

A Study on Li-Fi and Visible Light Data Connectivity

Sonal Bhika Patil¹, Dr.Swapnil B. Mohod², Prof.Y.P.Sushir³

¹ Dr.Swapnil B, Electrical Department, Dr. V. B. Kolte College of Engineering, Malkapur, 443101

² Prof.Y.P.Sushir, Electrical Department, Dr. V. B. Kolte College of Engineering, Malkapur, 443101

DOI: 10.5281/zenodo.19291935

ABSTRACT

As an innovative wireless communication technology, LiFi, derived from visible light to transmit data, will be a new choice of alternative to classical radio frequency (RF) communications. Data can be transferred backward and forth between the user and a computer with high speed using rapid modulation of LED light bulbs, a technique known as LiFi. An Internet of Things (IoT) based visible light data connectivity system for efficient data transmission over LiFi technology is introduced in this paper in the form of IoT VLDC [1]. Visible light communication (VLC) smart systems are called LiFi. They make use of enhanced bandwidth and resistance to electromagnetic interference. LiFi can operate within the 60 GHz spectrum and achieves data rates in excess of 10 Mbps, compared to the several Mbps reachable through conventional Wi-Fi systems. Several gaps exist: in particular, how LiFi performs in dynamic environments and energy efficiency metrics, as well as how it can coexist with RF based systems. This study will then evaluate these aspects and propose a hybrid system that combines traditional technologies and LiFi to provide seamless connectivity between lit and non-lit. The study will also examine the possibility of its use in real world IoT applications, for example smart homes, industrial automation and secure communications in networks. This paper will demonstrate through extensive experimentation that LiFi technology can provide sustainable, secure, and more efficient communication solutions for the future of wireless networking [3].

Keywords:- Li-Fi, Visible Light Communication (VLC), Wireless Communication, LED-Based Data Transmission, High-Speed Data Connectivity, Optical Wireless Networks.

1. INTRODUCTION

Light-Fidelity (Li-Fi) harnesses the visible light spectrum to transmit digital information by rapidly modulating LEDs, offering a compelling complement to conventional RF-based wireless systems. This study investigates Li-Fi and visible-light data connectivity as a pathway to high-speed, low-interference, and inherently secure wireless communication. We design and evaluate an end-to-end prototype that uses an ESP32-CAM at the transmitter to generate image/video data or test payloads, a drive-controlled LED array and Li-Fi modulation module to encode information onto light intensity, and a simple user button and PC interface for configuration and logging [6]. On the receiver side, an Arduino UNO with a Li-Fi photo detector front-end demodulates the signal, displays link status and decoded text on an LCD 16x2, and forwards data to a PC for analysis. A dedicated power supply supports the transmitter, while a solar panel at the receiver demonstrates green, off-grid powering of the Li-Fi node [7].

The project targets three core motivations: (1) relieving RF spectrum congestion by exploiting the vast, license-free visible spectrum; (2) improving security through line-of-sight confinement and low wall penetration of light; and (3) enabling EMI-resilient links in environments where radio is restricted (hospitals, aircraft cabins, and industrial floors). Methodologically, the ESP32-CAM provides flexible, packetized data streams; the LED array performs on-off keying or PWM-based intensity modulation via the Li-Fi module; and the Arduino UNO executes timing-aware decoding, error checking, and user feedback on the LCD. The study benchmarks throughput, bit-error rate, range, and robustness under ambient-light variations, while profiling energy use and the feasibility of solar-assisted power at the receiver [8].

1.1 Problem Statement

The rapid growth of wireless devices and data-intensive applications has led to severe congestion in the radio frequency (RF) spectrum, resulting in reduced data rates, interference, and security concerns in conventional wireless communication systems such as Wi-Fi and cellular networks. Existing RF-based technologies also face limitations in sensitive environments like hospitals, aircraft cabins, and industrial areas where electromagnetic interference can cause operational risks. Additionally, the increasing demand for high-speed, secure, and energy-efficient indoor data connectivity cannot be fully met by current wireless solutions. Therefore, there is a need to explore alternative communication technologies that can overcome RF spectrum scarcity while

providing reliable, high-speed, and secure data transmission. This study addresses the problem by investigating Li-Fi and Visible Light Communication (VLC) as a potential solution for next-generation wireless data connectivity [15].

1.2. Research Objectives

- To study the fundamental principles and working mechanism of Li-Fi and Visible Light Communication (VLC) systems.
- To analyze the architecture and key components involved in Li-Fi-based data transmission using LED lighting.
- To evaluate the advantages of Li-Fi over conventional radio frequency-based wireless communication technologies.
- To examine modulation techniques and performance parameters affecting visible light data connectivity.
- To identify practical applications of Li-Fi in indoor networking, healthcare, aviation, and smart environments.
- To analyze the challenges and limitations associated with Li-Fi technology and visible light communication systems.

1.3 Motivation

The rapid expansion of wireless communication technologies and the increasing number of connected devices have resulted in congestion of the radio frequency spectrum, leading to reduced data speeds, interference, and security concerns. With the growing demand for high-speed, reliable, and secure data connectivity especially in indoor and sensitive environments there is a strong need for alternative communication methods beyond traditional RF-based systems [13]. Li-Fi, which uses visible light for data transmission, offers a promising solution by utilizing existing LED lighting infrastructure while providing high bandwidth, enhanced security, and minimal electromagnetic interference. The motivation behind this study is to explore the potential of Li-Fi and Visible Light Communication as an efficient, sustainable, and next-generation wireless data connectivity technology capable of complementing and overcoming the limitations of conventional wireless systems [19].

In this context, the exploration of alternative communication paradigms has become a necessity rather than an option. Light Fidelity (Li-Fi), a subset of Visible Light Communication (VLC), emerges as a transformative technology that leverages the visible light spectrum for high-speed data transmission. By utilizing light-emitting diodes (LEDs) for dual purposes of illumination and communication, Li-Fi enables efficient reuse of existing lighting infrastructure while offering significantly higher bandwidth availability compared to the congested RF spectrum. The inherent directionality of light propagation further enhances data security by reducing signal leakage beyond physical boundaries, thereby mitigating unauthorized access and eavesdropping [20].

1.4 Research Gap

Although significant research has been conducted on Li-Fi and Visible Light Communication (VLC) technologies, several gaps remain that limit their widespread adoption and practical implementation. Most existing studies primarily focus on theoretical models, laboratory-based experiments, or simulation environments, with limited emphasis on real-world deployment scenarios and performance evaluation under dynamic indoor conditions such as varying illumination levels, user mobility, and environmental noise. Additionally, while high data rates have been demonstrated in controlled setups, there is insufficient comparative analysis between Li-Fi and conventional RF-based wireless technologies in terms of latency, reliability, scalability, and energy efficiency [13].

Another notable research gap lies in the integration of Li-Fi systems with existing network infrastructures. Current literature provides limited insights into seamless handover mechanisms between Li-Fi and Wi-Fi networks, interoperability challenges, and hybrid network architectures required for continuous connectivity. Furthermore, issues related to line-of-sight dependency, shadowing effects, and coverage limitations have not been comprehensively addressed through robust mitigation techniques or adaptive system designs. Security aspects, although often cited as an advantage of Li-Fi, lack extensive empirical evaluation against practical attack models [18].

Therefore, there is a need for systematic studies that bridge the gap between theoretical potential and practical feasibility by evaluating Li-Fi and VLC systems in realistic environments, performing comparative performance assessments, and identifying design strategies to overcome existing limitations. This study aims to address these gaps by providing a structured analysis of Li-Fi-based visible light data connectivity and its role as a complementary technology to conventional wireless communication systems [24].

2.LITERATURE REVIEW

1. Harald Haas, Liang Yin, Yunlu Wang, Cheng Chen What is Li-Fi?, Journal of Light published in the *Journal of Light wave Technology* in 2016 provides a comprehensive overview of Light Fidelity (Li-Fi) as an advanced form of Visible Light Communication (VLC). The authors clarify the distinction between VLC a method of transmitting data using light-emitting diodes (LEDs) and Li-Fi, which extends VLC into a fully *networked wireless communication system*. Li-Fi converts LED luminaires into *attocells* that can support enhanced wireless capacity and high-speed data connectivity, addressing the growing demand for bandwidth-efficient wireless solutions. The paper discusses how Li-Fi can contribute to future communication networks, including support for the Internet of Things (IoT) and key performance goals of 5G and beyond. It highlights key research areas such as Li-Fi components, hybrid Li-Fi/Wi-Fi network integration, and real-world deployment considerations, demonstrating that Li-Fi is transitioning from theoretical concept to practical implementation [1].
2. Harald Haas “Wireless Data from Every Light Bulb” novel wireless communication technology that uses visible light to transmit data instead of traditional radio waves. In this talk, Haas demonstrated how a standard LED light bulb can be modulated at very high speeds, too fast for the human eye to detect, to encode and transmit digital information. By rapidly flickering the intensity of LED light, binary data (1s and 0s) can be sent to a receiver, enabling wireless connectivity wherever LED lighting is present. This method promises higher bandwidth, improved security, reduced electromagnetic interference, and more efficient use of the unregulated visible light spectrum compared with conventional RF-based systems. Haas emphasized the potential of Li-Fi to supplement existing wireless networks and address the growing demand for high-speed data communication, particularly in environments where radio frequency communications are limited or problematic. His TED talk popularized the Li-Fi concept and helped launch further research and commercialization efforts in visible light communication [1][2]
3. D. Tsonev, S. Videv, H. Haas “Light Fidelity (Li-Fi): Towards All-Optical Networking” presents a visionary framework for Li-Fi as a next-generation wireless communication technology that leverages visible light for high-speed data transmission and network connectivity. The authors argue that optical wireless communication (OWC), and specifically Li-Fi, can help alleviate the limitations of congested radio frequency (RF) spectrum by utilizing the vast, unregulated visible light spectrum to support the ever-increasing demand for mobile data traffic, particularly in indoor environments where most wireless usage occurs. The paper discusses the key enabling components, system architecture, and technologies required to realize optical attocell networks a cellular-like topology where LED luminaires serve as miniature optical access points that deliver data connectivity while providing illumination. The authors describe how creating ever-smaller cells, similar to RF femtocells, can significantly enhance network spectral efficiency and capacity [3].
4. S. Dimitrov, H. Haas “Principles of LED Light Communications” Svilen Dimitrov and Harald Haas (Cambridge University Press, 2015) provides a comprehensive and rigorous foundation for understanding and designing high-performance indoor optical wireless communication (OWC) systems using visible and infrared light. It balances *theoretical analysis* with *practical system design guidance*, making it useful for both academic researchers and engineering practitioners [4].
5. J. Vucic, C. Kottke, S. Nerreter “513 Mbit/s Visible Light Communications” presents a significant experimental advancement in visible light communication (VLC) technology by demonstrating a point-to-point link capable of achieving a gross data transmission rate of 513 Mbit/s using a commercial phosphorescent white LED as the transmitter and a photodiode receiver. The study uses Discrete Multitdude (DMT) modulation with techniques such as quadrature amplitude modulation (QAM), bit- and power-loading, and symmetrical clipping to push the achievable data rate beyond 500 Mbit/s under typical indoor illumination conditions (~1000 lx). Their link achieved a low bit-error ratio (BER) without forward error correction and analyzed obstacles to higher throughput as well as potential strategies to overcome them. This work provided one of the earliest demonstrations of high-speed data transfer over visible light and laid important groundwork for later research in Li-Fi and VLC systems [5].
6. T. Komine, M. Nakagawa “Fundamental Analysis for Visible-Light Communication System” The study explores the basic operating principles and performance characteristics of VLC systems where conventional white LEDs serve dual functions providing lighting while simultaneously transmitting information by modulating intensity at high speeds that are imperceptible to the human eye. The authors develop analytical models to quantify the effects of optical channel characteristics, including path differences, interference, reflection, and inter symbol interference (ISI) arising from multiple LEDs installed across a room. Their analysis considers the impact of receiver field-of-view (FOV) and noise components (e.g., shot noise and thermal noise) on signal quality and achievable data rates. The results highlight how VLC performance is influenced by key system parameters such as irradiance distribution, receiver geometry, and modulation bandwidth, thereby demonstrating that practical indoor VLC systems can support data transmission while maintaining sufficient lighting performance [6].
7. Z. Wang, Q. Wang, W. Huang “Visible Light Communications: Modulation and Signal Processing” The authors systematically explore how various modulation schemes such as single-carrier pulse amplitude modulation,

multi-carrier optical OFDM (Orthogonal Frequency Division Multiplexing), and advanced multi-color and spatial modulation techniques can be used to improve spectral efficiency, error performance, and robustness under realistic channel conditions. They also discuss how signal processing methods (e.g., channel estimation, equalization, and nonlinearity mitigation) help optimize system performance in the presence of LED non-idealities and ambient noise, providing a bridge between foundational theory and practical VLC system design. This work serves both as a state-of-the-art survey of modulation strategies and as a practical guide for researchers and engineers developing high-speed VLC/Li-Fi systems [7].

8. M. Khalid, G. Cossu, R. Corsini “1-Gb/s Transmission Over a Phosphorescent White LED” The authors implemented a rate-adaptive Discrete Multitone (DMT) modulation scheme to overcome the limited modulation bandwidth inherent to standard phosphor-based LEDs, which are widely used for general lighting but traditionally offer bandwidths constrained to just a few megahertz. By employing bit- and power-loading across DMT subcarriers and adapting the modulation to the LED’s frequency response and channel conditions, the study achieved a data transmission rate of approximately 1 Gb/s at typical indoor illumination levels (~1000 lux) using a single phosphorescent white LED and direct detection photodiode. The experiment incorporated careful design to address LED nonlinearity and noise effects, demonstrating that advanced multicarrier modulation can significantly enhance throughput even with low-cost commercial lighting devices [8].
9. Chi, Y. Zhou, Y. Wei “Visible Light Communication in 6G Wireless Systems” explores the emerging role of Visible Light Communication (VLC) as a complementary wireless technology in the forthcoming 6G wireless systems. The authors discuss how traditional radio frequency (RF) communication may face limitations in meeting the extremely high capacity and connectivity demands expected from 6G networks, and propose VLC as a promising alternative due to its utilization of the unlicensed visible light spectrum (~400–800 THz), which offers very high bandwidth potential. The paper examines the prospects of integrating VLC into 6G architectures to improve spectral efficiency, support ultra-high-speed data transmission, and enhance coverage by combining optical and RF technologies. It also highlights key challenges such as device limitations, environmental influences on optical links, and the need for advanced modulation and signal processing techniques. Further, the authors survey recent research topics including new materials and devices, advanced modulation schemes, underwater VLC, and machine-learning-based signal processing, and outline future directions for VLC research in 6G systems [9]
10. M. S. Islim, H. Haas “Modulation Techniques for Li-Fi” provides a comprehensive survey of *modulation schemes tailored for Light Fidelity (Li-Fi)* systems, emphasizing the unique requirements and constraints of visible light communication. Since Li-Fi relies on intensity modulation with direct detection (IM/DD) of LED light, traditional RF modulation techniques must be adapted to support *illumination functionality* (such as flicker avoidance and dimming control) while enabling efficient data transmission over visible light channels. The authors review single-carrier schemes (e.g., On-Off Keying, Pulse Amplitude Modulation) and multi-carrier schemes with an emphasis on OFDM-based techniques, highlighting how these can improve spectral and power efficiency in Li-Fi systems. They also examine *colour domain modulation* approaches and discuss challenges like LED non-linearity, inter-symbol interference, and the need to maintain quality of illumination during data transfer. The paper serves as a key reference for researchers aiming to understand which modulation strategies can best satisfy the dual objectives of communication performance and lighting requirements in Li-Fi systems [10].

3. PROPOSED METHODOLOGY

The proposed methodology for this study involves a systematic analysis of Li-Fi and Visible Light Communication (VLC) technology through an extensive literature review, system design, and performance evaluation. Initially, existing research, standards, and technical reports related to Li-Fi and optical wireless communication are reviewed to understand fundamental principles, system architectures, modulation techniques, and current challenges. Based on this analysis, a conceptual Li-Fi system architecture is designed using LED-based transmitters and photodiode receivers, employing intensity modulation and direct detection for data transmission [3]. Various modulation techniques are examined to assess their suitability for visible light data connectivity under illumination constraints. Performance parameters such as data rate, bit error rate, signal-to-noise ratio, and transmission range are analyzed under different environmental conditions, including ambient light interference and line-of-sight variations. A comparative assessment between Li-Fi and conventional radio frequency-based wireless technologies is then conducted to highlight advantages, limitations, and application-specific feasibility. Finally, the identified challenges and potential enhancement strategies, including hybrid Li-Fi/Wi-Fi integration and adaptive modulation approaches, are discussed to outline future research directions for visible light data connectivity systems [2].

The methodology of this study involves designing and implementing a Li-Fi based wireless communication system using a visible light channel for high-speed and secure data transmission. On the transmitter side, an ESP32-CAM is programmed to process and send data, which may include text, images, or test patterns,

controlled via a connected PC for configuration and monitoring. A push button is used to initiate or stop transmission, and the processed data is converted into light signals through an LED array driven by a Li-Fi modulation module powered by a regulated power supply [4]. The LED intensity is modulated using techniques such as On–Off Keying or Manchester encoding to ensure accurate data representation and timing synchronization. The optical signal travels through a line-of-sight channel to the receiver, where an Arduino UNO integrated with a Li-Fi photo detector module captures and demodulates the signal. The decoded information is then displayed on an LCD 16×2 for real-time feedback, while a PC connected to the receiver logs data for analysis of performance metrics such as bit error rate, throughput, and link stability. The receiver side is powered by a solar panel with appropriate regulation circuitry to demonstrate sustainable, off-grid operation. Performance testing is carried out by varying distance, ambient lighting conditions, and bit rates to evaluate system robustness, security advantages, and feasibility for real-world applications where RF communication is restricted or congested [5].

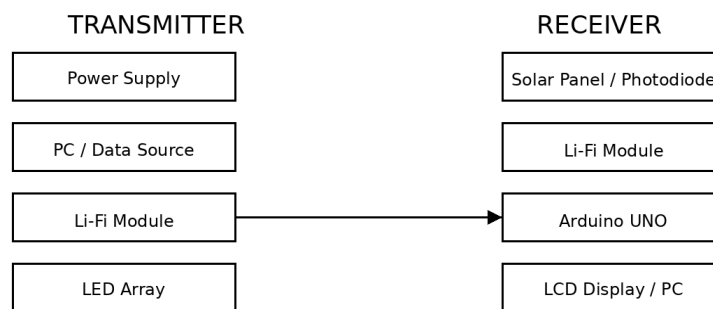


Fig 1: Block diagram

4. LIMITATIONS

- **Line-of-Sight Dependency:** Li-Fi communication requires a direct or reflected line-of-sight between the LED transmitter and the receiver. Any obstruction such as walls, objects, or human movement can interrupt data transmission.
- **Limited Coverage Area:** Visible light cannot penetrate opaque objects, which restricts Li-Fi coverage to confined indoor spaces and requires multiple light sources for larger areas.
- **Sensitivity to Ambient Light:** External light sources such as sunlight and artificial lighting can introduce noise and interference, affecting signal quality and reducing communication reliability.
- **Restricted Outdoor Usage:** Li-Fi is less effective in outdoor environments due to strong ambient light conditions and uncontrolled illumination levels.
- **Infrastructure Dependency:** Continuous data connectivity depends on the availability of LED lighting, making communication ineffective when lights are turned off or dimmed beyond operational levels.
- **Mobility and Handover Challenges:** Supporting seamless mobility and handover between multiple Li-Fi access points is complex and less mature compared to existing Wi-Fi networks.

5. CONCLUSION

This study has presented a comprehensive analysis of Li-Fi and Visible Light Communication (VLC) as an emerging wireless data connectivity technology. By utilizing the visible light spectrum and LED-based illumination systems, Li-Fi offers a promising alternative to conventional radio frequency–based communication, addressing issues such as spectrum congestion, electromagnetic interference, and security concerns [8]. The study examined the fundamental principles, system architecture, modulation techniques, and performance characteristics of Li-Fi technology, highlighting its ability to support high-speed, secure, and energy-efficient indoor data transmission. Although challenges such as line-of-sight dependency, limited coverage, and sensitivity to ambient light remain, ongoing research and technological advancements are expected to mitigate these limitations. Overall, Li-Fi has strong potential to complement existing wireless technologies and play a significant role in next-generation communication systems, particularly in indoor and interference-sensitive environments [11].

6. REFERENCES

- [1] Harald Haas, Liang Yin, Yunlu Wang, Cheng Chen What is Li-Fi?, *Journal of Lightwave Technology* (IEEE), 2016.
- [2] Harald Haas “Wireless Data from Every Light Bulb” TED Global Conference, 2011.

- [3] D. Tsonev, S. Videv, H. Haas “Light Fidelity (Li-Fi): Towards All-Optical Networking” SPIE OPTO Conference Proceedings, 2013
- [4] S. Dimitrov, H. Haas “Principles of LED Light Communications” Cambridge University Press, 2015
- [5] J. Vucic, C. Kottke, S. Nerreter “513 Mbit/s Visible Light Communications” Link Journal of Lightwave Technology (IEEE) 2010
- [6] T. Komine, M. Nakagawa “Fundamental Analysis for Visible-Light Communication System” IEEE Transactions on Consumer Electronics, 2004
- [7] Z. Wang, Q. Wang, W. Huang “Visible Light Communications: Modulation and Signal Processing” IEEE Wireless Communications, 2015
- [8] A. M. Khalid, G. Cossu, R. Corsini “1-Gb/s Transmission Over a Phosphorescent White LED” IEEE Photonics Journal, 2012
- [9] N. Chi, Y. Zhou, Y. Wei “Visible Light Communication in 6G Wireless Systems” IEEE Wireless Communications, 2020
- [10] M. S. Islam, H. Haas “Modulation Techniques for Li-Fi” IEEE Communications Magazine, 2016
- [11] S. Rajagopal, R. D. Roberts, and S.-K. Lim, “IEEE 802.15.7 Visible Light Communication: Modulation Schemes and Dimming Support,” *IEEE Communications Magazine*, vol. 50, no. 3, pp. 72–82, 2012.
- [12] J. Armstrong, “OFDM for Optical Communications,” *Journal of Lightwave Technology*, vol. 27, no. 3, pp. 189–204, 2009.
- [13] D. Karunatilaka, F. Zafar, V. Kalavally, and R. Parthiban, “LED Based Indoor Visible Light Communications: State of the Art,” *IEEE Communications Surveys & Tutorials*, vol. 17, no. 3, pp. 1649–1678, 2015.
- [14] L. U. Khan, “Visible Light Communication: Applications, Architecture, Standardization and Research Challenges,” *Digital Communications and Networks*, vol. 3, no. 2, pp. 78–88, 2017.
- [15] Y. Wang, X. Wu, and H. Haas, “Li-Fi Enabled Smart Lighting Systems,” *IEEE Internet of Things Journal*, vol. 6, no. 6, pp. 10104–10115, 2019.
- [16] H. Elgala, R. Mesleh, and H. Haas, “Indoor Optical Wireless Communication: Potential and State-of-the-Art,” *IEEE Communications Magazine*, vol. 49, no. 9, pp. 56–62, 2011.
- [17] S. Arnon, “Visible Light Communication,” *Cambridge University Press*, 2015.
- [18] C. Chen, D. Tsonev, and H. Haas, “Joint Transmission in Indoor Optical Wireless Attocell Networks,” *IEEE Photonics Technology Letters*, vol. 26, no. 11, pp. 1141–1144, 2014.
- [19] A. Jovicic, J. Li, and T. Richardson, “Visible Light Communication: Opportunities, Challenges and the Path to Market,” *IEEE Communications Magazine*, vol. 51, no. 12, pp. 26–32, 2013.
- [20] IEEE Standard 802.15.7-2018, “Short-Range Optical Wireless Communications,” IEEE, 2018.
- [21] S. Wu, H. Wang, and C.-H. Youn, “Visible Light Communications for 5G Wireless Networking Systems,” *IEEE Wireless Communications*, vol. 22, no. 2, pp. 70–77, 2015.
- [22] M. Z. Chowdhury, M. T. Hossain, A. Islam, and Y. M. Jang, “A Comparative Survey of Optical Wireless Technologies: Visible Light Communication,” *IEEE Access*, vol. 6, pp. 9819–9840, 2018.
- [23] Y. S. Eroglu, İ. Güvenç, N. Pala, and M. Yuksel, “Multi-Element VLC Networks: LED Assignment, Power Control, and Optimum Combining,” *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 1, pp. 121–135, 2018.
- [24] X. Li, R. Zhang, and L. Hanzo, “Cooperative Load Balancing in Hybrid Visible Light Communications and WiFi,” *IEEE Transactions on Communications*, vol. 63, no. 4, pp. 1319–1329, 2015.
- [25] Y. Wang and H. Haas, “Dynamic Load Balancing With Handover in Hybrid Li-Fi and Wi-Fi Networks,” *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 9, pp. 1851–1862, 2015.