IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 18, Issue 5 Ser. II (Sep. – Oct. 2026), PP 13-19
www.iosrjournals.org

Data Transmission through Light using Li-Fi - A Futuristic Technology

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ABSTRACT
Li-Fi (Light Fidility) is a wireless communication technology that uses visible light, Infrared radiation or UV radiation for data transmission. In this process of communication, the main components are LED (light source), Photodiode or LDR (photo detector), modulation drivers and signal processing unit. The main advantage of Li-Fi is that data transmission speeds up to 100Gbps can be achieved under laboratory conditions, which is more advantageous than Wi-Fi, where we can achieve data transmission speeds up to 6Gbps only. Hence Li-Fi has a future in communication technology, where Li-Fi can replace Wi-Fi. However, multiple challenges are associated with the deployment of this technology, attributed to both the LDR and LED. The characteristics of LDRs vary with the intensity of light falling on them, depending on the distance of the source or receiver, the intensity of the light source, and the wavelength of the various components of white light. Additionally, ordinary light possesses the inherent property of dispersion. The challenges prevalent in this context include dependence on line of sight, limited operational regions, non-functionality in darkness, and constraints posed by light fixtures and environmental conditions.
Keywords: *Wireless communication, data transmission, Wi-Fi, Li-Fi, Visible communication, LED, LDR and Photodiode.*

Date of Submission: 12-09-2026 Date of Acceptance: 22-09-2026

I. INTRODUCTION

Communication is very important in our day to day life. Early civilizations have used different modes of communication like beacon fires, smoke, and flags are used for signaling as a part of communication to give their presence or address. In the 4th century BCE, the Greek Hydraulic Semaphore System used water flow and visual signals for communication.

During Roman-Greek war times, sunlight was used as a signal by reflecting using reflectors like mirrors and shields. In 1792 Claude Chappe developed the optical semaphore telegraph system in France, using towers with movable arms or transmitting messages. In 1810 Carl Friedrich Gauss used two mirrors in order to send signals between two stations. In 1867 Sir Henry Christopher Mance invented the heliograph, a device that used mirrors and sunlight to send Morse code. It was used in military operations. The first photophone was invented by Alexander Grahambell and Charles Sumnar Tainter in 1880, who transmitted voice signals using modulated sunlight. It is the first wireless technology that works on light. In 1935 army of Germany created a photophone in which tungsten filament functions as a source of light. During the period of 1950s to 1960s, development of LASER enabled more precise and efficient optical communication. In 1962 Lincoln laboratories were able to do experiments on optical communication using gallium arsenide LED as transmitter successfully and to send television signals over a distance of 30 miles [3]. Modern optical wireless communication uses LEDs and LASER lights in transmission of signals. In 1966 ***Charles K. Kao and George Hockham*** proposed the use of *fiber-optic cables* for telecommunications. Kao demonstrated that optical fibers could transmit data over long distances with low attenuation (loss). In 1970 Corning Glass Works developed low-loss optical fiber (20 dB/km), making fiber-optic communication practical for commercial use.

LiFi (Light Fidelity) technology is a wireless communication system that uses light to transmit data. It is an innovative alternative to traditional Wi-Fi, which uses radio frequency signals. The history of LiFi technology can be traced back to the early 2000s, with key milestones along the way:

In 2003, the concept of Visible Light Communication (VLC) began gaining attention as researchers explored using light for data transmission. VLC is the foundation upon which Li-Fi is built. Until 2008, the term " Li-Fi" has not yet been coined, but research on modulating LED light for data transfer was developing.

During the period of 2010-2011 the emergence of Li-Fi technology has started. In 2011 Professor ***Harald Haas*** from the University of Edinburgh coined the term " Li-Fi" during his famous TED Global Talk. He demonstrated how an LED light bulb could transmit high-speed data, introducing the idea of using visible light as a data transmission medium. 2012 to 2015 is the period of development and commercialization of Li-Fi. In 2012, Fraunhofer Heinrich Hertz Institute in Germany and other research institutions started experimenting with VLC and Li-Fi technology. In 2013, Companies like purelyLi-Fi (co-founded by Harald Haas) emerged, focusing on developing Li-Fi-enabled products and solutions. In 2014 Early prototypes of Li-Fi systems achieved data speeds of over 1Gbps in laboratory settings. In 2015 Li-Fi technology made headlines when it achieved speeds of up to 224 Gbps under lab conditions. 2016 to 2020 is the period of advancements and Real-world applications. The Real-world tests were conducted in offices and industrial environments. A notable pilot project took place in a French company, enabling high-speed internet through LED lighting. Li-Fi technology started gaining interest in sectors like aviation, healthcare, and defense in 2017, due to its security and electromagnetic interference-free properties. In 2018 ***pure Li-Fi*** introduced ***Li-Fi-XC***, the first plug-and-play Li-Fi system, marking a step towards mainstream adoption. In 2019, Li-Fi systems were integrated into lighting infrastructure in offices, schools, and hospitals in Europe and Asia. In 2020 The IEEE 802.11bb Task Group was established to work on a global standard for Li-Fi technology, ensuring compatibility and promoting its adoption. In 2021 The standardization process continued, and more companies, including Signify (formerly Philips Lighting), joined the development of Li-Fi solutions. In 2023 The IEEE 802.11bb Standard for light-based wireless communication was officially published, marking a major step toward global Li-Fi adoption.

Wi-Fi Vs Li-Fi

Energy consumption is more due to router operation. In deploying Wi-Fi, we require routers, access points and adopters. Coming to Li-Fi, light waves including IR and UV can be used as a medium of transmission, which is easy to produce. With this we can achieve speeds up to 100 Gbps. The frequency band is 430-770THz. The area covered by a light source is limited, therefore it covers limited region. Light signals cannot penetrate walls and obstacles. Li-Fi communication is suitable for secure and high-speed indoor use such as hospitals, aircraft and IOT. Wi-Fi is not suitable for aircraft. In view of security, Li-Fi is good as they cannot penetrate walls, since their deployment uses LED light sources and photo detectors [4]. LiFi (Light Fidelity) is a wireless communication technology that uses visible light, ultraviolet, or infrared light for data transmission. It is a subset of Visible Light Communication (VLC). The idea was popularized by Professor ***Harald Haas*** in 2011, and since then, it has gained significant attention in both academic research and industrial applications.

STATEMENT OF THE PROBLEM

The problem addressed by this research is the exploration and optimization of Li-Fi (Light Fidelity) technology for high-speed, secure, and interference-free data transmission, while overcoming its inherent limitations. Li-Fi, utilizing visible light, infrared, or ultraviolet radiation for wireless communication, promises remarkable data speeds, surpassing traditional Wi-Fi capabilities. However, its widespread adoption is hindered by critical challenges such as dependence on line-of-sight, limited operational range, and non-functionality in darkness. These limitations restrict its effectiveness for large-scale outdoor applications and necessitate the development of standardized protocols. Despite its potential, there is a need for comprehensive studies to enhance Li-Fi's efficiency and integration into existing infrastructures. Current research shows that modulation techniques like On-Off Keying and Orthogonal Frequency Division Multiplexing can enhance Li-Fi’s performance, yet the technology requires further refinement to address its range and line-of-sight constraints. Additionally, the introduction of the IEEE 802.11bb standard in 2023 highlights the industry's effort to establish a unified framework for light-based communication, fostering interoperability and broader adoption.

HYPOTHESIS

In this research paper, we hypothesize that Li-Fi (Light Fidelity) technology, leveraging visible light, infrared, or ultraviolet radiation, can significantly outperform traditional Wi-Fi in terms of data transmission speed, security, and energy efficiency, despite its inherent challenges. The hypothesis posits that through the strategic integration of key components such as LEDs, photodiodes, and advanced modulation techniques, Li-Fi can achieve unprecedented data rates, potentially reaching up to 100 Gbps or more in controlled environments. The research further hypothesizes that the limitations of Li-Fi, including its dependence on line-of-sight, limited operational range, and functionality constraints in the absence of light, can be mitigated through technological advancements and standardization efforts like the IEEE 802.11bb standard. The hypothesis also suggests that Li-Fi's unique attributes make it particularly suitable for specific applications where Wi-Fi's limitations are pronounced, including in sensitive environments like hospitals, aviation, and underwater communication systems. Additionally, the integration of Li-Fi into smart city infrastructure could revolutionize data access and management. Experimental investigations within this study aim to validate these hypotheses by examining the performance parameters of Li-Fi systems under varying conditions, focusing on the effects of distance, light wavelength, and system component optimization. Ultimately, the hypothesis envisions that with continued research and development, Li-Fi technology could play a pivotal role in the evolution of next-generation communication networks, offering a viable alternative to traditional wireless communication methods.

II. AIM AND OBJECTIVES

Aim :

The aim of this research paper is to explore and evaluate the potential of Li-Fi (Light Fidelity) as a revolutionary wireless communication technology, focusing on its capabilities for high-speed data transmission using light-based communication. The study seeks to understand the advantages, limitations, and applications of Li-Fi, as well as the impact of recent developments, such as the IEEE 802.11bb standard, on its adoption and integration into modern communication networks.

Objectives:

1. To compare the performance of Li-Fi with traditional Wi-Fi technology in terms of data transmission speeds, energy consumption, and security.
2. To investigate the challenges and limitations of Li-Fi technology, including its dependence on line-of-sight and limited operational range.
3. To explore various applications of Li-Fi in sectors such as healthcare, aviation, underwater communication, and smart cities.
4. To review the impact of the IEEE 802.11bb standard on the standardization and global adoption of Li-Fi technology.
5. To conduct an experimental study examining the performance of an Arduino-based Li-Fi system, focusing on the effect of distance and light wavelength on photo current and resistance.
6. To identify potential improvements in system components, such as the use of photodiodes and appropriate LED colors, to enhance the performance and range of Li-Fi systems.
7. To evaluate the prospects of integrating Li-Fi technology into future communication networks, including its role in 6G networks.

III. REVIEW OF LITERATURE

Now a days we are using Wi-Fi for Internet and mobile communication, where the number of receivers can be connected. Wi-Fi uses radio waves as a medium of transmission. Their speeds are generally ranging from Mbps to few Gbps. Wi-Fi's are available in different spectrums like 2.4GHz, 5GHz etc. They can cover large areas within router range. These waves can penetrate walls and obstacles, but they are highly susceptible to interference from other RF devices. It is generally suitable for wireless networking at homes, offices and public spaces. Coming to the security point of view, Wi-Fi signals are less secure, as they can be easily intercepted.

Data Transmission and Speed

- Haas (2011): Introduced the term "LiFi" and demonstrated its potential to achieve data rates exceeding 10 Gbps in laboratory settings using light-emitting diodes(LEDs) for data transmission.
- Chowdhury et al. (2018): Conducted experiments showing that Li-Fi can achieve data rates of up to 224 Gbps in controlled environments.
- Pathak et al. (2015): Explored techniques for improving data transmission efficiency, such as multiple-input and multiple-output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM).

Modulation Techniques

- Ghassemlooy et al. (2015): Investigated various modulation techniques like On-Off Keying (OOK), Pulse Position Modulation (PPM), and OFDM, highlighting the balance between speed, complexity, and reliability in LiFi systems.
- Zhang et al. (2017): Focused on dimming support in LiFi systems, ensuring that data transmission does not affect lighting quality.

Channel Modeling and Performance Analysis

- Armstrong (2013): Developed channel models for indoor environments, analyzing the impact of reflection, shadowing, and interference on LiFi performance.
- Wu et al. (2017): Studied the effects of mobility and beam misalignment on LiFi performance, proposing hybrid systems combining Li-Fi and Wi-Fi to enhance connectivity.

Integration with Existing Technologies

- Huang et al. (2018): Suggested hybrid Li-Fi - Wi-Fi networks to leverage the advantages of both technologies. LiFi provides high-speed data transmission, while Wi-Fi offers broader coverage.
- Haas & Yin (2015): Proposed the concept of optical attocell networks, which use small coverage areas (attocells) to enhance spectral efficiency and reduce
- Line-of-Sight Requirement: LiFi requires a clear line-of-sight for optimal performance. Obstructions can significantly degrade the signal quality (Ghassemlooy et al., 2015).
- Limited Range: LiFi is primarily suitable for short-range communication, making it less effective for large-scale outdoor applications.
- Standardization: Although the IEEE 802.11bb standard for LiFi was introduced in 2023, widespread adoption and interoperability remain challenges (Tsonev et al., 2015).

While Li-Fi has significant advantages in specific use cases, its inability to function without direct line-of-sight and light makes it less versatile than Wi-Fi for general use.

Applications for Li-Fi Technology

- Healthcare: LiFi is preferred in hospitals due to its immunity to electromagnetic interference, ensuring safe wireless communication in sensitive environments (Chowdhury et al., 2018).
- Aviation: Li-Fi can enable in-flight connectivity without interfering with avionics systems (Haas, 2013).
- Underwater Communication: Since radio waves face limitations underwater, light-based communication (Li-Fi) offers a viable alternative (Kaushal & Kaddoum, 2016).
- Smart Cities: Integration of Li-Fi with streetlights and smart homes for high-speed data access (Ayyash et al., 2016).

Challenges and Limitations

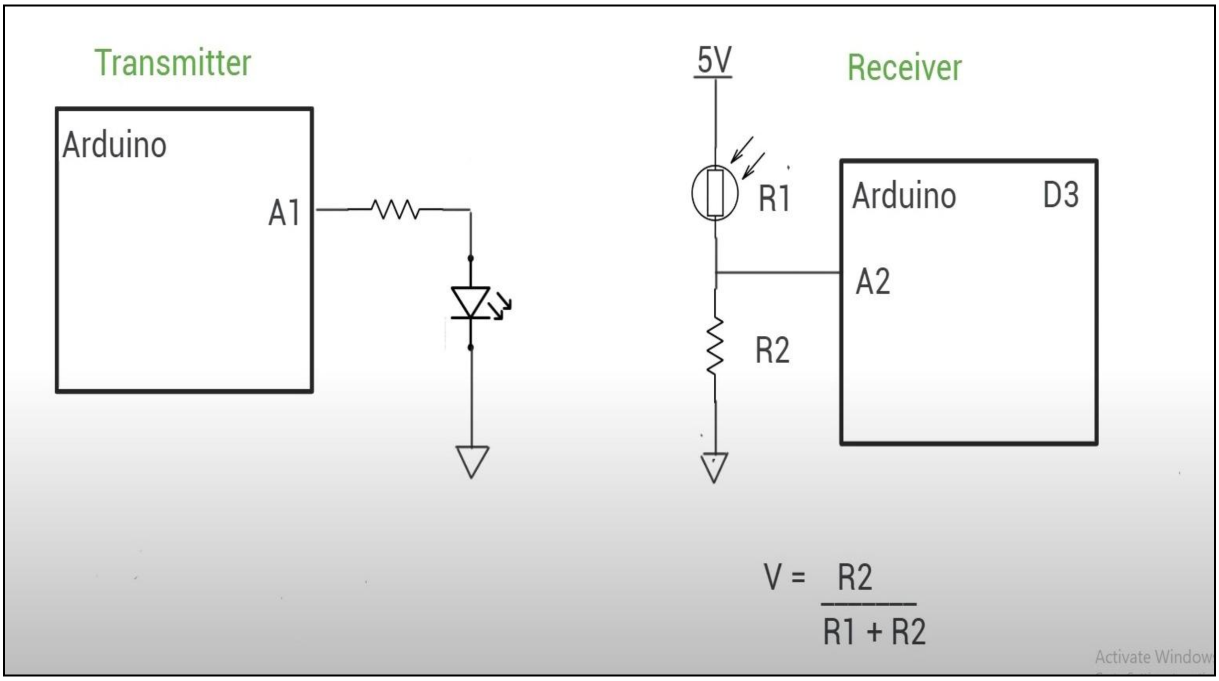
- Line-of-Sight Requirement: Li-Fi requires a clear line-of-sight for optimal performance. Obstructions can significantly degrade the signal quality (Ghassemlooy et al., 2015).
- Limited Range: Li-Fi is primarily suitable for short-range communication, making it less effective for large-scale outdoor applications.
- Standardization: Although the IEEE 802.11bb standard for Li-Fi was introduced in 2023, widespread adoption and interoperability remain challenges (Tsonev et al., 2015).

5. ***Recent Developments***

IEEE 802.11bb Standard (2023): This standard defines the physical and media access control (MAC) layer specifications for light-based wireless communication, promoting global adoption (IEEE, 2023).
PureLiFi: Developed commercial Li-Fi products like LiFi-XC and LiFiMAX, enabling plug-and-play solutions for offices and industrial environments.
Integration with 6G: Researchers (Chowdhury et al., 2020) highlighted the potential role of Li-Fi in 6G networks to meet growing data demands and provide ultra-reliable low-latency communication (URLLC).

EXPERIMENTAL SETUP DESCRIPTION

This study has been conducted using the following circuit.



The experimental arrangement consists of the Transmitter circuit and Receiver circuit. Transmitter transmits digital data in the forms of 0's and 1's. Transmitter circuit contains ARDUINO, Switch, LED. The receiver circuit also contains ARDUINO, LDR, resistor and LED. The main components are LED light source, photo detector, modulation driver and signal processing unit. LED light source at the transmitter end functions as a Transmitter, which converts electrical signals into light. LEDs with high modulation speeds are used for this purpose [8]. LDR functions as photodetector. LDR at the receiver end circuit functions as the receiver. It captures modulated light and converts into electrical signals. Arduino at transmitter end functions as a modulation driver which modulates LED light source to encode data. The signal processing unit at the receiver end decodes the received light signal into a readable format.

WORKING

At the transmitting end a button is added, which is connected to Arduino. As this button is pressed, LED is turned ON. In the Transmitter circuit along with LED, a resistor is connected. This resistor helps to limit the current, so that LED doesn't burn out.

At the receiving end, a photo detector (LDR), receives the light modulated signals and converts them back into electrical signals. If the voltage has passed a certain threshold, then they will be detected. The voltage at A_2 can be found by using relation $\frac{5*R_2}{R_1+R_2}$. More the light that hits the LDR, the higher the voltage at point 'A_2'. The electrical signals that are received are processed and converted into usable digital information.

IV. EXPERIMENT, RESULTS AND DISCUSSION

An experiment is also conducted to study the variation of LDR with the distance of source. Simultaneously the optical response of photodetector is also studied with the variation of wavelength(color) at fixed distance.

The experimental results obtained are tabulated and plotted.

DISTANCE (cm)	VOLTAGE(V)	CURRENT (µA)	RESISTANCE (Ω)
10	0.5	1	0.5M
20	0.6	0.8	0.75M
30	0.8	0.7	1.14M
40	1.1	0.6	1.8M
50	1.2	0.5	2.4M

60	**1.2**	**0.4**	**3M**

It can be concluded that by changing the distance the resistance offered and also the response current is changing. The photo current is more when photo resistive cell is nearer and it's decreasing with the distance.

VARIATION OF PHOTO CURRENT WITH LIGHT(WAVELENGTH)

WAVELENGTH (nm)	PHOTOCURRENT (μA)
436(Blue)	17.6
546(Green)	20.6
580(Yellow)	53.6
600(Orange)	27
680(Red)	34

Response of photo conducting cells is also changing along with wavelength. From results obtained. It can be concluded that the optical response of cells is close to eye. The photocurrent is maximum for yellow color light.

V. CONCLUSION

Early communication systems used visual signals, progressing through inventions like semaphore systems and the heliograph, to modern optical communications using LEDs and LASER. The development of fiber-optic cables in the 1960s marked a significant advancement, enabling long-distance, low-attenuation transmission. Li-Fi, or Light Fidelity, emerged in the early 2000s as a technology using light waves for data transmission, distinct from Wi-Fi's use of radio waves. Coined by Professor Harald Haas in 2011, Li-Fi has seen research and commercialization efforts leading to high-speed data transfers, with reported lab speeds up to 224 Gbps. Despite its potential for secure and interference-free communication, challenges like range limitations and line-of-sight dependency remain. The IEEE 802.11bb standard, published in 2023, aims to address these by promoting global adoption and standardization. Li-Fi is particularly suited for environments requiring high-speed, secure communication free from electromagnetic interference, such as healthcare, aviation, and underwater applications.

Experimental study shown that how photo current and resistance vary with distance and light wavelength, highlighting Li-Fi's potential but also its dependency on specific conditions for optimal performance. In Li-Fi transmission of data is performed using visible light generally emitted by LED. In traditional electrical systems voltage levels corresponding to binary '1' and '0' are standardized, but in this Li-Fi system voltage levels cannot be standardized they depend on LED driver circuit [9]. Binary '1' is interpreted as LED is ON, emitting light, this corresponds to higher voltage level , i. e forward voltage generally between 2v to 3.5v. Binary '0' is interpreted as LED is OFF, not emitting light ,which corresponds to lower voltage level(or 0V[10].From the experiments ,it is clear that the response of LDR is depending on distance of receiver, intensity of incident light, and wavelength of light. It can be concluded that standardization of voltage levels is critical. If any stardization is done due to interference of light from other sources may cause change in the intensity of incident light that hit LDR may change voltage level and Arduino may convert into wrong signal. From experimental data, it is also clear that Li-Fi system is primarily short range. Ordinary light is having the problem of spreading. Due to this reason, the intensity of incident light on LDR is also decreasing. These shortcomings may be resolved by using photo diodes instead of LDR in combination with operational amplifier, which raises strength of signal and response time in this way range can be increased. Choosing the colour of LED will enhance voltage level, so that range of receiver can also be increased because photo current depends on colour. Generally, LEDs are current driven devices. By choosing IR sources noise problems can be solved. By selection of proper devices range can be increased.

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