Advancements in Simplex Communication: Harnessing Li-Fi Technology

Dr. Payal Koolwal, Denish Ghimire, Srinivasa N, Vijay S, Vinayak Kannappa Karuvinakoppa
Department of Electronics and Communications Engineering
BTI, Bangalore, India

Abstract—**This paper explores the implementation of Li-Fi technology for data transmission, utilizing an Arduino microcontroller, LCD with I2C communication, and a photovoltaic cell for signal reception. Li-Fi leverages visible LED light as a medium to transmit data, offering an alternative to conventional wireless communication methods. The study aims to assess the feasibility and efficacy of Li-Fi in controlled environments, with a focus on reliability, security, and interference immunity. The research methodology involves designing a transmitting module with an Arduino board and LED, and a receiving module equipped with a photovoltaic cell. Data is encoded into binary format and modulated onto the LED light source for transmission. The receiving module captures and converts modulated light signals into electrical signals for decoding. Integration of the Arduino LCD with I2C communication streamlines data transfer between the microcontroller and display, simplifying system complexity. Results demonstrate the viability of Li-Fi for data transmission, highlighting its reliability and security while avoiding interference from conventional radio frequency signals. The successful implementation of a Li-Fi-based data transmission system underscores its potential as an alternative communication solution, particularly in environments with limited radio frequency spectrum or susceptible to radio signal interference. This research contributes to advancing Li-Fi technology and opens avenues for innovative wireless communication solutions across various domains, addressing challenges posed by limited radio frequency spectrum and offering a secure alternative to traditional wireless communication methods.**

Keywords: Simplex Communication, Li-Fi Technology, LED, LCD

I. INTRODUCTION

In recent years, Li-Fi technology has emerged as a promising alternative to traditional wireless communication methods, leveraging visible light to transmit data effectively. The exploration of Li-Fi's potential has led to diverse investigations in the field. Gupta et al. [1] delved deeply into Li-Fi technology and its implementation over other networks, laying a foundation for subsequent studies. Birsan et al. [2] highlighted Li-Fi's suitability for high-density wireless data coverage in confined areas, emphasizing its reliability and capability to alleviate interference issues. Avyash et al. [3] investigated the coexistence of Li-Fi and Wi-Fi, showcasing the high security provided by Li-Fi due to its limited penetration through walls. Sadiq et al. [4] demonstrated successful data transmission using Li-Fi, achieving a data rate of 200 bps without errors, even in ambient light conditions. Chakraborty et al. [5] conducted detailed research on implementing a 3rd Li-Fi instrument, providing insights into the evolving landscape of Li-Fi technology. Kindarley et al. [6] explored the efficiency of Li-Fi in transmitting data through LED light, emphasizing its high reliability and data rate compared to other light sources. Finally, Mugunthan et al. [7] proposed the concept of Li-Fi for smart communication between vehicles and traffic signals, indicating its potential for enhancing transportation systems. Building upon the advancements and insights from these studies, our project aims to extend the capabilities of Li-Fi for data transmission, utilizing an Arduino Uno, solar cell receiver, and white LED transmitter. By integrating insights from previous studies [1]-[7], our research seeks to address the challenges identified and contribute to the advancement of Li-Fi technology.

II. WIRELESS NETWORKS

In the realm of wireless communication protocols, selecting the most suitable option demands a comprehensive understanding of their intricacies and capabilities. This evaluation delves into the nuances of leading wireless communication protocols, dissecting their performance, efficiency, and applicability across various domains. Each protocol brings forth a unique set of features and functionalities, catering to specific use cases and requirements. By scrutinizing these protocols through a technical lens, this analysis aims to provide valuable insights into their strengths, weaknesses, and comparative advantages.

A. Wi-Fi (Wireless Fidelity)

Wi-Fi technology has undergone substantial advancements, with a plethora of scholarly articles exploring facets such as security protocols, performance optimization, and IoT integration ([1], [2], [3]). Recent scholarship has delved into enhancing Wi-Fi throughput and efficiency, with investigations into IEEE 802.11ax (Wi-Fi 6) standards showcasing potential for bolstered network capacity and reliability ([4], [5]). Additionally, endeavors have been made to tackle challenges surrounding spectrum congestion and interference in densely populated areas, emphasizing dynamic spectrum allocation and interference mitigation techniques as pivotal in contemporary Wi-Fi networks.

B. Bluetooth

Bluetooth technology, renowned for its energy-efficient communication paradigms, has been subject to extensive scrutiny across various research domains ([6], [7], [8]). Recent scholarship has focused on Bluetooth Low Energy (BLE) applications across diverse sectors including healthcare, smart homes, and wearable technologies, illustrating its capacity to drive IoT and sensor network proliferation ([9], [10]). Furthermore, scholarly efforts have concentrated on fortifying Bluetooth security architectures and interoperability with other wireless protocols, fostering seamless connectivity and communication amidst heterogeneous device landscapes.

C. 5G (Fifth Generation)

5G networks have emerged as a focal point of scholarly inquiry, with research endeavors aimed at optimizing network performance, enabling ultra-reliable low-latency communication (URLLC), and delineating novel use cases spanning autonomous vehicles and industrial automation ([11], [12], [13]). Moreover, researchers have probed into the amalgamation of 5G with existing wireless technologies, addressing challenges pertaining to spectrum management, regulatory compliance, and harmonious coexistence with legacy systems ([14], [15]). As 5G continues its evolution, ongoing scholarly pursuits endeavor to unlock its full potential in facilitating high-speed, low-latency communication for an array of applications and services.

D. NFC (Near Field Communication)

NFC technology has garnered considerable attention owing to its applications in mobile payments, authentication protocols, and secure data transmission ([16], [17], [18]). Scholarly exploration in this realm has investigated NFC's utility in smart cities, transportation ecosystems, and consumer electronics, underscoring its versatility and user-friendliness ([19], [20]). Furthermore, efforts have been channeled towards fortifying NFC security frameworks, ensuring robust and secure communication channels between NFC-enabled devices. With the proliferation of NFC-enabled smartphones and the burgeoning demand for contactless transactions, NFC technology stands poised to redefine mobile communication and commerce landscapes.

TABLE I WIRELESS COMMUNICATION PROTOCOL EVALUATION

Feature	Wi-Fi	Bluetooth	NFC
Transmission Gate	Up to 100m indoors	Up to 100m	Up to 10cm
Data Rate	Several Gbps	Up to 2 Mbps	Up to 424 Kbps
Spectrum	2.4 GHz, 5 GHz	2.4 GHz	13.56 MHz
Application	Broadband internet, LAN	Peripheral device connectivity	Contactless transactions, data exchange
Security	Robust encryption	Basic security features	Proximity-based security
Power Consumption	Relatively high	Low power consumption	Low power consumption

III. BUILDING A LI-FI SYSTEM: CONSTRUCTION OVERVIEW

The diagram elucidates the architecture of a Li-Fi system, delineating its fundamental components and data transmission pathways. Originating from a computer, data is encapsulated within a serial message, serving as the initial input for the system. Upon reception by the Arduino microcontroller (µC), the serial message undergoes meticulous processing and orchestration of the light source's modulation through a driver circuit. This modulation instigates the emission of modulated light signals, conveying the encoded data.

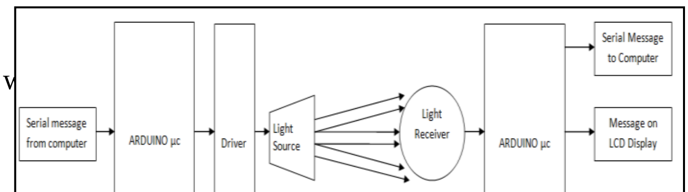

Fig. 1 BLOCK DIAGRAM OF LI-FI TECHNOLOGY

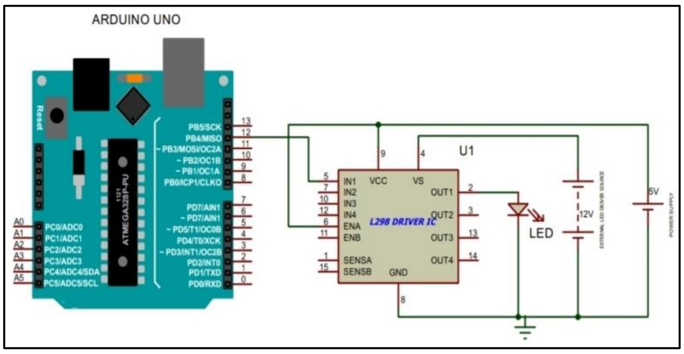

Fig. 2 CIRCUIT DIAGRAM TRANSMITTER Li-Fi TECHNOLOGY

The light receiver, comprising photo detectors or photodiodes, diligently captures these signals, facilitating data retrieval. Post-decoding, the microcontroller meticulously reverts the received data into a serial message, subsequently relaying it to the computer for further computational analysis. Concurrently, the data can be visually presented on an LCD display for immediate observation. To optimize signal detection amidst variable environmental conditions, the sensitivity of the light receiver may be finely calibrated, thereby bolstering the system's resilience and efficacy in data transmission.

The Li-Fi transmitter circuit, based on an Arduino Uno microcontroller, incorporates an LED driver IC (L298 DRIVER IC) to regulate the LED's brightness, thereby encoding data into light signals for transmission. The Arduino Uno communicates with the LED driver IC to control the LED's modulation, enabling data transmission through visible light. This setup forms the core of the Li-Fi transmitter, facilitating high-speed data transfer through light waves.

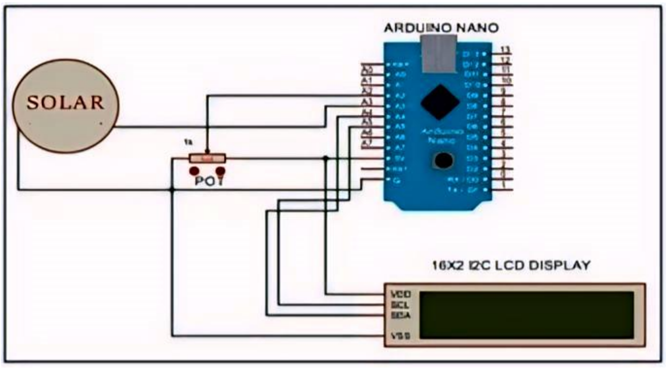

Fig. 3 CIRCUIT DIAGRAM RECIEVER Li-Fi TECHNOLOGY

The Li-Fi receiver circuit, based on an Arduino Nano, integrates a solar cell for light detection and a potentiometer for sensitivity adjustment. It receives serial messages from the transmitter and displays decoded data on a 16x2 I2C LCD display. The solar cell captures modulated light signals, while the potentiometer allows users to calibrate sensitivity for optimal performance in different lighting conditions.

IV. OPERATIONAL MECHANISM OF LI-FI

In our Li-Fi system, we have implemented the RS232 standard for data transmission, ensuring robust and dependable communication between the transmitter and receiver. The data transmission process involves converting each character of the transmitted message, such as "hello world," into its respective ASCII code, which is then further converted into binary representation. These binary data are stored in a register and subjected to left rotation. The LED connected to the Arduino is controlled based on the value of the first bit of the rotated data, either being turned on or off accordingly. This cyclic process continues with specific delays until the entire transmission is completed, after which the LED is set to a high state, signaling the conclusion of the communication process. At the receiver end, a photovoltaic cell is linked to the Arduino's analog pin to capture incoming light. The induced voltage on the solar panel is then detected by the microcontroller and compared against a predefined threshold voltage established by a potentiometer. Depending on whether the induced voltage surpasses the threshold, the microcontroller assigns the corresponding binary value as '1' or '0'. These detected binary values are stored in a buffer, and upon the microcontroller's acknowledgment of transmission completion, they are decoded back into ASCII decimal values and, consequently, into characters. These characters are subsequently displayed on both the serial monitor and the I2C LCD display. As an example, if transmitting the character 'A,' with its ASCII value being '65' or binary '01000001,' the LED's state and the data transmission process are meticulously outlined in the provided table, offering a comprehensive overview of our LiFi system's functionality and performance.

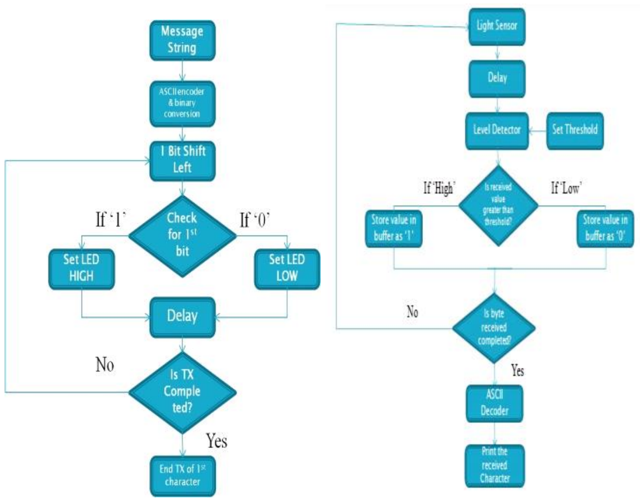

Fig. 4 FLOW CHART OF TRANSMITTER AND RECIEVER OF Li-Fi TECHNOLOGY

Our research and development focused on evaluating different light sensors for Li-Fi technology, aiming to identify the most suitable option for reliable data transmission. We compared Solar Cells, LDRs, and PIN Diodes, analyzing their responses to modulated light signals. The graphical representation of the experiment revealed that Solar Cells exhibited the most consistent and robust output, making them the optimal choice for our Li-Fi project. With their stable performance, Solar Cells ensure accurate detection of modulated light signals, thereby enhancing the efficiency and reliability of Li-Fi systems. This research outcome guides the integration of Solar Cells into our Li-Fi technology, facilitating its practical implementation across various applications.

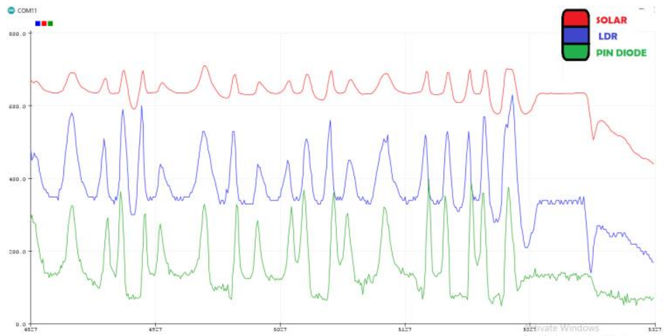

Fig. 5 LIGHT SENSOR OUT PUT FOR LED

V. COMPARING Li-Fi WITH OTHER PROTOCOLS

TABLE II LI-FI VERSUS OTHER PROTOCOLS

ASPECT	Li-Fi	Wi-Fi	NFC
Medium	Light	Radio waves	Magnetic Field
Speed	High	High	Low
Ranges	Limited	Medium-High	Very Short
Security	High	Moderate	High

The comparative analysis between Li-Fi and other communication protocols provides valuable insights into their respective strengths, weaknesses, and suitability for various applications. Li-Fi, utilizing visible light as the medium for data transmission, offers distinct advantages over traditional wireless communication protocols such as Wi-Fi, Bluetooth, and NFC. While Wi-Fi excels in providing ubiquitous wireless connectivity over longer distances, Li-Fi offers higher data rates and enhanced security by leveraging the optical spectrum. Bluetooth, commonly used for short-range communication between devices, lacks the bandwidth and speed capabilities of Li-Fi. Similarly, NFC, primarily employed for contactless payments and data exchange at close proximity, faces limitations in data transfer speed and range compared to Li-Fi. Overall, the comparison highlights Li-Fi's potential for high-speed, secure, and energy-efficient wireless communication in environments where traditional radio frequency-based protocols may be constrained or susceptible to interference.

These advantages and disadvantages delineate the unique attributes of Li-Fi technology, shaping its applicability and performance in various scenarios:

A. Advantages of Li-Fi

1. High Data Transfer Rates: Li-Fi offers significantly faster data transmission speeds compared to traditional wireless communication technologies, facilitating rapid data exchange.

2. Increased Bandwidth: Leveraging the vast optical spectrum, Li-Fi enables higher bandwidth allocation, accommodating more data-intensive applications.

3. Enhanced Security: The utilization of visible light as the transmission medium enhances security by confining signal propagation to specific areas, reducing the risk of unauthorized access.

4. Immunity to Electromagnetic Interference: Li-Fi operates in the optical spectrum, rendering it immune to electromagnetic interference from sources such as electronic devices and radio signals.

5. Reduced Electromagnetic Radiation: Unlike radio frequency-based communication systems, Li-Fi emits negligible electromagnetic radiation, minimizing potential health risks associated with prolonged exposure.

6. Integration with Existing Lighting Infrastructure: Li-Fi can be seamlessly integrated into conventional lighting systems, leveraging existing infrastructure for data transmission, thereby reducing implementation costs.

B. Disadvantages of Li-Fi

1. Line-of-Sight Communication: Effective Li-Fi communication typically requires a direct line of sight between the transmitter and receiver, limiting its applicability in scenarios with obstructed or distant endpoints.

2. Interference from Lighting Flicker: Variations in light intensity, such as flickering from fluorescent or LED lighting, can interfere with Li-Fi signals, affecting data transmission reliability.

3. Standardization and Interoperability: The absence of standardized protocols and interoperable hardware may hinder the widespread adoption of Li-Fi technology, necessitating concerted efforts for standardization.

4. Limited Penetration through Opaque Materials: Unlike radio waves, visible light signals cannot penetrate opaque materials, restricting the coverage and range of Li-Fi networks in environments with obstacles or barriers.

These attributes underscore the nuanced considerations involved in deploying Li-Fi technology, balancing its advantages with potential limitations to optimize its effectiveness in diverse applications.

VI. CONCLUSION & RESULT

Through meticulous integration of hardware and software components, this project has been successfully developed to harness the potential of Li-Fi technology for data transmission. Extensive comparative analysis of various color LEDs has been conducted to ascertain their efficiency, enabling the selection of the most suitable LED for the project requirements. Additionally, an evaluation of three different light sensors has been performed, culminating in the identification of the optimal sensor for precise light detection in the Li-Fi system. The culmination of these efforts has resulted in the achievement of a remarkable data transmission speed of 200 bps using a white LED as the transmitter and a photovoltaic cell as the receiver. The comprehensive design and implementation of the Li-Fi system have yielded significant outcomes, demonstrating the feasibility and efficacy of utilizing visible light for high-speed data transmission. The rigorous experimentation and analysis conducted throughout the project have not only enhanced our understanding of Li-Fi technology but also enabled the identification of key factors influencing its performance. The attained data transmission speed of 200 bps underscores the potential of Li-Fi as a promising alternative to conventional wireless communication methods, offering enhanced efficiency and reliability. These results pave the way for further exploration and advancement of Li-Fi technology in diverse real-world applications, driving innovation and progress in the field of wireless communication.

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