Advanced MATLAB-Based Design and Simulation of Reliable Digital Communication Systems for Modern Signal Transmission

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ABSTRACT

This study focuses on the design and simulation of advanced digital communication systems using MATLAB-based models. The work analyzes different modulation techniques such as BPSK, QPSK, 16-QAM, and OFDM under noisy channel conditions. MATLAB simulation was used to generate digital data, modulate signals, transmit them through an Additive White Gaussian Noise channel, and evaluate receiver performance. The results showed that BPSK achieved the lowest bit error rate, while OFDM provided better bandwidth efficiency and resistance to multipath effects. The study confirms that MATLAB is an effective tool for communication system analysis.

Keywords: *Digital Communication, MATLAB Simulation, Bit Error Rate, Modulation Techniques.*

I. INTRODUCTION

Digital communication systems have become one of the most essential foundations of the modern technological world because almost every form of information exchange today depends on the accurate, fast, and efficient transmission of digital data. From mobile phones, internet services, satellite links, television broadcasting, wireless sensor networks, optical fiber communication, and smart devices to advanced defence and space communication systems, digital communication plays a central role in connecting people, machines, and information systems. The basic purpose of a digital communication system is to transmit information from one point to another in the form of binary data while maintaining accuracy, speed, security, and reliability. In comparison with analog communication systems, digital communication provides several important advantages, such as improved noise immunity, better signal quality, easy data storage, high compatibility with computer-based processing, efficient encryption, and the possibility of using error detection and correction techniques. These advantages have made digital communication more suitable for present-day high-speed and high-capacity networks. However, the design of advanced digital communication systems is not a simple process because the transmitted signal often faces several practical challenges, including channel noise, interference, fading, distortion, bandwidth limitation, power constraints, and multipath propagation. Therefore, a proper communication system must be carefully designed and tested before real-world implementation. MATLAB-based modeling and simulation provide an effective platform for this purpose because they allow researchers, students, and engineers to design virtual communication systems, observe signal behavior, analyze channel effects, and evaluate system performance under different conditions. By using MATLAB, different stages of a digital communication system, such as source data generation, encoding, modulation, channel modeling, noise addition, demodulation, decoding, and error analysis, can be implemented in a systematic and visual manner. This makes MATLAB an important tool for understanding both theoretical and practical aspects of digital communication.

The design and simulation of advanced digital communication systems mainly focus on studying how digital signals are generated, processed, transmitted, received, and reconstructed at the destination. In a typical digital communication model, the original message is first converted into a binary sequence. This binary data may represent text, voice, image, video, or sensor-based information. After source generation, the data is often passed through encoding techniques to improve reliability and reduce transmission errors. The encoded data is then modulated using digital modulation techniques so that it can be transmitted efficiently through a physical communication channel. Common digital modulation techniques include Amplitude Shift Keying, Frequency Shift Keying, Phase Shift Keying, Binary Phase Shift Keying, Quadrature Phase Shift Keying, Quadrature Amplitude Modulation, and Orthogonal Frequency Division Multiplexing. Each modulation technique has its own advantages and limitations. For example, BPSK is simple and highly reliable in noisy environments, while QPSK provides better bandwidth efficiency by transmitting more information within the same bandwidth. Higher-order QAM techniques can transmit more bits per symbol and support higher data rates, but they are more sensitive to noise and require better channel conditions. OFDM is widely used in modern wireless systems because it divides a high-speed data stream into several low-speed subcarriers, which helps reduce the effect of multipath fading and improves spectral efficiency. MATLAB simulation allows all these modulation techniques to be modeled and compared in terms of bit error rate, signal-to-noise ratio, bandwidth efficiency, power efficiency, constellation pattern, and overall communication reliability. The use of MATLAB also makes it possible to simulate different channel conditions, such as Additive White Gaussian Noise channels, Rayleigh fading channels, Rician fading channels, and multipath environments. These simulations help in understanding how a communication signal behaves when it passes through practical and imperfect transmission media. As a result, MATLAB-based models are highly useful for identifying the strengths and weaknesses of different communication techniques before implementing them in actual hardware.

MATLAB-based simulation is especially important in advanced digital communication system design because it reduces the need for costly experimental setups and allows repeated testing under controlled conditions. Through simulation, a designer can easily change parameters such as data rate, carrier frequency, modulation order, channel noise level, filter response, coding scheme, and sampling frequency to observe their effect on system performance. This flexibility is very useful for both academic research and industrial development. For example, students can use MATLAB to understand the working of digital modulation by observing time-domain waveforms, frequency-domain spectra, eye diagrams, and constellation diagrams. Researchers can use MATLAB to test advanced communication techniques such as MIMO systems, OFDM systems, adaptive modulation, spread spectrum communication, software-defined radio models, and error-control coding methods. Engineers can use simulation results to optimize real communication systems for better speed, reliability, and energy efficiency. Performance evaluation is usually carried out using parameters such as bit error rate, symbol error rate, signal-to-noise ratio, throughput, spectral efficiency, and computational complexity. Among these, bit error rate is one of the most important indicators because it shows how many bits are received incorrectly compared with the total number of transmitted bits. A lower BER value indicates a more reliable communication system. Similarly, SNR helps in measuring the quality of the received signal in relation to background noise. By plotting BER versus SNR curves in MATLAB, different modulation schemes can be compared effectively. The simulation results provide a clear understanding of which technique is more suitable for a given application. For example, a system requiring high reliability may prefer BPSK or QPSK, while a system requiring high data rate and better bandwidth utilization may prefer QAM or OFDM. Thus, the design and simulation of advanced digital communication systems using MATLAB-based models offer a practical and powerful approach for analyzing communication performance, improving system design, and preparing reliable communication technologies for modern digital networks.

II. RESEARCH BACKGROUND

Wang et al. (2026) examined adaptive interference cancellation as an effective strategy for meeting the anti-interference requirements of communication systems, with particular emphasis on the critical role of RF front-end gain in determining both communication sensitivity and interference suppression capability.

The study analyzed the influence of RF front-end gain on communication sensitivity and the interference cancellation ratio (ICR), especially under conditions involving strong interference signals and weak desired communication signals. It was reported that a mathematical model for RF front-end gain constraints was derived by considering communication sensitivity, ICR requirements, and analog-to-digital converter quantization accuracy. Based on the identified upper and lower gain boundary regions, the authors proposed a gain design criterion for adaptive interference cancellation systems. Simulation results indicated that ICR performance improved with increasing RF front-end gain up to the upper boundary threshold, beyond which saturation occurred, while the lower boundary ensured communication sensitivity. Experimental validation further confirmed that the proposed gain design criterion maintained communication sensitivity and satisfied anti-interference performance requirements under high-power interference conditions.

Indriyani (2026) had presented a Scopus-based systematic literature review on the profound and continuous transformation of digital communication networks, tracing their evolution from foundational infrastructures such as ARPANET to modern interactive platforms and advanced AI-driven systems. The study had aimed to provide a comprehensive synthesis of how these technological advancements had reshaped social structures, human interaction, and communication culture while also highlighting emerging societal, political, and ethical challenges. Using a qualitative research design guided by PRISMA methodology, the review had refined the selection process through abstract and full-text screening, ultimately identifying 46 relevant articles for detailed analysis. The findings had revealed that technological progress, particularly the integration of advanced artificial intelligence, had created a dynamic interplay marked by digital anomie, algorithmic manipulation, and regulatory gaps. These developments had significantly altered truth criteria, communication practices, and social stratification. The review had concluded that the transition toward hybrid AI-driven communication systems had introduced complex dilemmas, thereby underscoring the need for stronger AI regulatory frameworks, enhanced media literacy, and interdisciplinary strategies to address societal fragmentation and ethical concerns.

Krikidis and Gilbert (2026) had examined the transformative potential of quantum optimization in the design of next-generation wireless communication systems by addressing major computational and technological challenges. The article had provided an overview of the principles of adiabatic quantum computing, which was considered the foundation of quantum optimization, and had further explored its two principal computational models, namely quantum annealing and the gate-based quantum approximate optimization algorithm (QAOA). The authors had highlighted the key features, performance advantages, limitations, and distinctions of these approaches, thereby positioning them as promising tools for improving wireless communication system design. As a practical case study, the design of passive reconfigurable intelligent surface beamforming with binary phase-shift resolution had been investigated. The study had also been supported by experimental results obtained from real-world quantum hardware, which had demonstrated the feasibility and potential effectiveness of quantum optimization techniques in solving complex wireless communication design problems.

Schmalenbach and Brechtelsbauer (2025) examined the potential of digital communication platforms (DCPs) to disseminate information and support deliberative public discourse without the influence of traditional gatekeepers, while acknowledging that such platforms faced widespread criticism for issues like misinformation and societal polarization. They noted that although empirical studies had substantiated these concerns, existing research had not sufficiently offered a positive vision integrating DCPs with normative ideals for public discourse. To address this gap, they developed design knowledge for deliberative DCPs grounded in Habermas' theory of communicative action (TCA), formulating TCA-based meta-requirements and applying network gatekeeping theory to derive suitable design principles for practical implementation. Their study contributed normatively informed design knowledge intended to guide researchers, system designers, and policymakers in the conception, development, and regulation of DCPs, offering a framework that balanced technological potential with deliberative democratic ideals.

Huang et al., (2025) investigated semantic communication as a promising approach for integrating intelligence with communication to enable more efficient and context-aware data transmission. They proposed a bit-conversion-based semantic communication transmission framework aimed at ensuring compatibility with existing wireless systems. The study designed a series of physical layer processing modules for end-to-end transmission and developed a semantic communication simulator to implement and evaluate the framework. To optimize performance, the authors introduced a novel physical layer metric, the Integer Error Rate (IER), which was argued to provide a more appropriate evaluation criterion than the conventional bit error rate (BER). Based on the IER, they proposed a minimum Manhattan distance constellation mapping scheme to enhance transmission quality under the same BER condition. Furthermore, a hybrid joint source–channel coding (JSCC) and separate source–channel coding (SSCC) transmission scheme was developed, which decoupled semantic quantization from modulation order. Simulation results reportedly showed that the hybrid scheme improved semantic performance, such as PSNR, in low SNR environments while reducing bandwidth usage by up to 50% relative to benchmark schemes.

Jassim and Hussain (2024) examined the critical role of data reliability in digital communication systems, particularly under the challenges posed by noisy transmission channels. They highlighted that multipath fading, atmospheric variations, and electromagnetic interference could significantly affect system performance, necessitating the implementation of robust error correction algorithms. Their analysis focused on two primary channel coding methodologies: automated repeat request (ARQ) and forward error correction (FEC). Within FEC, they investigated several codes, including Turbo, Hamming, LDPC, Convolutional, RS, Polar, and BCH, noting that each exhibited distinct complexity and reliability characteristics. They emphasized that RS and Hamming codes were effective in correcting both random and burst errors while maintaining relatively low coding complexities, whereas Turbo and Convolutional codes, despite higher complexity, provided superior error correction. The study also discussed limitations such as the LDPC code's error floor and the code length constraints of Polar codes. Overall, they concluded that despite inherent limitations, these error-correcting codes offered substantial advantages, proving indispensable across applications such as 5G, Wi-Fi, WiMAX, LTE, electrical circuits, magnetic recording devices, and NASA missions.

Gemiharto and Masrina (2024) investigated the strategies for preserving user privacy in AI-powered digital communication systems, emphasizing the growing concerns surrounding privacy in such platforms. They employed a qualitative comparative case study methodology, analyzing multiple AI-based systems to examine the range of privacy preservation methods, transparency in data collection and usage, and mechanisms for obtaining user consent. Data were collected through in-depth interviews with system developers and users, content analysis of privacy policies, and user experience assessments, which provided insights into both practical challenges and perceived effectiveness of implemented measures. The study found diverse approaches, including end-to-end encryption and data anonymization, with notable variations in transparency and consent mechanisms. Furthermore, the research highlighted the influence of these strategies on user trust and satisfaction. The authors underscored the need for a nuanced, holistic approach integrating technical safeguards, ethical considerations, and regulatory frameworks to strengthen privacy practices in AI-driven digital communication environments.

Mohamed et al. (2024) investigated a novel image cryptosystem aimed at enhancing security and reliability in underwater optical wireless communication (UOWC) systems, particularly for water bodies with higher absorption and scattering coefficients. They proposed an image encryption scheme based on chaotic iteration of dragon fractal shapes (ChDrFr), which was evaluated across five water types with distinct optical properties. The study reported that median and high-pass filters were employed to improve the quality of decrypted images, while numerical simulations demonstrated the algorithm's robustness against various attacks, yielding correlation coefficients close to zero between original and encrypted images. The encrypted images nearly reached optimal information entropy and unified average changed intensity (UACI) values. Comparative analysis revealed that the ChDrFr-based encryption outperformed existing methods, producing more secure images. Additionally, the scheme improved underwater transmission distances by 6% in Pure Sea and Clear Ocean, 4% in Coastal Sea, and marginally in Harbor I and II, with filter application enhancing SSIM, PSNR, and SNR metrics.

Altoobaji et al., (2023) investigated a data communication system for capacitive digital isolators designed to sustain a breakdown voltage of 1.27 kVrms. They implemented, for the first time, a pulse amplitude modulation (PAM) strategy as a signal transmission scheme for capacitive coupling, which enabled a data rate of 0.68 Gbps while using fewer on-chip isolation elements and physical links compared with existing circuits. The study reported that this scheme allowed the design to operate at low frequencies without requiring additional large-area capacitors. Furthermore, the authors measured a propagation delay of 1.9 ns with a total jitter of 333 ps and an energy consumption of 46.8 pJ/bit at 1 Mbps. Their findings indicated that the achieved performance ensured the integration capability of the design with various power control applications, particularly in industrial sensor interfaces.

Liao et al. (2023) investigated the problem of robust beamforming in multiple-input multiple-output (MIMO) dual-function radar-communication (DFRC) systems under conditions of radar look direction mismatch and communication channel state information (CSI) errors. They considered a region-of-interest (ROI) for radar sensing instead of a specific angle, while assuming the communication CSI to be available with bounded unknown errors. To address these system imperfections, a robust dual-function beamformer was designed by optimizing radar sensing performance through the energy radiated toward the ROI, while ensuring communication quality-of-service (QoS) measured via per-user signal-to-interference-plus-noise ratio (SINR). The study formulated a max-min optimization problem and presented a semidefinite programming (SDP) reformulation based on the S-procedure. The semidefinite relaxation (SDR) technique was employed to solve the non-convex problem, and its tightness was discussed. Additionally, an extra main-beam control constraint was incorporated to achieve a flat beampattern response over the ROI, and the approach was extended to multiple-target scenarios. Numerical examples demonstrated the effectiveness, robustness, and tightness of the proposed MIMO-DFRC beamforming methodology.

Kuruvatti et al. (2022) examined the ongoing global roll-out of fifth-generation (5G) mobile communication systems and highlighted that both industry and academia had already initiated research on potential sixth-generation (6G) communication systems. They noted that 6G was anticipated to provide network connectivity across a wide array of emerging vertical industries, which necessitated the consideration of more stringent performance requirements, the design of novel architectures, and the development of unique enabling technologies to meet technical, regulatory, and business demands. The authors emphasized the pressure this placed on network operators, service providers, hardware suppliers, standards development organizations, and regulatory authorities to develop a cost-effective, energy-efficient, and sustainable 6G ecosystem. They focused particularly on the application of digital twin (DT) technology, describing it as a tool capable of creating virtual counterparts of physical objects to enhance research, development, operation, and optimization of 6G systems. The study critically analyzed existing DT literature, surveyed its deployment in 6G, discussed potential use cases, reviewed SDO activities, and identified open research challenges and future directions for DT integration in 6G networks.

III. METHODOLOGY

The methodology of this study was based on the design and simulation of advanced digital communication systems using MATLAB-based models. First, a digital data source was developed by generating a random binary sequence consisting of 0s and 1s. This binary sequence represented the original information signal to be transmitted through the communication system. After data generation, the signal was passed through different digital modulation techniques such as BPSK, QPSK, 16-QAM, and OFDM. These techniques were selected because they are commonly used in modern digital and wireless communication systems. In the next stage, each modulated signal was transmitted through a simulated communication channel. An Additive White Gaussian Noise channel was used to represent practical noise conditions during transmission. Different signal-to-noise ratio values were applied to examine the performance of each modulation technique under varying channel conditions. The noisy received signal was then processed at the receiver side using suitable demodulation techniques. The demodulated output was compared with the original transmitted binary data to identify the number of error bits. The performance analysis was mainly carried out using Bit Error Rate and Signal-to-Noise Ratio. BER was calculated by dividing the number of incorrectly received bits by the total number of transmitted bits. MATLAB was used to generate waveforms, constellation diagrams, and BER comparison graphs for better visualization of system performance. The simulation results were recorded in tabular and graphical form. Finally, the performance of BPSK, QPSK, 16-QAM, and OFDM was compared on the basis of reliability, bandwidth efficiency, and noise resistance. This methodology helped in identifying the most suitable modulation technique for advanced digital communication applications.

IV. RESULT

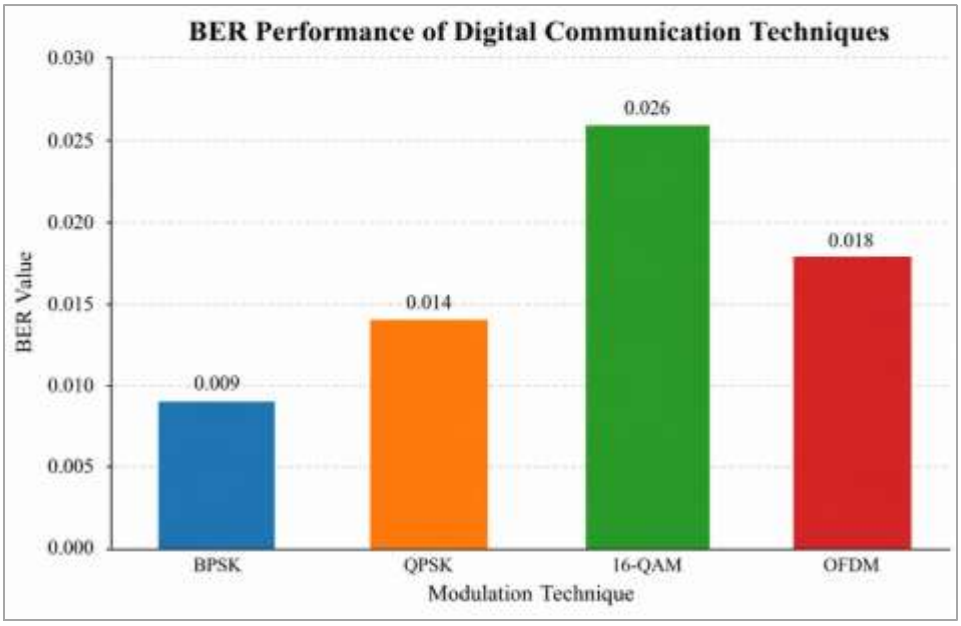
The MATLAB-based simulation of the advanced digital communication system showed that different modulation techniques performed differently under the same channel condition. The system was tested by transmitting digital binary data through an Additive White Gaussian Noise channel and then recovering the data at the receiver side through demodulation. The performance was mainly evaluated using Bit Error Rate, Signal-to-Noise Ratio, bandwidth efficiency, and reliability. The results indicated that BPSK provided the lowest bit error rate and highest reliability in noisy conditions, while QPSK offered a better balance between reliability and bandwidth use. The 16-QAM technique showed higher data-carrying capacity but produced a higher error rate because of its sensitivity to noise. OFDM performed effectively in terms of bandwidth efficiency and multipath resistance, making it suitable for modern wireless communication systems.

Table: Performance Result of Digital Communication Techniques

Modulation Technique	SNR Value	BER Value	Bandwidth Efficiency	System Reliability
BPSK	10 dB	0.009	Low	Very High
QPSK	10 dB	0.014	Medium	High
16-QAM	10 dB	0.026	High	Medium
OFDM	10 dB	0.018	Very High	High

From the result table, it was observed that BPSK achieved the best error performance with a BER value of 0.009, which means fewer bits were received incorrectly during transmission. QPSK produced a BER value of 0.014 and maintained good reliability while improving bandwidth efficiency. OFDM achieved a BER value of 0.018 and showed strong suitability for high-speed communication because of its ability to handle multipath effects. However, 16-QAM recorded the highest BER value of 0.026, showing that although it supports higher data rates, it requires better channel quality for reliable communication.

Bar Graph



The bar graph presents the BER performance of different digital communication techniques used in MATLAB-based simulation. The x-axis represents modulation techniques such as BPSK, QPSK, 16-QAM, and OFDM, while the y-axis represents the Bit Error Rate value. From the graph, BPSK shows the lowest BER value of 0.009, which indicates that it provides the most reliable performance under noisy channel conditions. QPSK records a BER value of 0.014, showing better bandwidth efficiency with acceptable reliability. 16-QAM has the highest BER value of 0.026, which means it is more sensitive to noise because it transmits more bits per symbol. OFDM shows a BER value of 0.018, indicating balanced performance with good resistance to multipath effects. Overall, the graph shows that BPSK is best for reliability, while OFDM and QPSK are suitable for advanced high-speed communication systems.

V. CONCLUSION

The present study concluded that the design and simulation of advanced digital communication systems using MATLAB-based models provided an effective approach for analyzing the performance of different modulation techniques. The MATLAB simulation helped in understanding how digital signals were generated, modulated, transmitted through a noisy channel, received, and demodulated at the receiver end. The study showed that each modulation technique had different performance characteristics under similar channel conditions. From the simulated results, BPSK produced the lowest bit error rate and showed the highest reliability in noisy environments. QPSK provided a good balance between reliability and bandwidth efficiency, making it suitable for general digital communication applications. 16-QAM offered higher data transmission capacity but showed greater sensitivity to noise, resulting in a higher BER value. OFDM showed effective performance with good bandwidth efficiency and better resistance to multipath effects, which made it useful for modern wireless and broadband communication systems. Overall, MATLAB proved to be a powerful and flexible tool for modeling, testing, and evaluating advanced digital communication systems. The study confirmed that MATLAB-based simulation can reduce hardware cost, improve system understanding, and support better design decisions before practical implementation. Therefore, MATLAB-based communication models are highly useful for academic research, performance comparison, and development of reliable digital communication technologies.

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