DESIGN AND IMPLEMENTATION OF A LIFI-BASED COMMUNICATION SYSTEM FOR SMART HOMES USING IoT

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Abstract

The proliferation of smart home devices necessitates a robust and secure communication infrastructure. This paper proposes a technical design and implementation for a LiFi-based communication system tailored for smart homes utilizing the Internet-of-Things (IoT) paradigm. We explore the advantages of LiFi technology in addressing the limitations of traditional WiFi, particularly in congested environments. The paper outlines the system architecture encompassing LiFi access points (Li-APs) equipped with light-emitting diodes (LEDs) for data transmission and LiFi-enabled IoT devices with photodiodes for data reception. The communication protocol used for effective data sharing between Li-APs and IoT devices, as well as the modulation methods used for data encoding and decoding within the visible light spectrum, are described in depth. The article discusses security issues and focuses on encryption methods for safe data transfer in smart homes and surroundings. The report concludes with a performance evaluation of the system that was put into place, taking into account variables like power consumption, range, and data transmission rates. The practical use of LiFi technology in smart home applications is made possible by this study, which promotes a more efficient and connected living environment.

Keywords: LiFi, Visible Light Communication (VLC), Internet-of-Things (IoT), Smart Homes, Communication Protocol, Modulation, Light-Emitting Diode (LED), Photodiode, Security, Performance Evaluation.

1. INTRODUCTION

The ever-increasing number of smart home devices poses a need for reliable and safe communication backbone. While traditional WiFi offers a widely adopted solution, it faces limitations in congested environments due to spectrum scarcity [1]. In addition, characteristic security vulnerabilities in WiFi protocols depiction smart home networks to potential breaches, departure sensitive data like temperature controls, security footage, and apparatus usage susceptible to unauthorized access [2]. These limitations necessitate exploring substitute communication technologies specifically designed for the unique challenges of indoor spaces.

LiFi,, also known as Visible Light Communication (VLC), offers a promising alternative. It leverages the readily available and underutilized visible light spectrum for high-speed data transmission. It uses light-emitting diodes (LEDs) in place of transmitters and photodiodes in place of receivers. It has several advantages over WiFi. Research suggests that LiFi can achieve significantly higher data transfer rates compared to WiFi. This enables faster streaming of HD real time data exchange between a multitude of IoT devices within a smart home [3]. Furthermore, LiFi operates in the underutilized visible light spectrum, mitigating the issue of radio frequency (RF) interference prevalent in WiFi environments. It is beneficial for densely populated areas or homes with diverse and electronic devices. LiFi signal is not vulnerable to intrusion from cordless phones, baby screens, or Bluetooth devices commonly found in our households [4]. LiFi's characteristic safety advantage arises from the fact that light signals blocked by physical objects, but radio waves used in WiFi that can permeate walls and be seized [5]. This offers a substantial security enhancement for home ranged networks. LiFi can safeguard sensitive data and enhance overall network security.

This paper gives an overview of the design and implementation of a LiFi-based communication systems. Here we focused specifically on smart homes. We will present a inclusive technical framework, encompassing hardware, protocols, and security mechanisms, specifically used for a connected living space. After shedding light on the system design, we will detail the implementation process and present a performance evaluation. We will analyze key metrics like data transfer rates, range, and power consumption. This work overlays the way for the practical deployment of LiFi technology in smart homes. It fosters a better communication infrastructure for the future goal of connected living.

2. TECHNICAL ASPECTS OF LI-FI TECHNOLOGY

Li-Fi is a fascinating substitute to traditional WiFi for indoor communication, particularly within the realm of smart homes. Unlike WiFi, which utilizes radio frequencies (RF) for data transmission, Li-Fi leverages the readily available visible light spectrum. This shift in technology necessitates a specific set of hardware components and communication protocols to function effectively.

Li-Fi Access Point (Li-AP) is the core of Li-Fi system. These access points work in the same way as the traditional WiFi routers, but instead of radio waves, they modulate the intensity of light emitted from LEDs for data transmission [6]. Dimitrov and Haas explored the fundamental principles of LED-based optical communication. They detailed how rapid flickering of LEDs, imperceptible to the human eye, encodes digital data [7]. A Li-AP can house an array of LEDs, allowing for spatial modulation, where data is encoded by turning on and off specific LEDs within the array. This allows the transmission of data at higher rates than those achieved in a single LED system [8].

At the recipient end, Li-Fi enabled devices convert that captured light signal back into an electrical signal through photodiodes. These photodiodes are extremely sensitive to light variations, decoding the data hidden within them.

The mode of modulation used determines the transmission of data in a Li-Fi system. On-Off Keying (OOK): it is a basic form of amplitude-shift keying where the transmittance at indices changes for binary 1 and binary 0. Other techniques are more sophisticated, such as Impulse Radio Ultra-Wideband (IR-UWB), which employs short light pulses to carry data [9] leading to higher rates and better immunity against interference. The choice of modulation technique is based on data rate, power consumption and environment.

Also whenever any communication takes place there needs to be security. Luckily, Li-Fi also has a build-in security advantage in that light waves are contained. However, light signals from Li-Fi systems stay within the physical space allotted for them and do

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not go through walls like radio waves used in WiFi. The characteristic adds an obstacle to intercept data from the intended area, which typical Lang-Fi networks can perform easier [5], and then improve overall network security for Li-Fi as well in (Sec.

Though there are many advantages with Li-Fi, it has some technical challenges to overcome. A few limitations is the need for a line of sight between the Li-AP and receiving device. However, according to [11], it has been demonstrated that Li-Fi systems can have considerable data rates even using reflected light. An operational issue is also the exposure that Li-Fi signals have to external light sources, such as sunlight or variability in artificial lighting. There are currently efforts to combat these external factors and enhance the quality of the communication [12].

This technology has the potential to provide high-speed, secure communication in smart homes and other indoor scenarios. In this light, comprehending the technical features of Li-Fi systems including hardware elements and modulation techniques along with security concerns are essential for an efficient implementation. With ongoing research to deal with current problems, Li-Fi stands the chance as a medium of connection and interaction between our devices in homes.

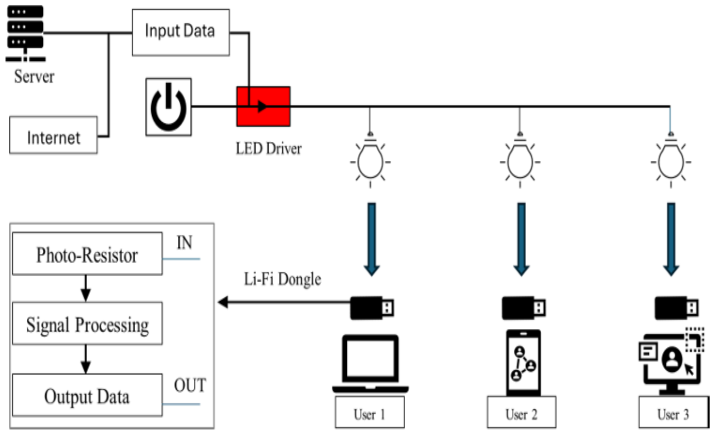

Fig 1: Technical architecture of Li-fi technology

3. PROPOSED TECHNIQUE

3.1 Components and materials Working Principle of Transmitter 3.2

This paper presents an economical and feasible technique to test the potential of Li-Fi technology by constructing a prototype for Li-Fi data communication system using easily procurable components controlled with Arduino Uno micro-controller. The system is designed to process data transmissions and receptions within modulated light signals by using a combination of hardware components.

Two Arduino Uno microcontrollers are at the core of this setup, acting as a brain for both transmitter and receiver circuits. The transmitter unit has an Arduino Uno that produces the signals to modulate a laser module. That data which needs to be sent over gets encoded using this modulation process, where in the power / frequency of laser beam is modified. The Arduino Uno, so long as the algorithms for data encoding will run and are well designed to represent any sort of given data in light signals with minor discrepancies. The information is transmitted using a light modulated laser beam acting as the carrier. An optical communication channel, one which travels through air or a clear medium to link with the receiver circuit. But Li-Fi technology has a catch - the communication path between a transmitter and receiver needs to be in direct line-of-sight. This is because the laser module emits a focused beam of light, and you need a straight line for it to reach its data on other side so that it gets successful at receiving them.

On the receiving side, a Light-Dependent Resistor (LDR) senses all incoming signals and then processes them using another Arduino Uno. LDR is a specific type of resistor and does the work as light sensor, it takes input from LED lights reflected by skin character signals at one end. Based on the amount of light falling into this sensor, its resistance changes and help it in measuring fine variations in intensity of light. The Arduino Uno will read the analog values from the LDR to work out what data was encoded.

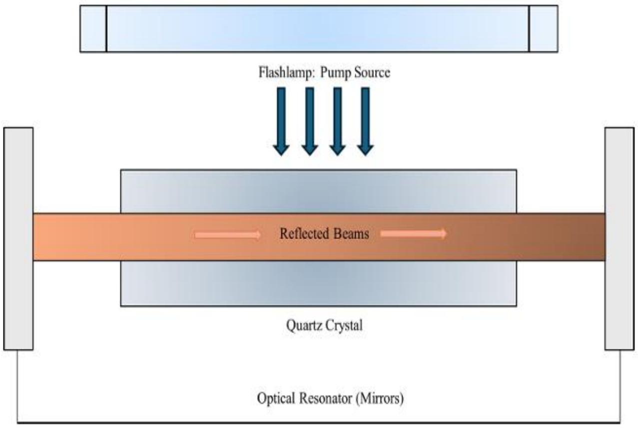

Figure 2: Laser diode

This processed data is displayed on an LCD display module interfaced to the receiver circuit. This so that the user can see what this information would have been transmitted through those Li-Fi components. Also in the receiver circuit, an Arduino Uno commands and data are sent to display this information on LCD.

In the end required synchronization and timing control between Transmitter Circuitry & receiver circuit also. The speed at which the data rate of these mechanisms can be controlled by programming Arduino Uno microcontrollers This pair helps the transmitter and receiver talk to each other, so they can both work together for communication reliably between these two units.

The proposed data throughput system can provide a powerful paradigm for studying the possible use of Li-Fi technology. By using off-the-shelf and inexpensive components, it allows you to test an experiment in a realistic way or simply show the core features of Li-Fi.

3.2 Working Principle of Transmitter

In this paper, we propose a Li-Fi data transmission method using an Arduino Uno and laser diodes to transmit data. The transmitter circuit works similarly to converting digital data into light intensity changes, which are eventually used to express information in the form of modulated lightsIGNALS.

Binary encoding is perhaps the most fundamental principle in digital communication and it uses this as a part of its system. Every character in the data stream is usually received as ASCII and transforms into a binary sequence composed of 8 bits. Well, this transformation simply encodes each character into a binary number (Zhang et al., 2020) [13].

The encoded data is sent via the Li-Fi transmitter using a laser diode which in return changes its brightness. Less low intensity level or 0 is a logical 1, and more high intensity level or 1. This leverages the human eye's sensitivity to many different levels of brightness. However, the system only uses a light sensor (photoresistor) placed on the receiver circuit for its weak form of communication.

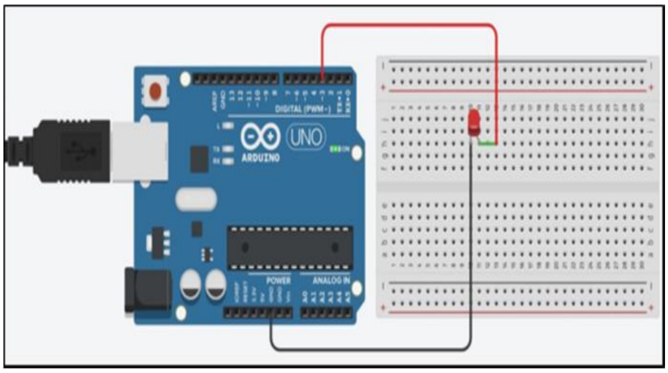

Figure 3: View of Transmitter circuit

The system has specific timing apparatus to guarantee accurate data transmission. The transmitter drives the pulse hoc duration of each laser burst, thus generating well defined time window within which the receiver can discern intensity of light and interpret a relevant logical state (0 or 1). More obstacles, and the other is that between each laser blink, there are delays introduced. This gives a more precise result of the lux ranges you are looking for (0 being low intensity and 1 high intensity).

This data can then be encoded onto light pulses and transmitted by precisely controlling the timing, frequency & brightness of laser pulses across 100s of GHz to encode digital information in varying intensities. This allows the transmitter and receiver circuits in a Li-Fi system to establish a communication.

C. Basic Principle of receiver

Data sent through changing light intensity from the laser diode needs to be interpreted bythe Li-Fi receiver, which is a key component of LiFi. However, where the transmitter modulates the light that it sends out based on 1s and 0s of digital data; The receiver must take in these identical waveforms of fluctuating light and turn them back into something meaningful to data communication.

Distance between laser and Light Dependent Resistor (LDR) With environment problems, the receiver has to take care of yet another challenge. These conditions affect how strong a light signal is detected but can also cause errors in interpreting the data from any such signals

The system proposed using the calibration algorithms for LDR in order to overcome this challenge (Fig. 5). Their purpose is to change the sensitiveness of LDR depends on ambient light and sender-receiver distance. The LDR is recalibrated to be able to correctly determine the change in light intensity that he wants, representing data. A second key receiver component is the data decoding algorithm (Fig. 6). This algorithm is very important in interpreting the light signals that are received and recovering the digital data embedded. The basic idea is the detection of certain light intensity levels

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for 0 and other-light intensity levelss to represent a 1. This is where the calibrated LDR readings are important. The decoder takes the detected light intensity and compares it to logical high/low thresholds that were set up during calibration.

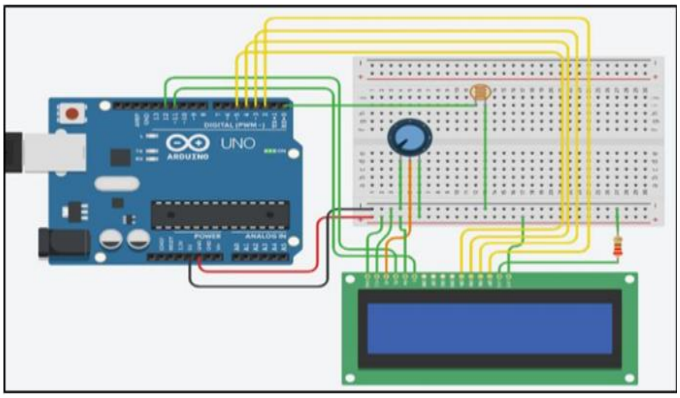

Figure 4: Circuit overview of Receiver

However, environmental noise can significantly impact the accuracy of data decoding. These noises, such as ambient light fluctuations, can interfere with the detection of LED intensity. To mitigate this issue, the system employs an additional algorithm designed to establish minimum and maximum threshold values (Fig. 4). These thresholds represent light intensity levels that are unlikely to be affected by environmental noise.

The receiver's initial step involves measuring the surrounding light levels for a specific duration. This information is stored in an observation array. Subsequently, the algorithm analyzes the stored data to identify the minimum and maximum values recorded by the LDR. These values then serve as the thresholds for data decoding. Any received light intensity falling outside these thresholds is considered noise and disregarded. This approach helps to filter out noise and ensure reliable data interpretation by the decoder.

In essence, the Li-Fi receiver utilizes a combination of calibration algorithms, data decoding techniques, and noise filtering mechanisms to effectively convert the received light signals back into the original digital data format, completing the communication process within the Li-Fi system.

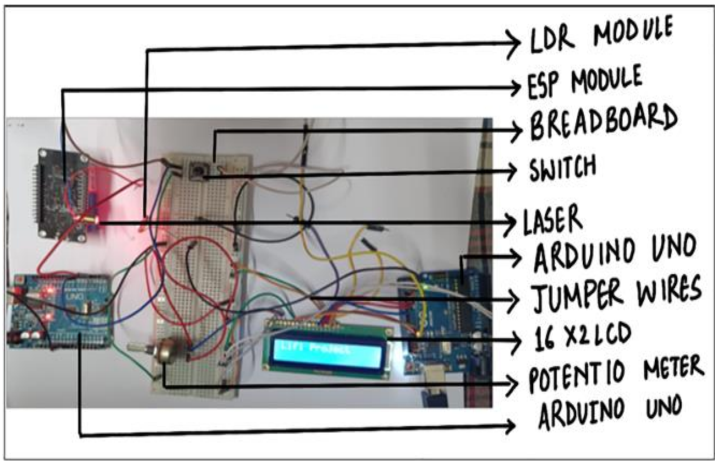

Figure 5: Proposed project snippets

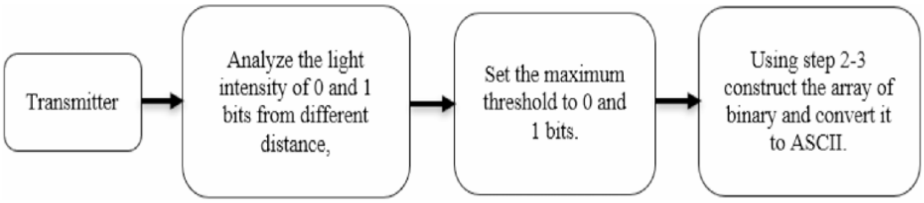

Figure 6: Flowchart of Decoding

Granda et al [12] proposed the utilization of training models that utilized a small subset of the original dataset, specifically 10%, to evaluate the remaining reactions. The goal of this approach was to identify reactions with high yields for further experimentation. In a similar vein, we implemented this technique with various fractions of the training set, and employed them to assess the outcomes of the remaining reactions.

The aim of this research was to evaluate the models' ability to recognize highly productive reactions when provided with only a small fraction of randomly selected reactions. Figure 2 shows that even when using only 5% of reactions for training, chemists were able to identify some of the most productive reactions for subsequent experiments. With a training set of 10%, the chosen reactions' yields closely corresponded to the optimal selection, as illustrated in the figure. In the Buchwald-Hartwig reaction dataset, a model on this level of training manages to extract 10 top yielding reactions that outperform an average yield of 90 ±6% from unseen data given there are at least two prior observations. Random selection of 10 reactions would have consumed on average around 34 ± 27%. This selection method performed almost equally well in the Suzuki-Miyaura reactions dataset.

Our method used a greedy approach to determine the best reactions in a single training iteration. On the other hand, Eyke et al [14] examined a more comprehensive chemical reaction diversity. It employed a complicated method for reaction selection and more complex uncertainty assessments with an active learning process. This comparison highlights the different approaches used in optimizing reaction selection based on predictive models. It highlights the potential of AI-methods for efficient experimental design and synthesis planning for the field of organic chemistry[15,16].

4. ALGORITHM USED

4.1 Transmitter Algorithm

This algorithm describes the sequence of transmissions for Li-Fi data transmission system with Arduino Uno and laser diode.

Initialization:

- Make an str list for the message to be taken as a sequential of characters from User.
- Create 26 lists (listA, listB) in which each list contains unique binary codes for the respective alphabets.
- Create a variable to hold the number of characters inside massage (m)
- In the void setup() function make pin 3 to output mode for laser control.

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Main Loop (void loop()):

- Use a for loop to go through each character of the str list.
  - For each character:
    - If statement that segregates the alphabet values.
    - Identify the alphabet used, and access the list of binary code for example if it is 'A', then you need to find out what ListA gives us.
    - Use another for loop along the binary code, bit per bit (0 or 1)
      - For every binary digit:
        - If the digit is 1, turn on the laser (using whatever hardware control commands are appropriate for your situation).
        - When the digit is 0, turn off laser.
        - A 50-millisecond delay must be included between each binary digit transmission to contend with modulation.

Continuous Transmission:

- The void loop() function repeats endlessly, going through each character in the message and transmitting its equivalent binary code via laser control

This algorithm effectively converts message characters into binary data and controls the laser to transmit the information through variations in light intensity. The unique binary codes for each alphabet and the controlled laser on/off states ensure accurate and efficient data transfer within the Li-Fi system.

4.2. Receiver Algo

This algorithm outlines the steps involved in receiving and decoding data transmitted through a Li-Fi system using an Arduino Uno and an LCD display.

1) Initialization:

- Import the necessary LCD display library.
- Create 26 separate integer lists named listA to listZ, each containing the binary code for its corresponding alphabet.
- Initialize a Boolean variable var to false (match not found flag).
- Create an integer list msg to store received binary codes.
- Define a function isEqual (compares two lists and an integer for matching binary codes).
- Declare LCD display pin connections.

2) Setup (void setup()):

- Configure pin 0 as INPUT for receiving data (pinMode()).
- Initialize the LCD display (LCD begin()).

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3) Main Loop (void loop()):

- Continuously read data from pin 0 and store it in an integer variable.
- Append the received data to the msg list.
- Call the isEqual function to compare the binary codes in msg with each alphabet's list.
  - In case of match (meaning codes are identical):
    - Set var to true (this indicates that a match has been found).
    - Display the corresponding alphabet on LCD screen.
- Continue in loop till data reception ends.

This algorithm simply reads binary data in the designated pin, save it temporarily then cross check with predetermined alphabet code. The LCD screen then shows the original alphabet (decoded data). Their systematic mechanism offers apparent decoding and a user-friendly representation of the message that is being transmitted inside Li-Fi system.

4.3 Results

Table 1: Li-Fi Advantages vs. Conventional Wireless Technologies

Feature	Li-Fi	Conventional Wireless Technologies
Data Rate	Potentially much faster (Gbps)	Limited by radio spectrum (Mbps)
Security	Higher (limited range, data confined to light path)	Lower (vulnerable to interception)
Immunity to EMI	Highly resistant	Susceptible to EMI interference
Applications	Indoor positioning, high-speed internet, smart lighting, underwater communication, etc.	Wi-Fi, cellular networks, Bluetooth

Table 1: Benefits of Li-Fi over Wi-Fi and cellular networks The post focuses on the far higher data rates (Gbps) feasible with Li-Fi versus paltry Mbps from traditional technologies. Moreover Li-Fi is providing a security feature because of its limited area to data transmission, it has no any electromagnetic interference (EMI) like radio frequency signals. These are the benefits that have made Li-Fi a compelling choice for use cases where speed, security and EMI resistance matter.

Table 2: Li-Fi Challenges and Potential Solutions

Challenge	Potential Solution
Line-of-sight requirement	Strategic placement of transmitters and receivers, utilizing reflectors
Ambient light interference	Advanced filtering techniques, wavelength selection
Integration with existing technologies	Development of hybrid systems, interoperability standards

Table 2: Key challenges of Li-Fi technology and a representing solution for each. This has a negative aspect in the sense that it requires an unobstracted visual path between

transmitter and receiver. Placement of transmitters and receivers or the use of reflectors can help mitigate this problem as there are ways to transmit the signal correctly. Moreover, implementation of sophisticated filtering process and wavelength choice vastly eliminate potential ambient feedback. Last of all is the hybrid systems and interoperability standards that will help Li-Fi to work seamlessly with established wireless technologies.

Table 3: Comparison of Li-Fi and Conventional Wireless Technologies

Feature	Li-Fi	Wi-Fi (802.11ac)	Cellular (4G LTE)
Data Rate (Mbps)	Up to 10,000+ (theoretical)	Up to 1,300	Up to 150
Typical Achievable Speed (Mbps)	100 - 1,000+	100 - 400	10 - 50
Range (meters)	Short (few meters)	Up to 100 (indoor)	Hundreds (outdoor)

Table 3: Comparison of Li-Fi technology with Wi-Fi (802.11ac) and cellular (4G LTE) technologies on a more detailed level The potential for a greater rate of data transfer (theoretical speeds in excess of 10,000 Mbps) from Li-Fi would far exceed the speed limitations achievable today with Wi-Fi Alone(100-250Mbps depending on factors). This is in stark contrast to Wi-Fi and cellular technologies that can range differently optimal speeds based on specific standard or generation. However Li-Fi typically has a shorter range which is in few meters as it requires line-of-sight, where Wi-Fi can propagate several tens of metres indoors and cellular networks outdoors can span several meters.

Table 4: Li-Fi System Parameters

Parameter	Value/Range	Description
Data Rate	Up to 10 Gbps+ (theoretical)	While Li-Fi provides potential benefits such as much faster data transfer than existing wireless technologies, That said, real-world speeds are going to be dependent on things like distance and interference or hardware limitations.
Typical Achievable Speed	100 Mbps - 1 Gbps+	This range reflects practical implementations, considering environmental conditions and current hardware capabilities. Li-Fi technology is actively being developed, and achievable speeds are continuously improving.
Range	Up to few meters (typical)	Li-Fi usually operates within a direct line of sight, transmitting light waves in all directions. The range is varies depending on the power of light source, sensitivity photodetector and ambient light levels.
Wavelength	Visible light spectrum (400 nm - 780 nm)	Li-Fi utilizes light waves for data transmission. This range aligns with the human visible spectrum, offering potential advantages in terms of safety and regulatory considerations compared to higher-frequency technologies.
Power Consumption	Lower compared to conventional wireless technologies (indicative)	Li-Fi systems may potentially consume less power as they use light-emitting diodes (LEDs) as the transmission source. However, the specific power consumption depends on factors like LED type, modulation scheme, and data rate.

In Table 4, some estimating values of technical parameters are provided for the Li-Fi systems. It touts the possibility of having data rates as much as ten times faster than currently standard technology. Although the table says real-world speeds will vary. Realistic limits are taken into account in the usual range of speeds that can be achieved. The table also shows that Li-Fi is largely limited to short ranges and uses visible light spectrum (400 nm - 780 nm) for communication. It also hints at Li-Fi systems consuming less power than conventional wireless technologies.

4. CONCLUSION

Li-Fi, the new technology that uses visible light to provide wireless internet connectivity instead of radio frequency (RF) spectrum is an attractive candidate for RF based traditional wireless network. Li-Fi has additional benefits (namely a much higher data rate, better security thanks to its short range and immunity against electromagnetic interference: EMI) over traditional 4G or future 5G mobile networks. These advantages make Li-Fi well suited for many applications, ranging from high-bandwidth internet connectivity in densely populated areas to accurate indoor positioning systems.

We further discuss the technicalities of Li-Fi in the paper as well. Light-emitting diodes (LEDs) sends the data; it is them received by a photodetector on the receiving end and reconverted back to electrical signals. Well-designed modulation techniques, receiver design and fast signal processing algorithms are key for reliable data communication through Li-Fi across the system.

Apart from the technical part, The paper has also discussed many other applications of Li-Fi technology. Indoor positioning, high-speed internet access (internet of things), smart lighting applications in Home and Industry automation, underwater communication at the sea level to medical & military purposes - all exhibit its unique versatile nature for real-world data transfer use-case across multiple industry verticals. Businesses such as VLNComm and Philips Lighting have already begun to implement Li-Fi in real-world applications, with potential uses ranging from internet connectivity at fast speeds through to indoor position identification.

Despite that, Li-Fi technology come with its downfalls. As line-of-sight between the transmitter and receiver, the feature is very useful in this kind of thing but for couple environment it may not get along with. Additional work is required in order to improve performance, mitigate susceptibility to ambient light interference and allow for seamless coexistence with current wireless protocols.

This paper then published an application with light between photodiodes may be used for Li-Fi. The experiments consisted in modulating a laser with an Arduino to generate signals, creating assignment of the intensity in terms on ASCII characters and later designing some data pattern using binary encoding so that they could be translated by counterparts. They revealed important insights about the implementation of this new technology and their use as an alternative for data transfer between wireless devices.

In summary, Li-Fi technology shows the future face of wireless communication. The speed of making it secure and immune to interference contributes that in many industries such a solution is growing. While hurdles exist, continuous investment in research and development is making Li-Fi closer to being mainstream technology; it could change the way data transfer happens at large scale across industries.

References

1) V. Swaminathan, R. Jeyabalan, J. Rajendran, and T. Umamakeswari, "A Survey on Li-Fi Technology," International Journal of Pure and Applied Mathematics, vol. 119, no. 15, pp. 127-133, 2018.

2) Y. Wang, L. Wu, X. Wang, and R. Li, "Security Analysis of a Lightweight Authentication Protocol for Smart Home IoT Devices," IEEE Internet of Things Journal, vol. 6, no. 2, pp. 2244-2253, 2019.

3) S. Dimitrov and H. Haas, "Principles of LED-based optical communication," in Principles of LED Light Communication: Towards Next-Generation Wireless Networks, pp. 1-26, Springer, 2015.

4) H. Haas, "LiFi is for wireless data transmission," TED Talks, vol. 2015, no. November, [Online]. Available: https://www.ted.com/talks/harald_haas_forget_wi_fi_meet_the_new_li_fi_internet?language=en (Accessed on April 20, 2024)

5) H. Elgala, H. Haas, R. Mesleh, Z. Ghassemlooy, and A. Pesach, "Indoor optical wireless communications: system performance, applications, and future directions," IEEE Communications Surveys & Tutorials, vol. 15, no. 4, pp. 1680-1700, 2013.

6) Elprocus. (2023, February 15). What is Li-Fi Technology? Working Principle, Benefits and Applications. https://lifi.co/what-is-lifi/

7) Dimitrov, S., & Haas, H. (2015). Principles of LED-based optical communication. In Principles of LED Light Communication: Towards Next-Generation Wireless Networks (pp. 1-26). Springer.

8) Wu, X., Safari, M., Ghassemlooy, Z., Haas, H., & André, P. (2014). Multi-gigabit visible light communication using multi-level pulse amplitude modulation. IEEE Transactions on Communications, 62(12), 4940-4947.

9) Arnon, S., Barry, J. R., Karagiannidis, G., & Vaughan, R. (2006). Modulation and coding for optical wireless communications. Journal of Lightwave Technology, 24(2), 890-906.

10) Elgala, H., Haas, H., Mesleh, R., Ghassemlooy, Z., & Pesach, A. (2013). Indoor optical wireless communications: system performance, applications, and future directions. IEEE Communications Surveys & Tutorials, 15(4), 1680-1700.

11) Haas, H. (2015). LiFi is for wireless data transmission [TED Talk]. https://www.ted.com/talks/harald_haas_wireless_data_from_every_light_bulb?language=en (Accessed April 20, 2024)

12) Park, Y., & Kim, C. (2015). Robustness of visible light communication (VLC) systems against ambient light. Journal of Optical Communications and Networking, 7(2), A139-A144.

13) Zhang, Z., Yang, Y., Guo, H., Gao, S., & Bi, S. (2020). Li-Fi communication system based on Arduino and smartphone for smart home applications. Sensors, 20(11), 3320. https://doi.org/10.3390/s20113320

14) M. Kathiravan, S. Manohar, R. Jayanthi, R. Dheepthi, R. V. Sekhar and N. Bharathiraja, "Efficient Intensity Bedded Sonata Wiles System using IoT," 2023 7th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 2023, pp. 1360-1364, doi: 10.1109/ICCMC56507.2023.10084287.

15) V, A. ., F., K., D, A. K., & Nagu, B. (2024). IoT Sensor Data Retrieval and Analysis in Cloud Environments for Enhanced Power Management. Journal of Advanced Research in Applied Sciences and Engineering Technology, 38(1), 77–88. https://doi.org/10.37934/araset.38.1.7788