modulation in achieving low error rates under optimized conditions and provides MATLAB-based insights for designing robust communication systems in multipath fading scenarios.

Keywords: 32-FSK modulation; Error rate analysis; Delay vector; K-factor; Wireless fading channels.

1. Introduction

Wireless communication systems face significant challenges in ensuring reliable data transmission, particularly in environments dominated by multipath fading and Doppler effects [1]. Modulation schemes, such as 32-Frequency Shift Keying (32-FSK), have gained attention for their ability to provide robust performance under adverse channel conditions [2]. This study explores the error rate performance of 32-FSK modulation, focusing on the impact of delay vectors, K-factor, and Doppler shifts. Using MATLAB simulations, the study offers insights into optimizing these parameters to improve system reliability. The primary objective of this research is to analyze the relationship between delay vectors and error rates in 32-FSK modulated systems under various channel conditions. By investigating how the K-factor (representing the strength of the Line-of-Sight (LOS) component) and Doppler shifts influence system performance, we aim to provide a comprehensive understanding of the conditions necessary for minimizing error rates [3]. The demand for efficient wireless communication systems continues to grow with the proliferation of data-intensive applications [4]. However, multipath fading and mobility-induced Doppler shifts often degrade system performance, leading to increased error rates [5]. Modulation schemes like 32-FSK offer promising solutions due to their resilience to noise and fading [6]. This research is motivated by the need to optimize system parameters, such as delay vectors and K-factor, to ensure reliable performance in fading environments, thereby contributing to the development of more robust wireless systems. Halder et al. (2023) analyzed 16-FSK performance over Rician channels, revealing that increasing the K-factor and delay vector improves bit error rates (BER), while Doppler shift minimally affects performance. These findings highlight the role of specific channel parameters in enhancing modulation schemes [7]. Zhao (2024) compared various modulation techniques, including FSK, over Rician channels. The study demonstrated that increasing SNR mitigates fading effects and emphasized the importance of parameter tuning in achieving optimal BER performance [8]. Mohammad et al. (2018) explored the application of deep learning for FSK demodulation under Rayleigh fading, showcasing its potential for error probability reduction. These insights are valuable for adapting machine learning approaches to Rician fading environments [9]. Wang et al. (2021) proposed energy-efficient adaptive modulation techniques for Rician fading channels, demonstrating significant improvements in BER and energy efficiency by optimizing modulation parameters [10]. These studies underscore the importance of parameter optimization in modulator and demodulator performance under Rician fading, providing a basis for extending research into 32-FSK systems. This paper builds on these findings by addressing a higher-order modulation scheme and exploring a broader range of parameters, contributing to advancements in robust wireless communication technologies.

This research focuses on evaluating the error rate performance of 32-FSK modulation in wireless fading channels by systematically analyzing the effects of delay vectors and K-factor variations. Through MATLAB simulations, we aim to provide practical insights into optimizing system parameters to minimize error rates in challenging multipath fading scenarios. By addressing the interplay of these key factors, this study contributes to advancing the design and robustness of modern wireless communication systems.

1.1. Study Objectives

The specific objectives of this study are:

a) To analyze the error rate performance of 32-FSK modulation in wireless fading channels using MATLAB simulations.

b) To evaluate the impact of delay vector variations on the error rate in multipath fading environments.

c) To investigate the influence of the K-factor, representing the strength of the Line-of-Sight (LOS) component, on system performance.

d) To study the combined effects of Doppler shift and diffuse Doppler shift on error rate performance.

e) To identify optimal system parameter configurations that minimizes error rates in 32-FSK modulation.

f) To provide insights for designing robust communication systems capable of operating efficiently in multipath fading scenarios.

2. Methodology

A comprehensive simulation environment is established using MATLAB to model the communication system and evaluate its performance under Rician fading conditions. The Rician fading channel model incorporates key parameters such as line-of-sight (LOS) power, K-factor, and Doppler spread [11]. Multipath fading is simulated using appropriate statistical distributions to accurately reflect real-world conditions [12]. The 32-FSK modulation scheme is implemented by mapping data symbols to distinct frequencies. Pulse shaping techniques, such as Gaussian shaping, are applied to optimize the spectral characteristics of the transmitted signal. A corresponding demodulator is designed to detect and decode the received signals, employing methods like matched filtering and signal-to-noise ratio (SNR)-based symbol decision. Performance metrics, including Bit Error Rate (BER) and Symbol Error Rate (SER), are measured to evaluate system effectiveness. To achieve robust results, the simulation

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systematically varies channel parameters such as LOS power, K-factor, and Doppler spread. BER is calculated by comparing transmitted and received data, and the process is repeated across multiple iterations with different channel conditions and parameter settings to ensure statistical significance.

3. Basic Block Diagram

The block architecture of a 32 -FSK modulator and demodulator with a Rician fading channel is shown in Figure 1. The approach entails creating the modulated signal with a 32-FSK modulator, sending it over a Rician fading channel to simulate realistic wireless channel conditions, and then applying 32-FSK demodulation to the received signal to retrieve the transmitted data. The transmission quality is determined by comparing the transmitted and received data, considering 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 0.001, the starting seed is 100, and the sampling duration is 0.002 ms. The 32-FSK modulator and demodulator channel separation was set to 2 KHz, and it would examine 5 samples each symbol. The parameters of the Rician Fading channel were varied because of the scenario analysis, and the Doppler shift of the direct path versus bit error rate was derived from each simulation.

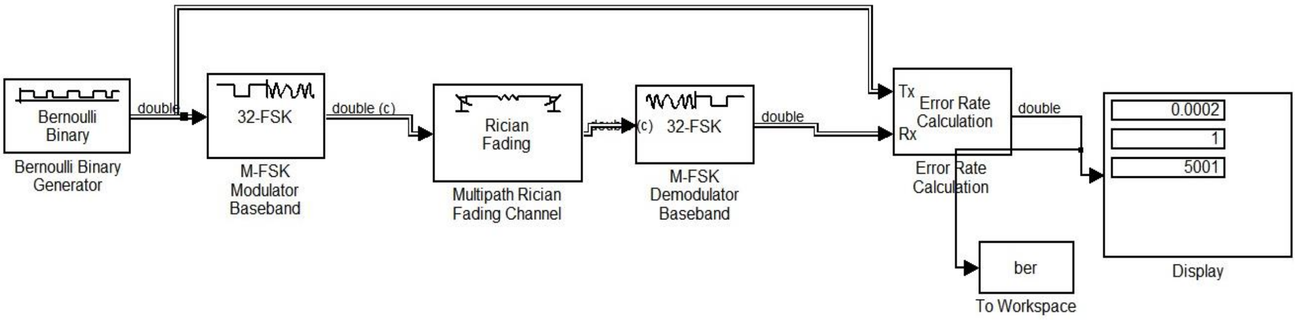

Figure 1. Block architecture of the 32-FSK modulator and demodulator system operating over a Rician fading channel

4. Results and Discussion

The figure 2 depicts the relationship between the Bit Error Rate (BER) and the K-Factor for a 32-FSK modulated system in a fading channel. The BER decreases significantly as the K-Factor increases, reflecting the impact of a stronger Line-of-Sight (LOS) component in mitigating fading effects. At lower K-Factor values, the BER is relatively high, indicating a higher susceptibility to multipath fading. However, as the K-Factor increases, the system performance improves, with the BER approaching near-zero levels. This trend highlights the effectiveness of increasing the LOS component in enhancing system reliability, particularly in challenging wireless environments.

The figure 3 highlights the relationship between the Bit Error Rate (BER) and the delay vector for a 32-FSK modulation scheme in a fading environment. The BER exhibits significant variations as the delay vector increases. Initially, at smaller delay values, the BER is low, indicating stable system performance. However, as the delay vector increases, the BER fluctuates, reaching peak values at certain delay intervals. These fluctuations reflect the sensitivity of the system to delay, which may cause inter-symbol interference and degrade performance. Towards the higher delay values, the BER stabilizes, potentially due to the reduced impact of multipath effects at longer delays. This trend underscores the importance of optimizing delay parameters to achieve reliable communication performance in fading environments.

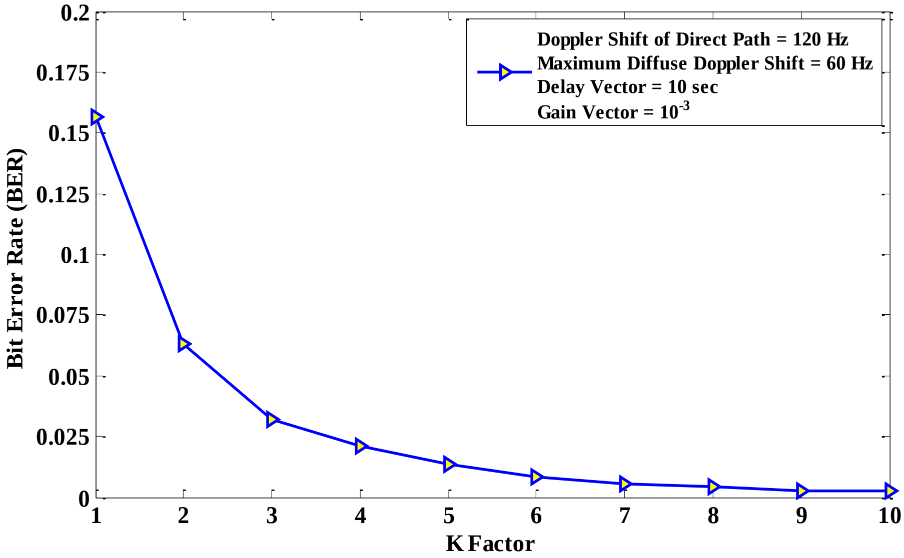

Figure 2. Bit Error Rate (BER) vs. K-Factor for 32-FSK Modulation in a Fading Channel

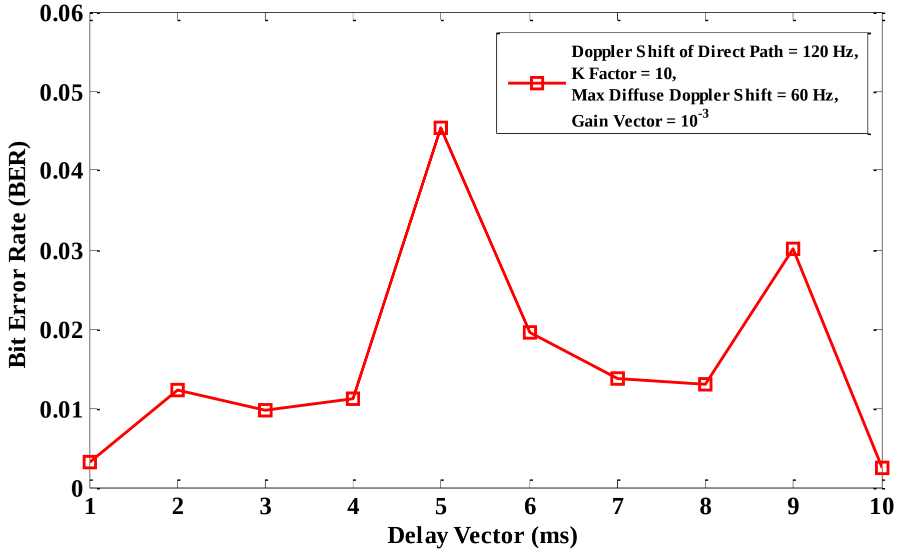

Figure 3. Bit Error Rate (BER) vs. Delay Vector for 32-FSK Modulation in a Fading Channel

The plots datasets highlight a clear relationship between delay vectors and error rates under varying Doppler shift, K-factor, and diffuse Doppler shift conditions. Generally, error rates increase with larger delay vectors, particularly for intermediate delays (e.g., 0.004 s to 0.005 s), before stabilizing or slightly decreasing at higher delays (e.g., 0.009 s). A notable trend is the consistent reduction in error rates as the K-factor increases, indicating the beneficial impact of a stronger Line-of-Sight (LOS) component. At higher K-factor values, such as 12, the system achieves near-zero error rates across most delay vectors. Smaller delay vectors (e.g., 0.001 s) uniformly result in minimal error rates regardless of the K-factor, while larger delays show greater sensitivity to K-factor changes, with higher values offering significantly improved performance. In some configurations, such as with the highest K-factor and smallest delay vector, the system achieves error-free operation. These findings suggest that optimizing the K-factor and maintaining smaller delay vectors can significantly enhance the error performance of the system.

5. Conclusion

This research investigated the impact of delay vectors and K-Factors on the Bit Error Rate (BER) performance of a 32-FSK modulation scheme in fading environments, considering parameters such as Doppler shifts and gain vectors. The analysis revealed that smaller delay vectors and higher K-Factors significantly improve BER performance, highlighting the importance of a strong Line-of-Sight (LOS) component in reducing errors. Additionally, the BER's sensitivity to delay vectors was observed, with performance stabilizing at higher delay values. These findings emphasize the need to optimize system parameters for enhanced reliability and efficiency in fading channels, particularly for high-data-rate applications.

6. Future Recommendation

Investigate other modulation schemes, such as 64-FSK or QAM, to compare their BER performance under similar conditions and determine the optimal scheme for specific scenarios. Extend the analysis to more complex fading models, including time-varying or frequency-selective channels, to account for diverse real-world communication scenarios. Incorporate advanced error-correction coding techniques, such as LDPC or Turbo codes, to mitigate the BER further and improve system robustness [13]. Utilize machine learning algorithms to predict optimal delay and K-Factor values dynamically, adapting to changing channel conditions in real time [14]. Validate the simulation results through hardware implementation and testing in practical environments, ensuring the applicability of the findings to real-world communication systems.

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 study.

Authors' contributions

All the authors made an equal contribution in the Conception and design of the work, Data collection, Simulation analysis, Drafting the article, and Critical revision of the article. All the authors have read and approved the final copy of the manuscript.

Availability of data and material

Authors are willing to share data and material according to the relevant needs.

References

[1] Wu, J., & Fan, P. (2016). A Survey on High Mobility Wireless Communications: Challenges, Opportunities and Solutions. IEEE Access, 4: 450–476. https://doi.org/10.1109/access.2016.2518085.

[2] Caruso, P., Iacono, S.D., & Paciello, V. (2023). Data Transmission Using FSK Modulation on an Unconventional Channel. 2023 IEEE International Workshop on Metrology for Industry 4.0 & IoT (MetroInd4.0 & IoT), Pages 36–41. https://doi.org/10.1109/metroind4.0iot57462.2023.10180200.

[3] Xiao, Z., Wen, H., Markham, A., Trigoni, N., Blunsom, P., & Frolik, J. (2015). Non-Line-of-Sight Identification and Mitigation Using Received Signal Strength. IEEE Transactions on Wireless Communications, 14(3): 1689–1702. https://doi.org/10.1109/twc.2014.2372341.

[4] Philip Chen, C.L., & Zhang, C.Y. (2014). Data-intensive applications, challenges, techniques and technologies: A survey on Big Data. Information Sciences, 275: 314–347. https://doi.org/10.1016/j.ins.2014.01.015.

[5] Huang, Z., Zheng, B., & Zhang, R. (2022). Transforming Fading Channel from Fast to Slow: Intelligent Refracting Surface Aided High-Mobility Communication. IEEE Transactions on Wireless Communications, 21(7): 4989–5003. https://doi.org/10.1109/twc.2021.3135685.

[6] Selim, B., Muhaidat, S., Sofotasios, P.C., Sharif, B.S., Stouraitis, T., Karagiannidis, G.K., & Aldhahir, N. (2021). Performance Analysis of Coherent and Noncoherent Modulation under I/Q Imbalance Effects. IEEE Access, 9: 36125–36139. https://doi.org/10.1109/access.2020.3028869.

[7] Halder, A., Tanshen, Md. R., Ahammad Ali, K., Juthy, F.K., Ali, Md. Y., & Jahan, N. (2023). Performance Analysis of 16-FSK Modulator and Demodulator Over Rician Fading Channel by Varying Channel Parameters. Asian Journal of Basic Science & Research, 05(02): 97–104. https://doi.org/10.38177/ajbsr.2023.5209.

[8] Zhao, L. (2024). Comparisons of PSK, APSK, and QAM over AWGN and fading channels. Applied and Computational Engineering, 36(1): 53–63. https://doi.org/10.54254/2755-2721/36/20230423.

[9] Mohammad, A.S., Reddy, N., James, F., & Beard, C. (2018). Demodulation of faded wireless signals using deep convolutional neural networks. 2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC), Pages 969–975. https://doi.org/10.1109/ccwc.2018.8301731.

[10] Wang, M., Chen, Z., & Chen, Z. (2021). Energy-Efficient Index Modulation with In-Phase/Quadrature Format in the Generalized Fading Channel. IEEE Access, 9: 117938–48. https://doi.org/10.1109/access.2021.3107955.

[11] Baki, A.K.M., Absar, Md. W., Rahman, T., & Ahamed, K.M.A. (2017). Investigation of Rayleigh and Rician fading channels for state of the art (SOA) LTE-OFDM communication system. 2017 4th International Conference on Advances in Electrical Engineering (ICAEE), Pages 325–329. https://doi.org/10.1109/icaee.2017.8255375.

[12] Luengo, D., & Martino, L. (2014). Statistical Simulation of Multipath Fading Channels for Mobile Wireless Digital Communication Systems. Simulation Technologies in Networking and Communications, Pages 265–308. https://doi.org/10.1201/b17650-13.

[13] Ali, M.M., Hashim, S.J., Chaudhary, M.A., Ferré, G., Rokhani, F.Z., & Ahmad, Z. (2023). A Reviewing Approach to Analyze the Advancements of Error Detection and Correction Codes in Channel Coding With Emphasis on LPWAN and IoT Systems. IEEE Access, 11: 127077–127097. https://doi.org/10.1109/access.2023.3331417.

[14] Kumar, A., Gaur, N., & Nanthaamornphong, A. (2024). Machine learning RNNs, SVM and NN Algorithm for Massive-MIMO-OTFS 6G Waveform with Rician and Rayleigh channel. Egyptian Informatics Journal, 27: 100531. https://doi.org/10.1016/j.eij.2024.100531.