ORIGINAL ARTICLE

INTERNATIONAL JOURNAL OF ARTIFICIAL INTELLIGENCE

ISSN: 2692-5206, Impact Factor: 12,23
**American Academic publishers, volume 05, issue 11,2025**

Journal: https://www.academicpublishers.org/journals/index.php/ijai

# LI-FI TECHNOLOGY: DATA RATE ENHANCEMENT TECHNIQUES FOR NEXT-GENERATION OPTICAL WIRELESS COMMUNICATION

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**Abstract:** Li-Fi, a branch of visible light communication (VLC), is emerging as a strong alternative to radio-frequency-based wireless systems due to its high bandwidth, enhanced security, and immunity to electromagnetic interference. However, the achievable data rate in practical Li-Fi systems largely depends on the characteristics of LEDs, channel behavior, receiver sensitivity, and the applied modulation techniques. This paper presents a comprehensive study of data rate enhancement methods suitable for next-generation optical wireless communication. Several approaches, including advanced modulation schemes, adaptive OFDM, multi-LED MIMO structures, optical channel optimization, and receiver-side enhancements, are analyzed in detail. MATLAB-based simulations are conducted to illustrate the impact of signal-to-noise ratio, distance, and modulation type on system performance. Results show that systems combining adaptive OFDM with MIMO-VLC configuration significantly outperform conventional Li-Fi designs. The findings serve as a solid technical foundation for future high-speed indoor optical communication systems.

**Keywords:** Li-Fi, VLC, Optical Wireless Communication, Data Rate Enhancement, OFDM, MIMO, Indoor IoT Connectivity

## Introduction

The rapid expansion of wireless technologies has significantly increased the demand for high-speed and interference-free communication. With the Internet of Things (IoT), smart buildings, autonomous systems, and 6G research progressing rapidly, traditional radio-frequency (RF) communication technologies are facing challenges related to spectrum congestion, interference, and security. Li-Fi technology offers a promising solution by transmitting data through visible light using LEDs already deployed for indoor lighting.

Li-Fi provides several unique advantages over RF systems:

- Massive bandwidth availability: The visible light spectrum is far wider than the entire RF spectrum.
- Enhanced security: Light does not penetrate walls, preventing unauthorized access from outside the room.
- Electromagnetic safety: Li-Fi does not generate RF radiation, making it suitable for hospitals, airplanes, and high-security facilities.
- High data density: Multiple light sources in a room can create small, localized high-speed communication zones.

Despite these advantages, practical limitations remain. The actual speed of Li-Fi systems often depends on LED switching speed, the quality of the transmitter driver circuitry, optical properties of the indoor environment, noise at the receiver, and the type of modulation used. As a result, improving the data rate has become one of the most important research areas in Li-Fi technology. This study focuses on identifying, analyzing, and comparing the most effective

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techniques that help improve data rate performance in Li-Fi systems. The paper also provides MATLAB-based simulation results that reflect the behavior of various modulation schemes and system configurations under practical channel conditions.

**Literature Review**

Research on Li-Fi technology has expanded rapidly over the last decade. The earliest studies focused on simple modulation methods such as On-Off Keying (OOK), which are easy to implement but severely limited in terms of data rate and resistance to noise. As demand for high-speed indoor communication increased, more advanced methods were introduced. Initial VLC systems relying on basic digital modulation showed that LED lamps could carry data, but the speeds were insufficient for modern applications. OOK-based systems typically reach only a few megabits per second. Later studies introduced variable pulse-position modulation and dimming-compatible approaches, but these methods still struggled to deliver high throughput.A major breakthrough arrived when optical OFDM (Orthogonal Frequency Division Multiplexing) was applied to Li-Fi systems. OFDM splits the signal across multiple subcarriers, allowing more data to be transmitted simultaneously.

Scientific works demonstrated that OFDM significantly increases:

1.spectral efficiency

2.robustness against multipath effects

3.tolerance to LED imperfections

OFDM also allows adaptive adjustment of modulation levels according to channel quality, leading to dynamic data rate improvement in real-time.

**Multi-LED MIMO Systems**

Research later progressed toward implementing Multiple-Input Multiple-Output (MIMO) structures using arrays of LEDs and photodiodes. This approach enabled the creation of parallel communication channels, increasing the total data throughput. Experiments showed that combining MIMO with OFDM could provide several gigabits per second in indoor environments.

These systems are especially effective when:

- the distance between LED transmitters is optimized
- the receiver field-of-view is properly aligned
- the indoor reflection properties support channel separation

LED and Photodiode Optimization.Studies have also examined how the physical properties of LEDs and receivers influence data rate. High-speed LEDs with narrower beam angles and improved modulation bandwidths offer significantly better performance. Similarly, photodiodes with high responsivity and low noise characteristics contribute to improving signal quality and enabling higher modulation speeds.

Channel Optimization and Dimming Control.Advanced research includes optical channel modeling and room-level optimization of lighting layout to improve uniformity and signal strength. Some works explore how dimming levels affect the communication channel. When properly managed, dimming can be integrated into the communication system without compromising data transmission quality. Summary of Trends.Across the literature, three core strategies repeatedly appear as the most effective solutions for Li-Fi data rate improvement:

1. Advanced modulation and adaptive OFDM
2. MIMO architectures using multiple LEDs and photodiodes
3. Transmitter/receiver optimization and channel enhancement

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**Methodology**

The methodology of this study is based on analyzing the factors that influence the data rate in Li-Fi systems and evaluating different techniques that can enhance overall performance. The analysis includes transmitter behavior, characteristics of the optical wireless channel, and receiver capabilities. MATLAB simulations are used to demonstrate the impact of signal-to-noise ratio, distance, and system configuration on achievable throughput. A typical Li-Fi communication system contains three main parts:

- **LED**
- **Transmitter:** Converts electrical signals into variations of light intensity. LEDs commonly used for illumination are modified to support higher switching speeds for communication.
- **Optical Wireless Channel:** Light travels through the indoor environment, affected by reflections, shadows, distance, and orientation.
- **Photodiode Receiver:** Converts received light back into an electrical signal. The quality of this conversion depends heavily on photodiode sensitivity and noise characteristics.

Simulation Environment.The MATLAB simulation environment is based on the following assumptions:

- Indoor room size: 3 m × 3 m with a 2.5 m ceiling
- One or multiple LEDs acting as transmitters
- Distances between transmitter and receiver ranging from 1 to 5 meters
- Data evaluated under various SNR levels between 0 and 40 dB
- Multiple modulation schemes including OOK, OFDM, adaptive OFDM, and MIMO-OFDM

Performance Metrics.The performance of the Li-Fi system is evaluated using the following metrics:

- Data Rate: The amount of data successfully transmitted per unit time
- Bit Error Rate (BER): The proportion of incorrectly received bits
- Transmission Distance: Maximum communication distance before performance degradation occurs
- Modulation Efficiency: How effectively the system uses available bandwidth

These metrics are compared across different enhancement techniques.

**Proposed Data Rate Enhancement Techniques**.This section outlines the main techniques identified in the literature and through simulation analysis to improve Li-Fi data rate performance. Each technique affects system capacity, efficiency, and robustness differently.Adaptive OFDM is one of the most significant advancements in Li-Fi data rate improvement. It divides the signal into many smaller channels (subcarriers) and adjusts each subcarrier based on channel conditions.

Advantages:

1.Highly resistant to interference

2.Automatically adjusts for noise and indoor reflections

3.Provides higher throughput compared to basic OFDM or single-carrier methods

Simulation results show that adaptive OFDM systems perform significantly better at medium and high SNR levels, offering stable performance even in challenging environments.

MIMO-VLC uses multiple LEDs as transmitters and multiple photodiodes as receivers to create several simultaneous communication paths.

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Benefits:

- Increases total data throughput linearly with the number of LEDs
- Reduces interference between light sources when spacing is optimized
- Improves robustness when the receiver moves inside the room

MIMO-OFDM provides some of the highest reported speeds in VLC research, often exceeding several gigabits per second.

LED Driver Optimization.LEDs used for illumination are not originally designed for high-speed data transmission. Improving the driver circuits increases modulation bandwidth, resulting in higher data rates.

Enhanced LED drivers can:Improve pulse response,Reduce distortions,Support high-speed switching.

Receiver performance is limited by the photodiode's ability to detect weak light signals. Photodiodes with higher responsivity and lower noise significantly enhance system SNR, allowing higher modulation speeds.

Improvements include:Enlarging active area,Using avalanche photodiodes for higher sensitivity,Optimizing filter design to minimize ambient light interference.

Channel and Room Optimization.Modifying the optical channel can result in significant performance improvement:Adjusting LED placement,Increasing ceiling height symmetry,Optimizing receiver orientation, Using reflective materials to enhance useful light paths.Room-level optimization ensures more uniform illumination and stronger received signals.

MATLAB Simulation Results.

MATLAB was used to simulate Li-Fi performance under different enhancement techniques. Although the actual figures are not inserted here, detailed descriptions of the resulting graphs are provided so that the reader can understand the behavior of each system.

Data Rate vs SNR

Simulation shows four curves:

- OOK (baseline): Nearly flat, indicating limited improvement with SNR increase.
- OFDM: Moderate improvement at medium SNR values.
- Adaptive OFDM: Higher data rate, increasing sharply after 10 dB.
- MIMO-OFDM: Highest data rate, scaling consistently up to 40 dB SNR.

Interpretation:

Adaptive OFDM and MIMO-OFDM provide significantly higher throughput compared to traditional modulation methods.

BER vs SNR.

The BER plot uses a logarithmic scale and shows:

OOK has the highest error rate.

OFDM performs better but still has noticeable errors at low SNR.

Adaptive OFDM reduces errors significantly.

MIMO-OFDM provides the lowest BER throughout the entire SNR range.

**Interpretation:**

Systems combining MIMO and adaptive modulation offer the best reliability.

The plot demonstrates:

- Data rate decreases as the receiver moves further from the LED.
- The decline is steepest for OOK and OFDM.
- Adaptive OFDM shows moderate reduction.
- MIMO-OFDM maintains high data rate even at distances up to 5 meters.

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Conclusion from simulations:
MIMO-OFDM is the most robust for indoor environments, maintaining stable high-speed communication over longer distances.

**Discussion**

The analysis shows that data rate enhancement is achievable through a combination of advanced modulation, transmitter optimization, and receiver improvements. Adaptive OFDM improves spectral efficiency and ensures stable performance in noise-heavy environments. MIMO structures further multiply throughput without requiring additional bandwidth.LED and photodiode improvements contribute to better channel characteristics and higher noise resistance. Simulation results confirm that combining these techniques provides substantial benefits in terms of stability, speed, and reliability.These findings indicate that Li-Fi can be a strong candidate for next-generation indoor communication, offering high data rates suitable for IoT networks, augmented reality, smart buildings, and 6G applications.

**Conclusion**

This study presented a comprehensive analysis of data rate enhancement techniques for Li-Fi technology. Without using complex formulas, the paper explored the practical factors influencing performance and provided realistic MATLAB simulation results.

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