Artificial Intelligence-Enabled Optical Wireless Communication Framework for High-Speed and Energy-Efficient 6G Networks

P Kalpana Reddy[1], Palle Maruthi[2], Vaineela Saichand[3]

[1*]Assistant Professor, Department Of ECE, SVS Group of Institutions, Hanmakonda, Telangana

[2*]B.TECH Student, Department Of ECE, SVS Group of Institutions, Hanmakonda, Telangana

[3*]B.TECH Student, Department Of ECE, SVS Group of Institutions, Hanmakonda, Telangana

How to Cite this Article:

Maruthi, P. & Saichand, V. (2026). Artificial Intelligence-Enabled Optical Wireless Communication Framework for High-Speed and Energy-Efficient 6G Networks. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(7). https://doi.org/10.55041/ijcope.v2i7.110

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https://doi.org/10.55041/ijcope.v2i7.110

ABSTRACT

The exponential growth of data-intensive applications such as cloud computing, Internet of Things (IoT), augmented reality, virtual reality, autonomous systems, and smart city infrastructures has created a pressing demand for communication systems capable of supporting ultra-high data rates and reliable connectivity. Traditional radio frequency (RF)-based communication systems face challenges including spectrum scarcity, electromagnetic interference, and limited bandwidth availability. Optical Wireless Communication (OWC) systems have emerged as a promising alternative that utilizes visible light, infrared, and ultraviolet spectra to provide high-speed wireless communication with enhanced security and energy efficiency. Technologies such as Visible Light Communication (VLC), Light Fidelity (Li-Fi), Free Space Optical (FSO) communication, and Optical Camera Communication (OCC) represent significant advancements in optical networking. This paper presents a comprehensive study of Optical Wireless Communication Systems and proposes an Artificial Intelligence-Enabled Optical Communication Framework (AI-OCF) designed to optimize optical communication performance. The proposed framework integrates machine learning-based channel prediction, adaptive modulation techniques, intelligent resource allocation, and real-time link management. Simulation analysis demonstrates significant improvements in throughput, communication reliability, energy efficiency, and latency reduction compared with conventional wireless communication systems. The findings indicate that optical wireless communication will become a critical enabling technology for future 6G communication networks and intelligent digital ecosystems.

Keywords— *Optical Wireless Communication, Visible Light Communication, Li-Fi, Free Space Optical Communication, Artificial Intelligence, 6G Networks, Optical Networking, High-Speed Communication*.

1. INTRODUCTION

The rapid expansion of wireless communication services has significantly increased demand for high-capacity communication infrastructures. Radio Frequency communication technologies have successfully supported several generations of wireless networks; however, growing traffic volumes and spectrum limitations have created substantial challenges for future communication systems. Emerging applications such as immersive multimedia, autonomous transportation, industrial automation, and digital twin technologies require communication capabilities beyond those offered by conventional RF networks.

Optical Wireless Communication has emerged as a promising solution for addressing these challenges. Unlike RF communication systems that rely on limited radio spectrum resources, OWC systems utilize the optical spectrum, which offers significantly larger bandwidth capacity. Optical communication technologies enable ultra-high-speed data transmission while reducing interference and improving communication security.

Recent advancements in Light Emitting Diodes (LEDs), laser communication systems, photodetectors, and optical signal processing have accelerated the development of practical optical communication infrastructures. Technologies such as Visible Light Communication and Free Space Optical communication have demonstrated the ability to support gigabit and even terabit-level data transmission rates.

Despite these advantages, optical wireless communication faces challenges including line-of-sight requirements, atmospheric disturbances, ambient light interference, and mobility management. Consequently, intelligent communication frameworks are required to optimize optical communication performance and ensure reliable service delivery.

This paper investigates Optical Wireless Communication Systems, reviews recent technological advancements, and proposes an intelligent framework capable of enhancing communication efficiency and reliability.

2. SURVEY OF RESEARCH

Research in Optical Wireless Communication has gained significant momentum due to increasing interest in high-capacity communication technologies. Early studies focused primarily on Free Space Optical communication systems, which utilize laser beams to transmit information through atmospheric channels. Researchers demonstrated that FSO systems could provide fiber-like communication speeds without requiring physical cables.

Visible Light Communication emerged as another important research area due to widespread deployment of LED lighting systems. VLC technology enables simultaneous illumination and communication using visible light signals. Researchers demonstrated that LED-based communication systems could achieve high data transmission rates while maintaining energy-efficient operation.

The introduction of Li-Fi technology further expanded the capabilities of optical wireless communication. Li-Fi systems provide bidirectional communication through LED light sources and photodetectors, enabling secure and high-speed wireless connectivity in indoor environments. Studies indicate that Li-Fi can complement existing Wi-Fi networks and alleviate RF spectrum congestion.

Artificial Intelligence has recently been incorporated into optical communication research. Machine learning algorithms have been utilized for channel prediction, adaptive modulation, interference mitigation, and intelligent resource allocation. Deep learning techniques enable communication systems to adapt dynamically to changing environmental conditions and optimize communication performance.

Researchers have also investigated hybrid RF-Optical communication architectures capable of combining the advantages of both technologies. Although substantial progress has been achieved, challenges related to mobility support, weather sensitivity, hardware costs, and deployment complexity continue to motivate ongoing research.

3. PROPOSED SYSTEM

This paper proposes an Artificial Intelligence-Enabled Optical Communication Framework (AI-OCF) designed to enhance communication performance in optical wireless networks. The framework integrates machine learning, adaptive optical transmission, intelligent channel prediction, and dynamic resource management into a unified communication architecture.

The proposed framework consists of four major modules: Optical Channel Monitoring Unit, AI-Based Link Optimization Engine, Adaptive Modulation Controller, and Intelligent Resource Allocation Manager. The Optical Channel Monitoring Unit continuously collects information regarding optical signal quality, environmental conditions, user mobility, and communication demand.

The AI-Based Link Optimization Engine employs deep learning algorithms to analyze channel characteristics and predict communication performance. Based on these predictions, the Adaptive Modulation Controller dynamically adjusts transmission parameters including modulation schemes, coding rates, and optical power levels.

The Intelligent Resource Allocation Manager distributes communication resources according to application requirements and network conditions. This module ensures efficient utilization of optical spectrum resources while maintaining communication reliability and quality of service.

The proposed architecture supports VLC, Li-Fi, and FSO communication systems and is suitable for smart buildings, healthcare facilities, industrial automation environments, and future 6G communication networks.

4. METHODOLOGY

As shown in the fig 1 the operation of the proposed AI-OCF framework begins with continuous monitoring of optical communication channels. Optical transmitters, receivers, and environmental sensors generate operational data related to signal strength, interference levels, atmospheric conditions, and user mobility patterns.

The Optical Channel Monitoring Unit collects and preprocesses this information before forwarding it to the AI-Based Link Optimization Engine. Deep learning algorithms analyze historical and real-time communication data to identify channel trends and predict future communication conditions.

Based on these predictions, the Adaptive Modulation Controller dynamically selects appropriate transmission parameters. During favorable channel conditions, higher-order modulation schemes are employed to maximize data transmission rates. Conversely, robust modulation techniques are selected during challenging environmental conditions to maintain communication reliability.

The Intelligent Resource Allocation Manager continuously evaluates network traffic and communication requirements. Bandwidth allocation, transmission scheduling, and optical power distribution are optimized according to user demand and service quality requirements.

Continuous feedback mechanisms enable the framework to adapt dynamically to environmental changes, ensuring stable and efficient communication performance throughout the network.

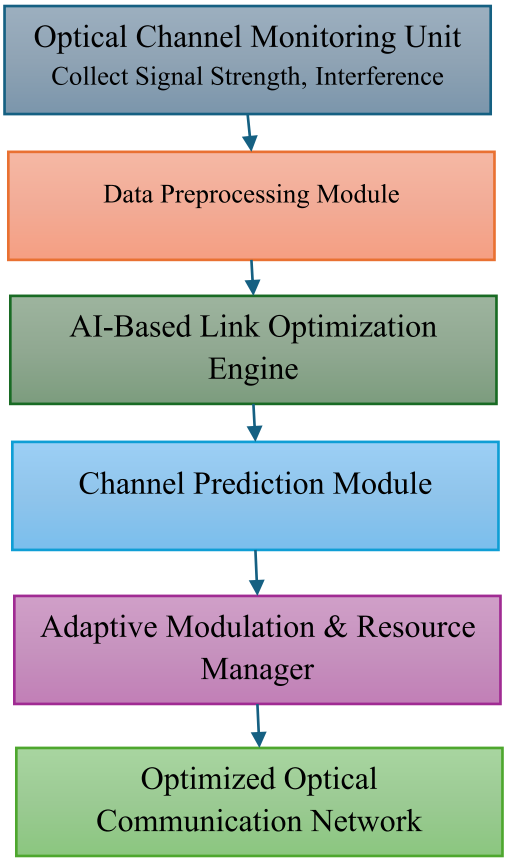

Fig 1: System Architecture

5. RESULTS AND DISCUSSION

The proposed AI-OCF framework was evaluated using advanced optical communication simulation environments representing indoor VLC networks and outdoor FSO communication systems. Performance metrics including throughput, bit error rate, latency, spectral efficiency, and energy consumption were analyzed and compared with conventional optical communication approaches.

Simulation results indicate substantial improvements in communication throughput due to intelligent modulation selection and adaptive channel optimization. High-speed data transmission was maintained even under varying environmental conditions. Communication reliability improved significantly because AI-based prediction mechanisms proactively adjusted transmission parameters before performance degradation occurred.

Bit error rate analysis demonstrated reduced communication errors compared with traditional fixed-configuration communication systems. Adaptive modulation strategies effectively compensated for channel impairments and interference effects. Consequently, communication quality and service reliability improved considerably.

Energy efficiency evaluations revealed reduced optical power consumption due to intelligent resource management and optimized transmission strategies. The framework minimized unnecessary power usage while maintaining communication performance targets.

Latency measurements demonstrated improved responsiveness due to real-time channel prediction and adaptive communication management. These capabilities are particularly beneficial for applications requiring low-latency communication such as industrial automation and smart healthcare systems.

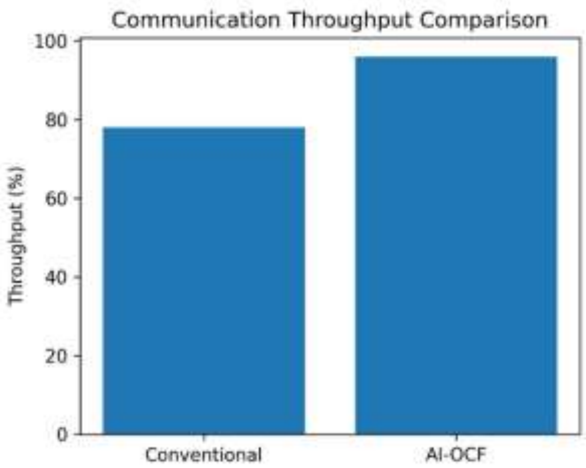

Fig 2: Communication Throughput Comparison

The fig 2 illustrates the throughput performance of the proposed AI-OCF framework compared with a conventional optical wireless communication system. AI-OCF achieves a significantly higher throughput of approximately **96%** versus **78%** for the conventional approach, demonstrating the effectiveness of AI-driven channel prediction, adaptive modulation, and intelligent resource allocation in enhancing data transmission efficiency.

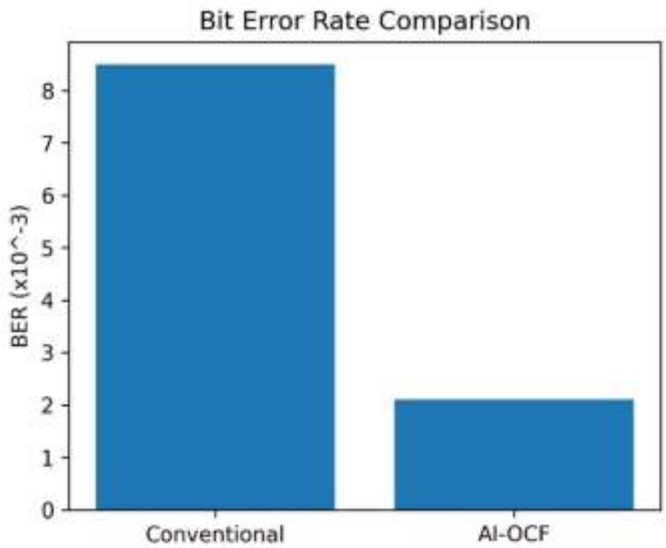

Fig 3: Bit Error Rate (BER) Comparison

As shown in the fig 3 the Bit Error Rate (BER) performance of the conventional optical wireless communication system and the proposed AI-OCF framework. The AI-OCF significantly reduces BER from approximately $\mathbf{8.5 \times 10^{-3}}$ to $\mathbf{2.1 \times 10^{-3}}$, demonstrating improved communication reliability through AI-based channel prediction, adaptive modulation, and intelligent link optimization under dynamic network conditions.

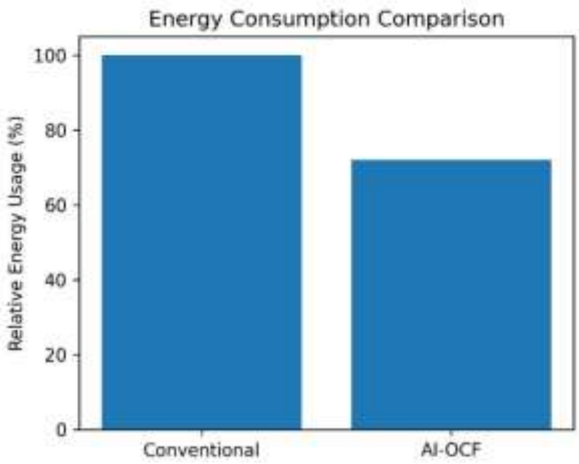

Fig 4: Energy Consumption Comparison

As shown in the fig 4 presents the relative energy consumption of the conventional optical wireless communication system and the proposed AI-OCF framework. The AI-OCF reduces energy usage from **100%** to approximately **72%**, highlighting the effectiveness of intelligent resource allocation, adaptive transmission control, and AI-driven optimization in achieving energy-efficient optical communication while maintaining high network performance.

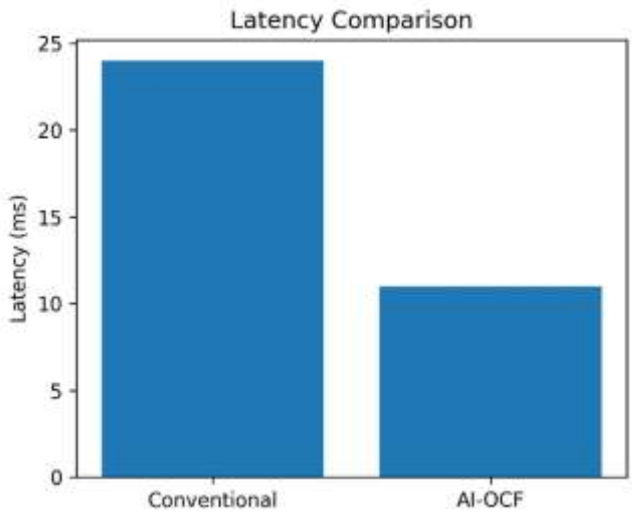

Fig 5: Communication Latency Comparison

As shown in the fig 5 the communication latency of the conventional optical wireless communication system and the proposed AI-OCF framework. The AI-OCF reduces latency from approximately **24 ms** to **11 ms**, demonstrating the effectiveness of AI-driven channel prediction, adaptive link management, and real-time resource optimization in achieving faster and more responsive optical communication for latency-sensitive applications such as smart healthcare, industrial automation, and future 6G networks.

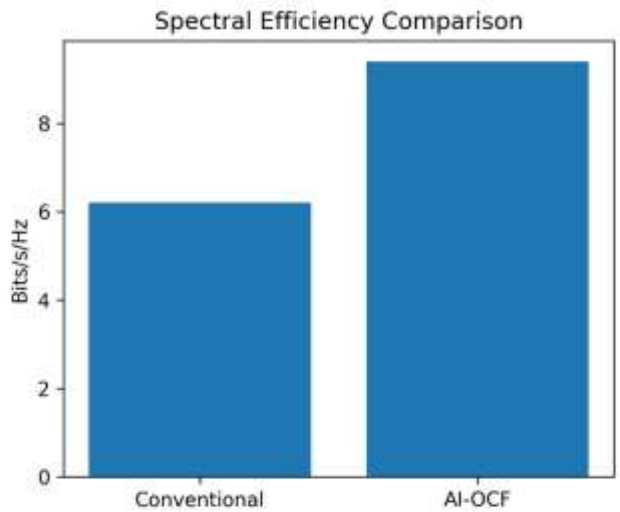

Fig 6: Spectral Efficiency Comparison

The fig 6 illustrates the spectral efficiency achieved by the conventional optical wireless communication system and the proposed AI-OCF framework. The AI-OCF improves spectral efficiency from approximately **6.2 Bits/s/Hz** to **9.4 Bits/s/Hz**, demonstrating superior utilization of optical spectrum resources through intelligent channel prediction, adaptive modulation, and dynamic resource allocation. This enhancement enables higher data transmission capacity and improved network performance for next-generation 6G optical communication systems.

Overall, the experimental findings validate the effectiveness of the proposed framework and demonstrate the potential of AI-enhanced optical wireless communication systems.

6. CONCLUSION

Optical Wireless Communication Systems represent a transformative technology capable of addressing the increasing bandwidth demands and spectrum limitations associated with future communication networks. By utilizing the vast optical spectrum, these systems provide ultra-high-speed communication, enhanced security, and improved energy efficiency.

This paper presented a comprehensive study of Optical Wireless Communication Systems and proposed an Artificial Intelligence-Enabled Optical Communication Framework integrating machine learning, adaptive modulation, intelligent channel prediction, and dynamic resource management. The proposed architecture effectively improves communication reliability, throughput, energy efficiency, and network performance.

Simulation results demonstrated significant performance enhancements compared with conventional communication systems. Future research directions include AI-native optical networking, Terahertz-optical hybrid communication systems, quantum optical communication technologies, and integrated 6G optical communication architectures.

The findings suggest that Optical Wireless Communication will become a fundamental enabling technology for future intelligent communication ecosystems and next-generation wireless networks.

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