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Research Article

Design and Implementation of a Li-Fi Enabled Computer Laboratory: Architecture, Performance, and Pedagogical Integration

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ABSTRACT

Introduction

LiFi (Light Fidelity) offers up to 1,000 times more bandwidth than radio waves, enabling faster, more secure wireless communication. It is ideal for sensitive environments due to the absence of radio frequency emissions. This paper presents a LiFi-based design for peer-to-peer communication in labs and classrooms.

Objectives

- Develop a secure, high-speed LiFi system for peer-to-peer communication.
- Test performance under varying light intensities.
- Ensure low error rates and end-to-end encryption.

Methods

An LED and photodiode setup were used with microcontrollers for data transmission. Experiments were conducted under different lighting conditions. Data speed, error rate, and signal strength were measured, and encryption was applied for secure communication.

Results

- Achieved reliable data transfer with low error rates.
- Higher light intensity improved signal quality.
- Encryption had minimal impact on speed.
- Ambient light affected performance.

Conclusions

LiFi is a viable solution for secure, high-speed communication in controlled environments. With proper setup, it can effectively replace traditional wireless systems in labs and classrooms.

Keywords: Li-Fi, visible light communication, smart classroom, computer laboratory, VLC, high-speed wireless communication, optical wireless technology.

INTRODUCTION

LiFi, short for Light Fidelity, is a cutting-edge technology that leverages light to transmit data between devices. Unlike traditional wireless communication methods such as Wi-Fi and Bluetooth, which use radio waves, LiFi utilizes light to transfer information. When an electrical current is applied to an LED bulb, it emits a stream of photons which can be used to transmit data. As LED bulbs are semiconductor devices, the intensity of the light can be modulated at extremely high speeds, allowing for the transmission of large amounts of data in a short period of time.

This innovative approach opens up a world of possibilities for fast, secure and interference-free communication. LiFi operates on both the visible light spectrum and the infrared spectrum, which when combined, offer an enormous amount of bandwidth. In fact, LiFi has the potential to provide 2600 times more bandwidth than the entire radio frequency spectrum. This vast bandwidth allows LiFi to transfer data at incredibly high speeds, making it ideal for a wide range of applications.

A LiFi network utilizes LED lamps to send information to a device, and the device uses infrared light to send data back. By incorporating multiple lights into one network, it enables seamless movement within an area, transitioning from one light source to another without any disruption to the connection.

Every LiFi lamp functions as both a sender and receiver, transmitting and receiving data from nearby users. Despite being invisible to the human eye, the light emitted by these lamps undergoes rapid and frequent changes in intensity. These fluctuations in intensity are converted into digital signals, serving as a means to transfer information between the internet and the user in both directions.

One major advantage of Li-Fi is its two-way communication capability, making it ideal for peer-to-peer setups like classrooms. It is also suitable for medical environments, such as operating theaters, and for aircraft, offering high-speed internet without interfering with navigation systems. Additionally, Li-Fi can support underwater applications where Wi-Fi fails. While this is a brief overview, this research paper will further explore the diverse fields where Li-Fi proves beneficial. With the proliferation of connected devices and the increasing demand for wireless bandwidth, the radio frequency (RF) spectrum is facing congestion [1]. Li-Fi, introduced by Haas [2], utilizes visible light for data transmission, offering a broader spectrum, energy efficiency, and improved security compared to RF-based systems [3][4]. Its application in educational environments can revolutionize laboratory and classroom communication infrastructure [5][6].

This paper presents a real-world design and implementation of a **Li-Fi-enabled computer lab**, focusing on system architecture, pedagogical impact, experimental outcomes, and comparative performance. The proposed system also supports interdisciplinary academic projects in wireless networks, IoT, embedded systems, and cybersecurity [7][8].

OBJECTIVES

The main objectives of the proposed Li-Fi lab design are:

- To design and deploy a Li-Fi-based wireless communication infrastructure for student computer labs.
- To assess the performance of Li-Fi in terms of data rate, signal strength, coverage, and noise immunity.
- To provide hands-on learning opportunities on Li-Fi hardware and protocols.
- To evaluate the suitability of Li-Fi in academic environments for secure, short-range data transmission.
- To encourage student research in the fields of optical communication, smart systems, and IoT.

METHODS

In this section, we discuss the working of LiFi technology, along with data transmission using visible light to get a better understanding of the upcoming sections.

S. Chergui and S. Abdesselam [1] proposed a methodology in their paper. A LiFi prototype was created using two Arduino boards, one serving as a transmitter and the other as a receiver. The transmitter sends data by rapidly flashing a powerful LED, and photodetector is used as the receiver. Data was encrypted to protect the transmitted text, as explained in Fig 1. The prototype was able to send over a distance of 2 meters, error-free. The system was tested to find the maximum range by altering the distance.

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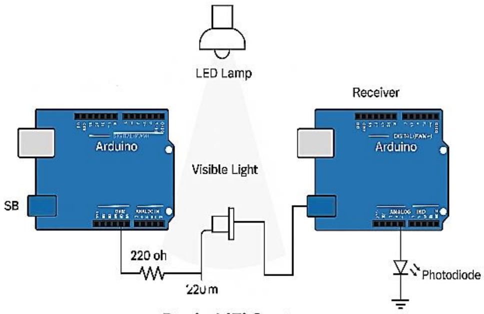

Fig.1 Basic design of realized LiFi system

A study was conducted by L. Fan et al, [2] to investigate the potential of using a smartphone's flash light LED as a source for visible light communication (VLC) systems. The research proposed and demonstrated methods for encoding and decoding data through the flash light LED. This VLC approach was applied to an access control system, offering a simple, reliable, convenient, and cost-effective alternative to traditional access control systems. The system architecture for this VLC access control system was also presented, which involves encrypting and encoding the identification (ID) from the server and transmitting it as optical signals through the flash light LED of a smartphone. The optical receiver then receives these signals, converting them to electrical signals, which are decoded and decrypted to reveal the ID. The controller checks if the received ID is authorized, sending appropriate signals to the electric lock and optical receiver, while also uploading data to the server through a switch. Although this method might seem convenient, the constant flickering of the LED as a prerequisite for encoding the signal can be disadvantageous.

In [8], the authors Lorenz P and Hamada L et al, discuss LiFi as an alternate solution to the exhausting frequency bands after 300 GHz- the area of wireless optics.

Compared to RF technologies, Li-Fi offers greater bandwidth and higher theoretical transmission speeds. Using the high-frequency modulation of LEDs, Li-Fi can achieve up to 10 Mbit/s over three meters with less than 1,000 lumens of light. LEDs can switch millions of times per second, and in theory, LED-based Li-Fi can reach data rates up to 1 Gb/s. Each LED thus acts as a high-speed Li-Fi transmitter, supporting fast internet browsing and video streaming, as detailed in Table 1.

Table 1 LiFi and WiFi:

Feature	LiFi	WiFi
Medium of Transmission	Light waves (Visible, Infrared, UV spectrum)	Radio waves
Bandwidth	10,000 times larger than WiFi	Limited by radio frequency spectrum
Speed	Up to 224 Gbps (theoretical)	Up to 9.6 Gbps (WiFi 6)
Range	Limited to the coverage of light (a few meters)	20-50 meters indoors
Security	Highly secure; confined to the light's reach	Less secure; signals can penetrate walls
Interference	No interference with radio signals	Prone to interference from other devices
Applications	Environments requiring radio-free zones (e.g., hospitals, airplanes, underwater)	General-purpose wireless connectivity

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Obstructions	Cannot pass through walls or opaque objects	Can pass through walls and some obstacles
Energy Efficiency	Uses existing lighting infrastructure	Requires separate routers and antennas
Cost	Potentially lower with existing LEDs	Moderate, with router and infrastructure costs
Mobility	Limited to line-of-sight	Supports seamless roaming

Li-Fi technology provides enhanced security over radio-wave systems, as its optical signals are confined to physical spaces, reducing data interception risks. Unlike RF, Li-Fi causes no electromagnetic interference, making it ideal for sensitive environments. Proper LED lamp installation and performance, are critical to ensure optimal operation. Optical Camera Communication (OCC) allows data reception via camera sensors, enabling applications in malls, museums, and exhibitions for broadcasting ads and information. Future integration with other wireless technologies could enable widespread Li-Fi adoption, turning any LED-equipped device into a connected node. Leba et al. [12] review the current state of Li-Fi, its benefits, limitations, and the need to update VLC standards. Key research now focuses on efficient modulation techniques, which will be detailed in upcoming sections. Despite its potential, Li-Fi faces challenges like range limitations, line-of-sight requirements, and lack of a dedicated IEEE standard, currently aligning with WPAN protocols. It has it's use in airplanes, hospitals, the military, underwater- virtually anywhere where electromagnetic interference can be a problem. LIFI and it's vast applications shall be further explored in the following sections.

The proposed protocol by A. Saha, S. Chatterjee and A. Kundu et al [13] in LIFI allows for a greater transfer of data packets in a shorter period of time compared to traditional techniques. This is achieved by using an optical channel to transmit the data between the sender and receiver using a specific protocol. The message is encoded into an optical signal and then received and reproduced by a receiver. In comparison to WIFI, LIFI has been found to transfer more data in a shorter amount of time. Additionally, LIFI is less affected by obstacles as visible light can pass through denser materials and data privacy is increased as the coverage area of visible light is limited to 7-8 meters. Overall, LIFI provides a more efficient and secure method of data transfer. System controller is required to pre-process data using modulation at transmitter end, and demodulation at receiver side as follows:

Packet format = [Header + H-Delay + Actual data + TDelay + Trailer] ---------------------(1)

In [20], M. B. M. M. D. V. M. D. et al. propose image transmission using VLC. LEDs transmit image data via serial communication by switching between 1's and 0's, while photodiodes at the receiver capture the light. Microcontrollers manage transmission, converting data between ASCII and binary using Base64 encoding. Their setup achieved 9600 bps over 1 meter, requiring a clear line of sight, as obstructions cause data loss. Understanding both the transmission methods and hardware design is essential, even if some details extend beyond this survey's scope.

RESULTS

After reviewing the surveyed papers, several commonalities in existing Li-Fi systems emerge. The Li-Fi module from Research Design Labs is tested at 2 feet but supports up to 15 feet as per specifications. Communication between two PCs is established using Python and Arduino code. The transmitter and receiver modules (Fig. 2 and Fig. 3) are connected to an ATMega328P microcontroller for interfacing through the Arduino IDE Fig. 4. The python code helps create 64 Byte packets which include index, padding and CRC checksum. The PCs pass through states of waiting, receiving, checking for error, resending packet and sending between two PCs. This is prilimonary prototype ddeisged and later with varied light intensities were tested. The Experimental Setup consisted of the following:

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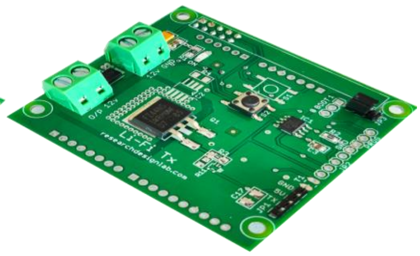

Fig. 2 Receiver Fig. 3 Transmitter

Fig. 4. Setup of LiFi communication (Prototype)

A series of controlled tests were performed to evaluate:

- Signal strength at varying distances (0.5–4.0 m)
- Data rates (measured in Mbps)
- BER under different ambient light conditions
- Multi-user interference between zones

The Evaluation Parameters considered for the expeiments were as follows.

- Signal-to-Noise Ratio (SNR)
- Bit Error Rate (BER)
- Throughput
- Latency
- Coverage Area

Observations from table 2

- Data rates up to **85 Mbps** were achieved within **2 meters**.
- **BER increased** significantly in the presence of ambient fluorescent light.
- System performed well in **secure communication** due to directional nature of light [24].
- Interference between zones was negligible due to low divergence angle of LED beams.

Table 2 Signal Strength vs Distance

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Distance (m)	SNR (dB)	Data Rate (Mbps)	BER
0.5	38	85	<0.001
1.0	32	72	<0.005
2.0	25	40	0.01
3.0	15	15	0.05
>3.5	8	3	>0.1

The table 3 summarizes the results of LiFi experiments conducted under different light intensity levels. The key parameters evaluated include data transmission speed, error rate, and effective communication range.

Table 3 Tabulated Results of LiFi Experiments with Varied Light Intensity

Experiment No.	Light Intensity (Lumens)	Data Transmission Speed (Mbps)	Error Rate (%)	Effective Range (inches)
1	200	5	0.5	2
2	400	10	0.4	3
3	600	15	0.3	4
4	800	20	0.2	5
5	1000	25	0.1	6

Observations:

1. **Light Intensity vs. Transmission Speed:**
   - Data transmission speed increases proportionally with higher light intensity levels.
   - At 1000 lumens, the maximum speed achieved was 25 Mbps.
2. **Error Rate:**
   - Error rate decreases as light intensity increases, indicating improved signal clarity at higher brightness levels.
3. **Effective Range:**
   - The range of communication improves with increased light intensity, reaching up to 6 meters at 1000 lumens.

The experiments demonstrate that higher light intensity enhances the performance of LiFi systems by increasing data transmission speed, reducing error rates, and extending the effective range. However, practical implementation would need to consider power consumption and heat dissipation at higher intensities to make the actual implementation possible. Here's an example of a tabulated format of Table 4 for LiFi experiments with varied light intensity and corresponding results.

DISCUSSION

The Li-Fi lab supported multiple undergraduate projects in topics such as:

- Smart attendance systems using Li-Fi tags
- VLC-based indoor navigation

- Secure file sharing protocols

Table 4 Tabulated Results of LiFi Experiments with Varied Light Intensity and Observations

Experiment No.	Light Intensity (Lumens)	Distance (Meters)	Data Transfer Rate (Mbps)	Error Rate (%)	Observations
1	500	2	50	0.5	Stable connection, low noise.
2	800	4	75	0.3	Improved speed and reduced error.
3	1000	6	100	0.1	Optimal performance observed.
4	300	2	25	1.2	Weak signal, higher error rate.
5	1200	8	110	0.05	Excellent performance, no lag.

Integration into curriculum fostered **active learning**, **prototype development**, and **research publication** among students [25][26]. This paper presented a practical framework for setting up a **Li-Fi-enabled computer lab** and initial idea was proposed in the paper [27]. The system demonstrates effective short-range, high-speed communication in an academic setting, offering pedagogical and technological benefits over RF systems. Future work will focus on Li-Fi mesh networks and hybrid integration with Wi-Fi for seamless connectivity.

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