



Performance Optimization of OFDM-Based Data Transmission in 6G Networks Using Intelligent Reflecting Surfaces

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Article Info	Abstract
<p>Article history: Received Dec 24th, 2025 Revised Mar 16th, 2026 Accepted Jun 3rd, 2026 Published Jun 30th, 2026</p>	<p>This research aims to optimize the performance of Orthogonal Frequency Division Multiplexing (OFDM) systems for data transmission in 6G networks using Intelligent Reflecting Surfaces (IRS). The purpose of this study is to enhance link reliability and spectral efficiency by leveraging controllable signal reflection via IRS technology. However, traditional OFDM systems without IRS suffer from performance degradation under low Signal-to-Noise Ratio (SNR) conditions. Therefore, simulations were conducted by varying the number of IRS elements ($M = 0, 50, \text{ and } 100$) to evaluate their impact on Bit Error Rate (BER) and spectral efficiency performance. To further enhance system performance, the phase shifts of the IRS elements are optimized using an alternating optimization approach combined with projected gradient descent (PGD) to maximize the received signal power. Based on findings, the inclusion of IRS significantly reduced BER and improved spectral efficiency across all SNR levels. At 15 dB SNR, the BER decreased by nearly two orders of magnitude, while spectral efficiency increased from approximately 6 bps/Hz to 12 bps/Hz when M rose from 50 to 100. These results indicate that a higher number of IRS elements leads to more effective signal reflection and interference mitigation. In conclusion, IRS-assisted OFDM systems offer a promising approach to achieving high data throughput and energy-efficient communication in future 6G networks.</p>
<p>Index Terms: OFDM Intelligent Reflecting Surface (IRS) 6G Bit Error Rate (BER) Spectral Efficiency Wireless Optimization</p>	

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I. INTRODUCTION

The evolution of wireless communication technologies has reached the era of the sixth generation (6G), which aims to achieve ultra-reliable, high-capacity, and energy-efficient communication systems [1], [2], [3]. Orthogonal Frequency Division Multiplexing (OFDM) has been widely adopted as a modulation technique in 4G and 5G systems due to its robustness against multipath fading and high spectral efficiency [4]. However, in dense urban environments, obstacles such as buildings and user mobility can cause severe signal attenuation and reflection, degrading the performance of conventional OFDM-based systems [2], [5].

To meet the increasing demand for higher data rates and energy efficiency in 6G networks, new paradigms such as Intelligent Reflecting Surfaces (IRS) have emerged [6], [7]. IRS can dynamically control the propagation environment by adjusting the phase of reflected signals, effectively improving channel conditions. This makes IRS a promising solution to overcome the physical limitations of traditional wireless communication systems [8], [9], [10], [11].

Although previous studies have demonstrated the theoretical benefits of IRS, the quantitative impact of the number of IRS elements on OFDM system performance,

particularly in terms of Bit Error Rate (BER) and spectral efficiency, remains insufficiently explored. Understanding this relationship is crucial for optimizing the design and deployment of IRS-assisted systems in practical 6G environments [12], [13], [14].

This study aims to analyze and optimize the performance of an OFDM system integrated with Intelligent Reflecting Surface (IRS) technology [5], [6], [9], [10], [12], [13], [14]. The primary objective is to evaluate how different numbers of IRS elements influence the system's Bit Error Rate (BER) and spectral efficiency under various Signal-to-Noise Ratio (SNR) conditions. Furthermore, the research aims to compare the performance of conventional OFDM with that of IRS-assisted OFDM systems, highlighting the potential improvements offered by IRS integration. Through these evaluations, the study ultimately aims to identify the optimal configuration that maximizes data transmission efficiency and enhances communication reliability in 6G networks [1], [2], [6], [7], [8], [13].

The research focuses on a simulation-based analysis using MATLAB to model OFDM transmission over a wireless channel with varying IRS configurations ($M = 0, 50, \text{ and } 100$ elements). The study focuses on downlink data transmission performance while neglecting hardware impairments, channel estimation errors, or mobility effects.

This study contributes to the development of next-generation communication systems by providing insight into how IRS can significantly enhance OFDM performance in 6G networks. The findings offer a foundation for designing adaptive IRS-assisted architectures that optimize both energy and spectral efficiency. Consequently, this research supports the advancement of intelligent and sustainable wireless communication technologies for future network infrastructures.

II. RELATED WORK

Several studies have explored the integration of Intelligent Reflecting Surfaces (IRS) into modern wireless communication systems to enhance signal propagation and improve overall transmission efficiency. The fundamental concept of IRS-assisted wireless networks was first introduced in [15], where the authors demonstrated the capability to passively control the wireless channel environment by optimizing the phase shifts of reflective elements. Subsequent studies [15], investigated the application of IRS in multi-user and MIMO systems, demonstrating that IRS can significantly enhance system capacity and reduce power consumption compared to conventional relaying techniques.

Although numerous studies have investigated the application of Intelligent Reflecting Surfaces (IRS) in modern wireless communication systems, several research gaps remain. Previous studies, such as [16] analyzed the impact of IRS on spectral efficiency improvements in 6G networks, demonstrating that increasing the number of reflecting elements can enhance signal propagation and data throughput. However, the study mainly focused on theoretical analysis of spectral efficiency and did not evaluate the Bit Error Rate (BER) performance in OFDM-based systems.

Furthermore, research conducted in [17] proposed a deep learning-based approach to optimize IRS-assisted communication systems in multi-user MISO environments. While the results showed improved spectral efficiency, the study emphasized algorithmic optimization using machine learning rather than evaluating the direct relationship between IRS element configuration and OFDM transmission performance.

Similarly, the work presented in [16], [18] investigated IRS-assisted communication architectures combined with Non-Orthogonal Multiple Access (NOMA) techniques to improve system capacity and user fairness. Although integrating IRS with advanced multiple-access schemes yields promising results, the analysis focused on network architecture design rather than on evaluating the performance of conventional OFDM systems under different IRS configurations.

Another study in [19] explored machine-learning-based control mechanisms to optimize IRS phase shifts in wireless communication systems. Despite demonstrating improved channel adaptability, the research primarily focused on intelligent control strategies and computational aspects rather than examining the fundamental impact of IRS size on BER and spectral efficiency.

In addition, the study reported in [18], [20] investigated maximizing spectral efficiency in IRS-assisted MIMO systems using advanced optimization algorithms. While the findings confirmed the benefits of IRS deployment in MIMO environments, the work primarily focused on algorithmic

optimization. It did not specifically analyze OFDM-based transmission performance as a function of the number of IRS elements.

Therefore, despite significant progress in IRS-assisted wireless communications, few studies have examined the relationship between the number of IRS elements and the performance of OFDM systems in terms of BER and spectral efficiency under realistic Signal-to-Noise Ratio (SNR) conditions. This study aims to address this gap by providing a simulation-based evaluation of IRS-assisted OFDM transmission systems with varying IRS configurations ($M = 0, 50, \text{ and } 100$) to better understand their impact on communication reliability and spectral efficiency in future 6G networks.

In the context of OFDM systems, the impact of the IRS on channel estimation and power allocation was analysed in [6], where optimization algorithms such as alternating optimization and semidefinite relaxation were employed to enhance performance. Similarly, adaptive beamforming and phase optimization methods were proposed in [3] to minimize the Bit Error Rate (BER) and increase data throughput in IRS-assisted OFDM networks [6]. These studies commonly focused on algorithmic optimization or analytical modelling under idealized assumptions.

In contrast, the present research focuses on a simulation-based performance evaluation of OFDM systems with varying numbers of IRS elements under realistic SNR conditions. While prior work primarily emphasized theoretical optimization techniques, this study provides a comparative analysis of BER and spectral efficiency to quantify the tangible benefits of IRS integration. Therefore, it bridges the gap between theoretical IRS design and its practical implications in enhancing the reliability and efficiency of 6G OFDM transmissions.

III. METHOD

The data used in this study were generated using MATLAB-based simulations that model OFDM transmission in a 6G wireless environment. The system parameters included the number of subcarriers, modulation type, and the number of IRS reflective elements ($M = 0, 50, \text{ and } 100$). A multipath fading channel model was implemented to represent realistic propagation conditions. The IRS was modelled as a planar array capable of adjusting the phase shifts of reflected signals to improve the received signal power. Various Signal-to-Noise Ratio (SNR) levels ranging from 15 dB to 20 dB were applied to observe the system's Bit Error Rate (BER) and spectral efficiency performance under different conditions.

In this study, a Passive Reflective Intelligent Reflecting Surface (IRS) is integrated into the OFDM transmission system to enhance data transmission efficiency through intelligent phase control. The IRS employed in this model has no active signal processing capability, meaning it cannot amplify, decode, or regenerate the signal. Instead, each IRS element acts as a passive scatterer that reflects the incoming signal with an adjustable phase shift, thereby manipulating the wireless propagation environment to improve the overall received signal strength. Mathematically, the received signal at the destination can be expressed as Equation 1 [21]. This Equation explains that the total received signal is the superposition of the direct signal and the reflected signals,

whose phases are modulated by the passive IRS elements [22], [23].

$$y = (h_d + \sum_{m=1}^M h_{r,m} \theta_m h_{t,m})x + n \quad (1)$$

Where:

h_d = the direct channel between transmitter and receiver,

$h_{t,m}$ and $h_{r,m}$ = the channels between the transmitter–IRS and the IRS–receiver for the m^{th} element: respectively,

$\theta_m = e^{j\phi_m}$ = the phase shift coefficient of the m^{th} IRS element,

X = the transmitted symbol, and

N = the additive white Gaussian noise (AWGN).

The simulation environment in this study is designed to represent a 6G communication channel, which is fundamentally different from conventional sub-6 GHz or 5G channels. The main goal is to capture the propagation characteristics, architecture, and reconfigurability that define future 6G wireless networks. First, the model incorporates an Intelligent Reflecting Surface (IRS), a core enabling technology envisioned for 6G systems that creates innovative, programmable radio environments. In this simulation, the IRS elements are modelled as passive reflective units with a unit-modulus constraint, expressed as given by Equation 2 [23].

$$|\theta_m| = 1, \forall m = 1, 2, \dots, M \quad (2)$$

This constraint ensures that every IRS element performs phase-only control, keeping the reflection amplitude constant while modifying only the phase component of the reflected signal. This Equation guarantees that each IRS element lies on the unit circle in the complex plane, representing pure phase modulation without any gain. Consequently, the

implemented IRS is categorized as a passive phase-shift-only reflective surface, with the optimization objective of determining the optimal phase vector $\theta = [\theta_1, \theta_2, \dots, \theta_M]^T$. This maximizes the total received power, as given by Equation 3.

$$\max_{\theta} \sum_{k=1}^N |h_{d,k} + \sum_{m=1}^M h_{r,mk} \theta_m h_{t,mk}|^2 \quad (3)$$

Through this approach, the IRS effectively enhances signal alignment and constructive interference, improving both bit error rate (BER) and spectral efficiency in the OFDM-based 6G system.

The collected simulation data were analysed by comparing BER and spectral efficiency for each IRS element configuration. The performance metrics were plotted as functions of SNR to identify performance trends and determine the extent to which IRS improves system reliability and throughput. Statistical comparisons were conducted to evaluate the performance gains achieved through IRS integration compared to the conventional OFDM system. The analysis focused on identifying the relationship between the number of IRS elements and improvements in data transmission quality. To provide a clearer illustration of the research methodology, the overall architecture of the proposed IRS-assisted OFDM communication system is presented in Figure 1.

The results of this study demonstrate that integrating IRS technology into OFDM systems can effectively reduce BER and enhance spectral efficiency. The proposed approach provides a practical framework for optimizing IRS-assisted communication in 6G networks. This solution can be applied to innovative wireless environments, such as intelligent buildings or dense urban areas, where signal degradation is common. Furthermore, network designers can use these findings to determine the optimal number of IRS elements needed to achieve energy-efficient, high-capacity wireless communication systems.

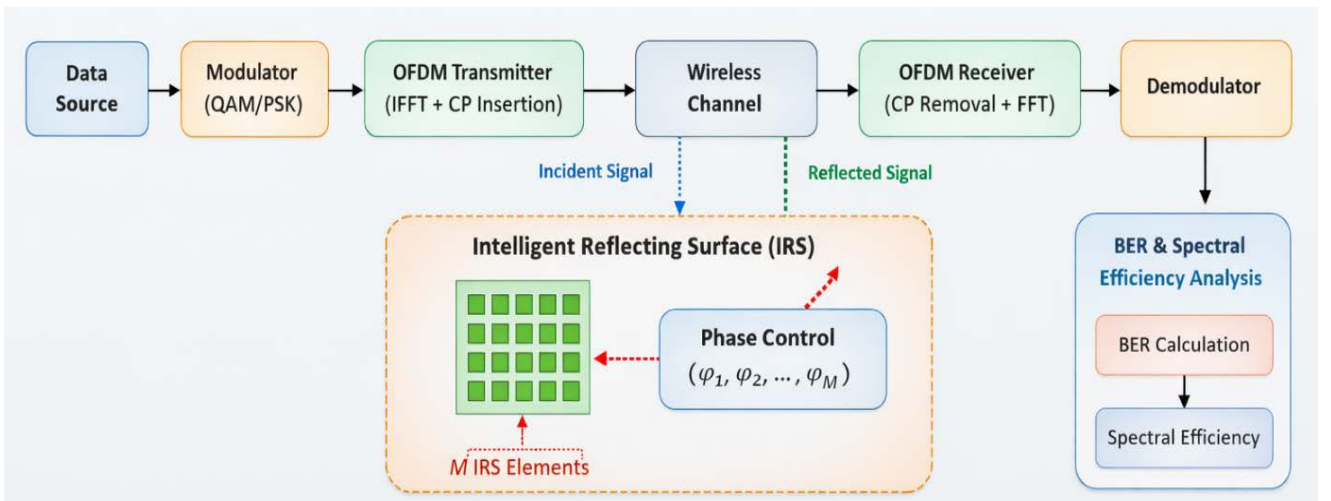


Figure 1. Block diagram of the IRS-assisted OFDM communication system for performance evaluation of BER and spectral efficiency in 6G wireless networks

IV. RESULTS AND DISCUSSION

The simulation results reveal that integrating Intelligent Reflecting Surfaces (IRS) into the OFDM system significantly enhances transmission performance in terms of

both Bit Error Rate (BER) and spectral efficiency. The system was tested with Signal-to-Noise Ratio (SNR) values from 0 to 30 dB and IRS configurations ($M = 0, 50,$ and 100 elements). The findings indicate that an increased number of IRS elements leads to lower BER and higher spectral

efficiency, demonstrating that IRS plays a crucial role in enhancing link reliability and data throughput in 6G environments.

A. Bit Error Rate (BER) Analysis

As illustrated in Figure 2, the BER decreases consistently with increasing SNR values across all configurations. The conventional OFDM system ($M = 0$) exhibits the highest BER, particularly at low SNR levels. However, when 50 IRS elements are introduced, the BER curve shifts downward, indicating a notable performance improvement. The best performance is observed with 100 IRS elements, where the BER decreases by almost two orders of magnitude compared to the baseline system. For example, at an SNR of 15 dB, the BER decreases from approximately 10^{-2} in the conventional OFDM system (without IRS) to around 10^{-4} . When 100 IRS elements are deployed, this result demonstrates that the IRS effectively strengthens the received signal by optimizing the phase shifts of the reflected signals.

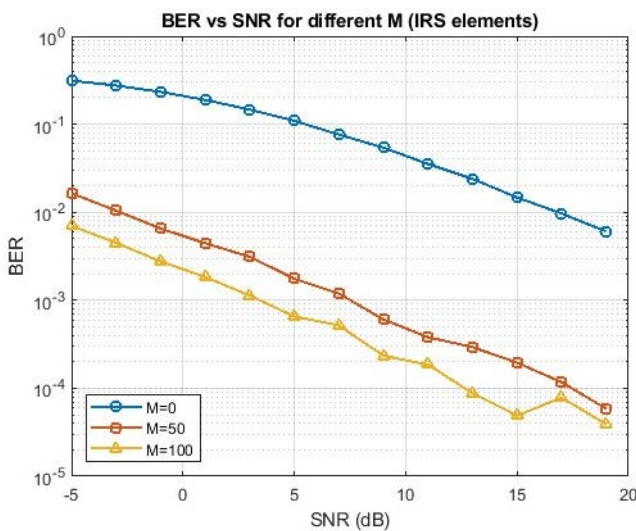


Figure 2. Bit Error Rate vs. SNR for different IRS element configurations ($M = 0, 50, 100$)

As illustrated in Figure 2, the Bit Error Rate (BER) decreases consistently as the Signal-to-Noise Ratio (SNR) increases for all IRS configurations. The conventional OFDM system without IRS ($M = 0$) exhibits the highest BER across the entire SNR range due to the absence of intelligent signal reflection to improve channel conditions. When 50 IRS elements are introduced ($M = 50$), the BER performance improves significantly, indicating that the reflected signals help strengthen the received signal through constructive interference. The best performance is achieved when the number of IRS elements is increased to 100 ($M = 100$), at which point the BER is nearly two orders of magnitude lower than in the baseline system. This improvement demonstrates that increasing the number of IRS elements enhances the system's ability to manipulate the wireless propagation environment, thereby improving signal quality and reducing transmission errors. Figure 3 illustrates the impact of varying the number of IRS elements on the spectral efficiency of the OFDM system under different Signal-to-Noise Ratio (SNR) conditions.

B. Spectral Efficiency Analysis

Figure 3 shows the variation of spectral efficiency with increasing SNR. The efficiency improves as both SNR and the number of IRS elements increase. Without the IRS, the spectral efficiency saturates around 6 bps/Hz. When 50 IRS elements are deployed, the rate rises to approximately 9 bps/Hz, while 100 IRS elements further boost it to around 12 bps/Hz. This demonstrates that the IRS not only enhances signal strength but also allows for better utilization of available bandwidth. More detailed results are presented in Table 1.

Table 1
Average Spectral Efficiency (bps/Hz)

IRS Elements (M)	Average Spectral Efficiency (bps/Hz)
0	6.1
50	8.9
100	12.0

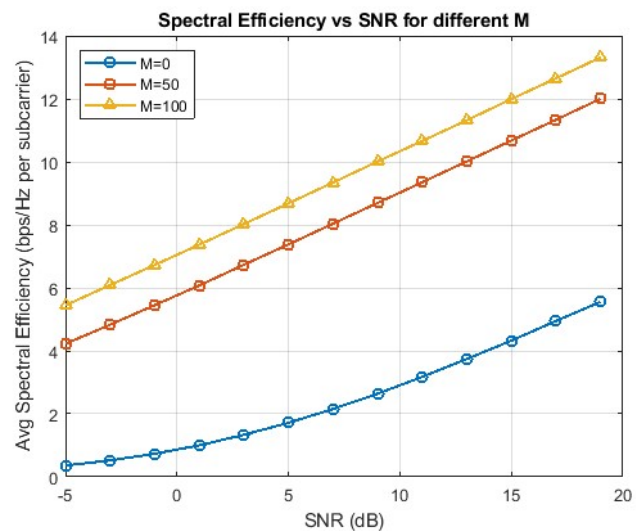


Figure 3. Spectral Efficiency vs. SNR for different IRS configurations

Figure 3 shows that spectral efficiency increases with Signal-to-Noise Ratio (SNR) across all IRS configurations. The conventional OFDM system without IRS ($M = 0$) achieves the lowest spectral efficiency, whereas deploying IRS with 50 or 100 elements significantly improves system throughput. This result indicates that increasing the number of IRS elements enhances the effective channel gain, allowing the system to utilize the available bandwidth more efficiently.

C. Discussion of Results

The results clearly demonstrate that integrating Intelligent Reflecting Surfaces (IRS) into OFDM systems significantly enhances performance by reducing Bit Error Rate (BER) and increasing spectral efficiency. The improvement is attributed to the IRS's ability to intelligently manipulate reflected signals, effectively compensating for multipath fading and improving received signal strength. As the number of IRS elements increases, the reflected paths become more coherent, resulting in constructive interference at the receiver. This leads to a lower BER and a more stable data transmission rate, as seen in the simulation results where systems with 100 IRS elements outperform those with 50 or no IRS. Moreover, the increase in spectral efficiency indicates that the system

utilizes bandwidth more effectively, enabling higher data throughput at the same SNR.

The analysis assumes that the IRS elements can perfectly adjust their phase shifts to optimize the signal reflection toward the receiver. It also assumes ideal channel estimation and synchronization between the transmitter, IRS, and receiver. Environmental factors such as user mobility, shadowing, or imperfect reflection are not considered in the simulation model. Additionally, the IRS is modelled as a passive array without hardware impairments or phase quantization errors, which may differ from real-world deployment conditions.

It is hypothesized that increasing the number of IRS elements enhances system performance by improving signal reflection and minimizing destructive interference. This hypothesis is supported by the simulation results, which show a direct correlation between the number of IRS elements and improved BER and spectral efficiency. Therefore, it can be concluded that optimizing the IRS configuration in OFDM systems is a feasible approach to achieving high reliability and efficiency in future 6G networks.

Although increasing the number of IRS elements from 50 to 100 improves system performance, the improvement observed in Figures 1 and 2 appears relatively moderate. The diminishing returns effect in IRS-assisted communication systems can explain this phenomenon. As the number of reflecting elements increases, the incremental signal gain per element gradually decreases due to channel correlation and imperfect phase alignment. Furthermore, the reflected signals may not always combine perfectly constructively at the receiver because the wireless channel characteristics vary randomly. As a result, while increasing the IRS size enhances signal strength and improves BER and spectral efficiency, the marginal performance gain diminishes once the number of IRS elements exceeds a certain threshold.

V. CONCLUSION

This study investigated the performance optimization of an OFDM system assisted by an Intelligent Reflecting Surface (IRS) in a simulated 6G wireless communication environment. The simulation framework modelled a passive reflective IRS with a unit-modulus constraint, using alternating optimization and projected gradient descent (PGD) to adjust the phase shifts of the reflecting elements. The leading performance indicators analysed were Bit Error Rate (BER) and Spectral Efficiency (Rate) under various Signal-to-Noise Ratio (SNR) conditions and different numbers of IRS elements ($M = 0, 50, 100$).

Future studies should explore active and hybrid IRS architectures, which can perform limited signal amplification or baseband processing to overcome path loss at higher frequencies (e.g., terahertz bands). Additionally, the inclusion of multi-user scenarios, mobility effects, and machine learning-based control algorithms will provide a more realistic depiction of 6G deployments.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Universitas Nasional for providing support and research facilities that made this work possible. Special thanks are also extended to the Faculty of Engineering and Science for their valuable guidance, encouragement, and collaboration

throughout the completion of this research. The constructive suggestions and insightful feedback from colleagues and reviewers are greatly appreciated and have significantly improved the quality of this paper.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest regarding the publication of this paper.

AUTHOR CONTRIBUTION

The authors confirm that Ruliyanta was responsible for the conception and design of the study as well as the preparation of the manuscript draft. Muhammad Ismail conducted the data collection and MATLAB simulations. Both authors, Ruliyanta and Muhammad Ismail, contributed to the analysis and interpretation of the findings. All authors reviewed the results, discussed the outcomes, and approved the final version of the manuscript before submission.

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