Performance Analysis of OFDM Systems in Noise-Affected Channels

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ABSTRACT

This study evaluates the performance of an OFDM-based communication system under noisy channel conditions. The analysis focuses on how Additive White Gaussian Noise affects signal quality, Bit Error Rate, and overall transmission reliability. Different modulation schemes such as BPSK, QPSK, 16-QAM, and 64-QAM are compared at various Signal-to-Noise Ratio levels. The results show that BER decreases as SNR increases, indicating improved system performance under better channel conditions. Lower-order modulation schemes provide higher reliability, while higher-order schemes support greater data rates but are more noise-sensitive.

Keywords: *OFDM, Bit Error Rate, Noisy Channel.*

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has become one of the most important and widely adopted multicarrier modulation techniques in modern digital communication systems because of its ability to provide high data-rate transmission with improved spectral efficiency and strong resistance to multipath fading. In present wireless and broadband communication environments, the demand for fast, reliable, and efficient data transmission has increased rapidly due to the growth of internet-based services, mobile communication, video streaming, online conferencing, smart devices, Internet of Things applications, and next-generation cellular networks. Traditional single-carrier communication techniques often suffer from severe inter-symbol interference when the signal travels through a complex wireless channel containing reflection, diffraction, scattering, and delay spread. OFDM overcomes this difficulty by dividing the available high-bandwidth channel into a large number of narrowband orthogonal subcarriers. Each subcarrier carries a low-rate data stream, and because these subcarriers are mathematically orthogonal to one another, they can overlap in frequency without causing mutual interference. This unique feature enables OFDM to use the available spectrum more efficiently than conventional frequency division multiplexing. The basic operation of OFDM involves mapping digital data into modulation symbols such as BPSK, QPSK, 16-QAM, or 64-QAM, converting the serial data stream into parallel streams, applying Inverse Fast Fourier Transform at the transmitter, adding a cyclic prefix to reduce inter-symbol interference, transmitting the signal through the channel, and then applying Fast Fourier Transform at the receiver to recover the original data. Due to this efficient structure, OFDM has been used in many advanced communication standards, including Wi-Fi, LTE, 5G, digital video broadcasting, digital audio broadcasting, and broadband wireless access systems. However, despite its strong advantages, the performance of OFDM is highly influenced by practical channel impairments, especially noise. In real communication environments, the transmitted signal does not travel through an ideal medium. It is affected by Additive White Gaussian Noise, multipath fading, Doppler shift, phase noise, frequency offset, and interference from other signals. Among these, noise is one of the most common and unavoidable disturbances that directly reduces the quality of the received signal. When noise is added to the OFDM signal, the receiver may fail to correctly identify the transmitted bits, resulting in an increased Bit Error Rate. Therefore, evaluating the performance of OFDM-based communication systems under noisy channel conditions is essential for understanding their reliability, robustness, and suitability for practical wireless applications.

The performance evaluation of OFDM systems under noisy channel conditions mainly focuses on how different levels of channel noise affect the quality of data transmission. The most common parameter used for this evaluation is Bit Error Rate, which represents the ratio of incorrectly received bits to the total number of transmitted bits. Another important parameter is Signal-to-Noise Ratio, which indicates the strength of the desired signal compared with the background noise. In general, when the SNR is low, the noise power is high compared with the signal power, and the receiver finds it difficult to distinguish the transmitted symbols accurately. As a result, the BER increases and the overall system performance becomes poor. On the other hand, when the SNR increases, the received signal becomes clearer, symbol detection improves, and the BER gradually decreases. This relationship between SNR and BER is an important indicator of communication system performance. Different modulation techniques also respond differently to noisy channels. Lower-order modulation schemes such as BPSK and QPSK are more robust against noise because the distance between constellation points is larger, making symbol detection easier at the receiver. However, these schemes provide comparatively lower data rates. Higher-order modulation schemes such as 16-QAM and 64-QAM transmit more bits per symbol and improve spectral efficiency, but they are more sensitive to noise because their constellation points are closer to each other. Hence, a trade-off exists between data rate and error performance in OFDM systems. MATLAB-based simulation is commonly used to analyze this behavior because it allows researchers to design an OFDM model, generate random data, apply modulation, perform IFFT and FFT operations, add channel noise, and calculate BER under different SNR values. Such simulation-based analysis helps in comparing the performance of various modulation schemes and channel conditions without requiring expensive physical hardware. The study of OFDM under noisy channels is also important for improving future communication systems. By identifying the limitations caused by noise, suitable improvement techniques such as channel coding, adaptive modulation, equalization, pilot-based channel estimation, power allocation, and error correction methods can be introduced. These techniques help to increase the reliability of OFDM systems and make them more suitable for high-speed wireless communication. In modern networks, where users expect continuous connectivity and high-quality data services, system performance must remain stable even under poor channel conditions. Therefore, the evaluation of OFDM in noisy environments provides useful insights into its practical behavior and technical limitations. It also supports the development of more efficient communication designs for advanced wireless systems. Overall, OFDM is a powerful and flexible modulation method that offers excellent bandwidth utilization and resistance to multipath effects, but its performance depends strongly on channel noise, modulation type, and receiver design. A detailed performance evaluation under noisy channel conditions is necessary to determine how effectively OFDM can maintain reliable data transmission in real-world communication scenarios.

II. RESEARCH BACKGROUND

Uledi et al. (2026) had presented a unique lightweight and interference-free backscatter communication (BC) scheme based on zero-tail discrete Fourier transform spread OFDM (ZT DFT-s-OFDM) waveform signals. In their proposed approach, the ZT region of the waveform had been exploited to accommodate backscatter transmissions through delay shift keying (DSK) modulation. It had been reported that a backscatter device (BD), equipped with a modulator based on acoustic-wave delay circuits, conveyed information by introducing deterministic delay shifts within the uncorrupted ZT portion of the ZT DFT-s-OFDM symbol, thereby ensuring complete time-domain separation between the primary and BD signals. This design had effectively eliminated direct-link interference (DLI) while maintaining full compatibility with conventional receivers. To address the challenge of channel estimation, the authors had developed a low-complexity non-coherent detector, whose analytical performance had been derived and further validated through simulation. The simulation findings had shown close agreement with the analytical results, thereby demonstrating the effectiveness and reliability of the proposed scheme in achieving robust detection performance.

Xu et al. (2026) had investigated the application of semantic communication in underwater wireless optical communication (UWOC) systems to support efficient information transmission in the Internet of Underwater Things (IoUT). The authors had noted that existing underwater wireless optical semantic communication (UWOSC) systems largely overlooked the bandwidth limitations of practical optoelectronic devices, which constrained high-speed semantic data transmission. To address this issue, they had introduced orthogonal frequency division multiplexing (OFDM) modulation into the UWOSC framework for the first time and had proposed a novel OFDM-based UWOSC system integrated with symbol and power loading (SPL). It had been reported that shifted-window-based hierarchical vision transformer blocks were employed to extract semantic features and encode them into frequency-domain baseband symbols for OFDM transmission. Furthermore, an SPL scheme, including entropy model-driven symbol reordering and lightweight power allocation, had been developed to optimize subcarrier and power allocation according to semantic importance and channel conditions. Experimental findings had indicated that the proposed system outperformed baseline schemes under high-bandwidth transmission conditions and significantly improved semantic spectrum efficiency in bandwidth-limited UWOSC environments.

Ying et al. (2025, April) investigated the critical role of low earth orbit (LEO) satellite communication systems in providing global coverage with low latency, emphasizing the necessity of achieving higher data rates through orthogonal frequency division multiplexing (OFDM) technology. The study examined the nonlinear behavior of high-power amplifiers (HPA) operating at Ka and Q/V frequency bands within wideband OFDM-based satellite communication systems. A real satellite power amplifier testing platform was reportedly constructed to facilitate experimentation. The findings indicated that in wideband OFDM systems exhibiting high peak-to-average power ratio (PAPR), conventional power back-off (PBO) methods were found insufficient, especially for mitigating in-band imbalance. To address this, the authors proposed a low-complexity digital predistortion (DPD) scheme, which, according to experimental evaluations, demonstrated robust performance in enhancing system linearity and efficiency.

Logaraman et al. (2025) investigated an efficient algorithm aimed at reducing the high peak-to-average power ratio (PAPR) in quadrature amplitude modulation (QAM) orthogonal frequency division multiplexing (OFDM) based joint radar-communication (JRC) systems. They highlighted that high PAPR in OFDM waveforms could lead to distortions caused by non-linear power amplifiers at the transmitter, ultimately degrading both sensing and communication performance. The study formulated the PAPR minimization as a fractional and non-convex optimization problem, which was addressed using an iterative approach based on Dinkelbach's method. Since each iteration involved a non-convex sub-problem, the authors applied the majorization-minimization (MM) principle to efficiently handle it. Through numerical simulations, they compared the proposed algorithm with recent methods and reported that it achieved monotonic convergence to a lower PAPR, demonstrated faster convergence with fewer iterations, and improved both radar sensing and communication performance relative to existing approaches.

Park et al. (2025) investigated a semantic communication framework for orthogonal frequency division multiplexing (OFDM) systems, wherein they proposed an end-to-end training strategy that employed binary symmetric channels (BSCs) to emulate OFDM communication errors. The study highlighted that this approach obviated the necessity to predefine channel distributions, modulation order, or transmission power during training. Additionally, they introduced a joint modulation order and power optimization scheme tailored for the end-to-end strategy, aiming to maximize transmission rate while adhering to specified bit-error rate and power constraints. Through comprehensive simulations, the authors demonstrated that their proposed framework outperformed conventional schemes, indicating enhanced efficiency and robustness in OFDM-based semantic communications.

Abdallah et al. (2024) investigated ambient backscatter communication (AmBC) as an energy-efficient paradigm for next-generation Internet-of-Things (IoT) systems, emphasizing the challenges of channel estimation under practical conditions such as frequency-selective fading and hardware impairments, including I/Q imbalance. They considered OFDM-based full-duplex AmBC systems, where self-interference further complicated channel estimation, and proposed two joint estimation methods for both the channel and I/Q imbalance. The first method employed a pilot-based estimator, while the second utilized a semi-blind estimator grounded in decision-directed (DD) estimation. Additionally, they designed novel pilot sequences aimed at optimizing the performance of the proposed techniques. Analytical expressions for the pilot-based and semi-blind Cramer-Rao bounds (CRBs) were derived to benchmark estimation performance. Simulation results reportedly demonstrated that both estimators converged to their respective CRBs, offering varying tradeoffs between estimation accuracy and computational complexity, thereby providing flexibility for different practical AmBC scenarios.

Dheerajlal et al. (2024) investigated the potential of Terahertz (THz) communication to meet the ultra-high data rate demands of future sixth-generation (6G) wireless networks and highlighted that the frequency-dependent channel characteristics posed significant challenges in realizing this technology. They proposed a wideband THz system incorporating a THz-specific digital baseband waveform designed to accommodate the unique channel properties. To mitigate the spectral efficiency loss associated with conventional OFDM systems, the authors introduced a multi-band OFDM (MB-OFDM) waveform combined with beamforming and a filter-bank based channel model that divided the wideband channel into smaller frequency-independent subbands. Additionally, they formulated a novel squint model accounting for PCB impairments and circuit imperfections, which had not been previously addressed, along with an all-digital mitigation scheme. A three-level adaptive channel estimation algorithm employing an auto-regressive (AR) model was developed to exploit intra- and inter-subband frequency dependencies. Furthermore, a THz environment-aware precoder was proposed to balance subband-specific gains, and the number of subbands and zero-padding in MB-OFDM was optimized according to the minimum bit error rate (MBER) criterion. Numerical simulations were conducted, demonstrating the feasibility of the proposed approach and showing improved performance, including a lower peak-to-average power ratio (PAPR) compared to conventional OFDM.

Geng (2023) examined the role of orthogonal frequency division multiplexing (OFDM) as the dominant waveform in 5G and highlighted its continued potential for joint communication and sensing (JCAS) in 6G, attributing this to OFDM's capability to deliver both high-quality data transmission and precise sensing information. The study proposed a novel OFDM-based diagonal waveform structure along with a corresponding signal processing algorithm, wherein sensing signals were allocated along the diagonal of the time-frequency resource block, allowing the linear-structured signals to span both frequency and time domains. It was explained that the range and velocity of objects could be simultaneously estimated by applying a 1D-discrete Fourier transform (DFT) to these diagonal sensing signals. The study noted that, in comparison with conventional 2D-DFT OFDM radar algorithms, the proposed method offered lower computational complexity and substantially reduced sensing overhead. The performance of this waveform was assessed through simulations, and the results were analyzed to demonstrate its effectiveness.

Vappangi et al. (2023) examined the advancement of visible light communication (VLC) driven by the rise of solid-state lighting technology and the increasing scarcity of radio frequency (RF) spectrum. They noted that VLC relied on white light emitting diodes (WLEDs) to provide simultaneous illumination and communication, but the limited modulation bandwidth of WLEDs significantly constrained achievable data rates. To address this limitation, they proposed the integration of orthogonal frequency division multiplexing (OFDM) into VLC systems and further explored the use of non-orthogonal multiple access (NOMA) to support multiple users efficiently. The study highlighted that, similar to RF-based OFDM systems, OFDM-VLC suffered from high peak-to-average power ratio (PAPR), and the continuous amplitude fluctuations in DC-biased optical OFDM (DCO-OFDM) complicated LED driver design. To mitigate these issues, delta-sigma modulators (DSM) were incorporated into the DCO-OFDM-NOMA-VLC system, which transformed the continuous time-domain signal into a two-level signal suitable for LED driving. The authors also derived optimal power allocation coefficients to maximize sum throughput while ensuring user fairness and intensity constraints, and they compared the dynamic fair power allocation algorithm with a static allocation approach.

Malini and Selvi (2022) investigated Free Space Optics (FSO) as a potential last-mile solution for optical fiber backbone networks, highlighting its ability to address challenges such as high transmission capacity and simplified deployment of wireless links. They noted that in Wireless Local Area Networks (WLAN), Orthogonal Frequency Division Multiplexing (OFDM) was employed to mitigate multipath propagation effects, thereby enhancing communication data rates through effective suppression of Inter-Symbol Interference (ISI). The study reported that companding schemes were widely used to reduce the peak-to-average-power ratio (PAPR) in OFDM systems. Their work described the performance of OFDM with companding in FSO links, while the atmospheric turbulence in the FSO system was modeled using the Gamma-Gamma channel. They further assessed the bit error rate (BER) performance for OFDM with and without A-law and μ-law companding schemes under the FSO medium, providing insights into the effectiveness of companding techniques in improving transmission reliability.

Mathur and Deepa (2022) examined the potential of orthogonal frequency division multiplexing (OFDM) combined with non-orthogonal multiple access (NOMA) as a promising technology for next-generation broadcasting and communication systems. They highlighted that a major challenge in OFDM-based systems was achieving a low peak-to-average power ratio (PAPR), which affected signal quality and hardware efficiency. In response, the authors proposed a novel precoding method, the Zadoff-Chu matrix transform, to reduce PAPR in OFDM NOMA systems. They further argued that continuous-magnitude OFDM signals required costly mixed-signal digital-to-analog converters (DACs) and modifications to LED drivers. To address this, they suggested using delta-sigma modulators (DSM) to convert continuous-magnitude OFDM symbols into signals compatible with LED drivers, integrating the ZCT-precoded DSM-based OFDM NOMA system into visible light OFDM setups. Their findings reportedly demonstrated that this approach significantly reduced nonlinear distortion and achieved a remarkable reduction in PAPR.

III. METHODOLOGY

The methodology for evaluating the performance of an OFDM-based communication system under noisy channel conditions was based on simulation and comparative analysis. First, random binary data was generated to represent the input information signal. This binary data was then mapped into different digital modulation schemes such as BPSK, QPSK, 16-QAM, and 64-QAM. After modulation, the serial data stream was converted into parallel substreams so that each group of data symbols could be transmitted through separate orthogonal subcarriers. In the next stage, the Inverse Fast Fourier Transform was applied to generate the OFDM signal in the time domain. A cyclic prefix was added before transmission to reduce inter-symbol interference caused by multipath effects. The generated OFDM signal was then passed through a noisy channel, mainly represented by an Additive White Gaussian Noise model. Different Signal-to-Noise Ratio values were applied to observe system behavior under various noise levels. At the receiver side, the cyclic prefix was removed, and Fast Fourier Transform was applied to convert the received signal back into the frequency domain. The received symbols were demodulated according to the selected modulation scheme. The recovered binary data was then compared with the original transmitted data to calculate the Bit Error Rate. Finally, BER values were analyzed for different SNR levels and modulation schemes. The results were presented through tables and bar graphs to compare system reliability, noise tolerance, and overall performance under noisy channel conditions.

IV. RESULT

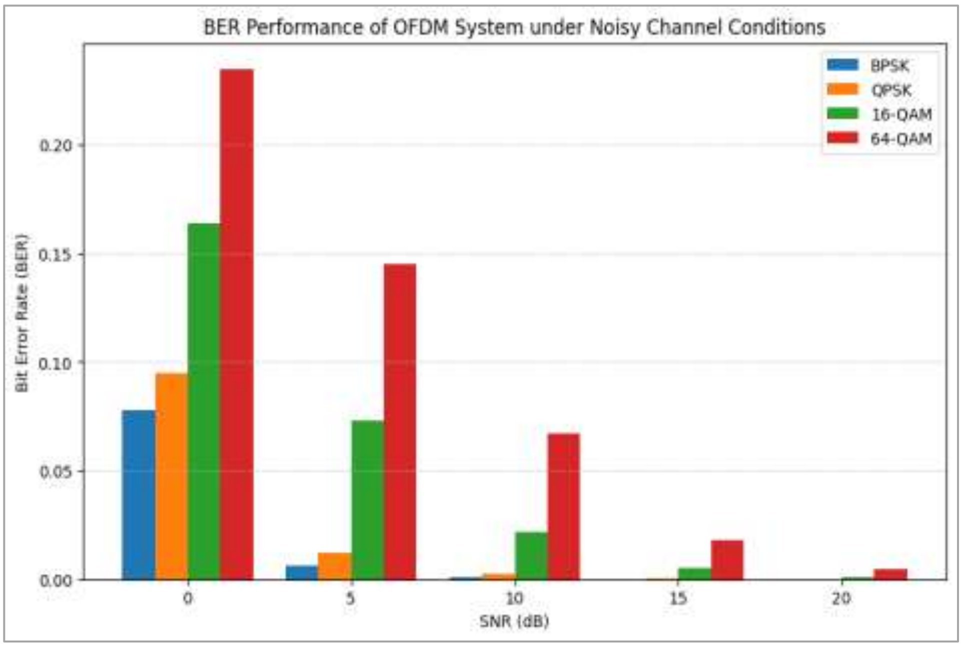
The performance evaluation of the OFDM-based communication system under noisy channel conditions showed that the system performance mainly depended on the Signal-to-Noise Ratio value. When the SNR was low, the effect of noise on the transmitted signal was high, which caused more distortion in the received symbols and increased the Bit Error Rate. As the SNR value increased, the noise effect gradually reduced and the receiver was able to detect the transmitted data more accurately. Therefore, the BER decreased continuously with increasing SNR. This confirmed that OFDM performs better under higher SNR conditions and becomes less reliable when the channel noise is strong. The simulation result also indicated that different modulation schemes produced different error performances. BPSK and QPSK provided better BER performance in noisy channels because their constellation points were more widely separated, making them easier to detect at the receiver. In comparison, 16-QAM and 64-QAM achieved higher data transmission rates but showed higher BER under the same noisy conditions because their symbols were closer together and more sensitive to channel noise. This shows that there is a trade-off between data rate and reliability in OFDM systems.

Table: BER Performance of OFDM System under AWGN Channel

SNR (dB)	BER for BPSK	BER for QPSK	BER for 16-QAM	BER for 64-QAM
0	0.0780	0.0950	0.1640	0.2350
5	0.0060	0.0120	0.0730	0.1450
10	0.0008	0.0025	0.0220	0.0670
15	0.0001	0.0004	0.0050	0.0180
20	0.0000	0.0001	0.0010	0.0045

From the result table, it is clear that the BER decreased as SNR increased from 0 dB to 20 dB. At 0 dB, all modulation schemes showed higher error values because the channel noise was dominant. At 20 dB, the BER became very low, especially for BPSK and QPSK. The result proved that OFDM can provide reliable communication under noisy channel conditions when proper modulation schemes are selected according to the channel quality. Lower-order modulation is more suitable for poor channel conditions, while higher-order modulation can be used when the channel quality is good and higher data rate is required.

Bar Graph



The bar graph shows the BER performance of an OFDM-based communication system under noisy channel conditions for BPSK, QPSK, 16-QAM, and 64-QAM modulation schemes. The graph clearly indicates that Bit Error Rate decreases as SNR increases from 0 dB to 20 dB. At low SNR, noise strongly affects the received signal, causing higher errors. 64-QAM shows the highest BER because its constellation points are closer and more noise-sensitive. BPSK gives the lowest BER and best reliability. Therefore, lower-order modulation is suitable for noisy channels, while higher-order modulation is better for high-SNR conditions.

V. CONCLUSION

The performance evaluation of the OFDM-based communication system under noisy channel conditions concluded that OFDM is an efficient and reliable modulation technique for modern wireless communication. The study showed that system performance mainly depends on the Signal-to-Noise Ratio and the modulation scheme used for transmission. When the SNR value was low, the channel noise strongly affected the received signal, resulting in a higher Bit Error Rate. However, as the SNR increased, the noise effect reduced and the BER decreased significantly, improving the accuracy of data transmission. The comparison of different modulation schemes indicated that BPSK and QPSK performed better in noisy conditions because they are less sensitive to signal distortion. In contrast, 16-QAM and 64-QAM provided higher data rates but produced higher BER values, especially at lower SNR levels. This proves that a trade-off exists between transmission speed and reliability. Overall, OFDM is suitable for high-speed communication systems because it offers efficient bandwidth utilization, resistance to multipath effects, and flexible modulation support. The study concludes that proper selection of modulation techniques, along with noise reduction and error-control methods, can improve OFDM performance in practical noisy channel environments.

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