ISSN: 2710-2165

Internet of Things Utilizing Light Fidelity Technology: A Review

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Abstract

Light Fidelity (Li-Fi) is an optical wireless communication technique that delivers high-speed data transmission rates by utilizing light-emitting diodes (LEDs). It is noteworthy that any light source available has the potential to be transformed into a functional Li-Fi node that can offer the possibility of communicating with the remaining sections of the Li-Fi communication network as well as the entire Internet infrastructure. The Li-Fi node utilizes light to provide efficient and secure communication among internet users, additionally allowing access from any location. Simultaneously, the Internet of Things (IoT) represents a collection of innovative and integrated technologies, offering an array of exciting services and solutions that have the potential to revolutionize our daily lives. The development of IoT results in a significant increase in smart devices and sensors. Such devices demand more efficient, faster, and secure data transmission. Li-Fi technology can satisfy the requirements of the forthcoming 6th generation IoT network. It can enhance data rates while consuming minimal energy. Consequently, it can be effectively integrated with the Internet of Things (IoT) in order to develop innovative and intelligent systems.

Keywords-Internet of Things (IoT), Light Fidelity (Li-Fi), Visible Light Communication (VLC), Wireless Fidelity (Wi-Fi)

I. INTRODUCTION

The Internet of Things (IoT) has been the subject of discussion and development by numerous researchers and scientists. However, it was introduced firstly by Kevin Ashton to describe the network of interconnected physical objects, including Device-to-Device (D2D) and Machine-to-Machine (M2M) communication that is integrated with the Internet. The purpose of such inter-networking is to facilitate interaction between devices and machines and enable the collection and exchange of data. The aforementioned devices produce a significant amount of data and utilize it to disseminate beneficial information, either among other devices or towards end-users. However, the increasing transmission of mass quantities of data is putting a strain on the current technologies, which use radio frequency and infrared spectrum bands for the transmission of data. According to a recent study [1], the number of connected devices will be reach 29.3 billion by 2023. As a result, the IoT network will become overloaded, with a large amount of data exchanging continuously. Researchers have attempted to improve communication systems to meet the demands of this continuous growth. One of the essential elements is the extensive bandwidth and data transfer speed. Wireless fidelity (Wi-Fi) technology is a widespread wireless networking technique utilizing within the electromagnetic spectrum to provide connectivity to the internet and various networks. It operates without the requirement of physical connection between transmitter and receiver. By utilizing radio frequency (RF), an electromagnetic field is generated when an RF current is supplied to an antenna, which subsequently propagates throughout the surrounding space. Wi-Fi technology has encountered challenges such as a limited bandwidth, interference, and security issues. Alternatively, some communication technologies employ the visible light spectrum (380 nm to 750 nm frequency band of 430–790 THz) as illustrated in figure 1, which offers a higher frequency bandwidth [2].

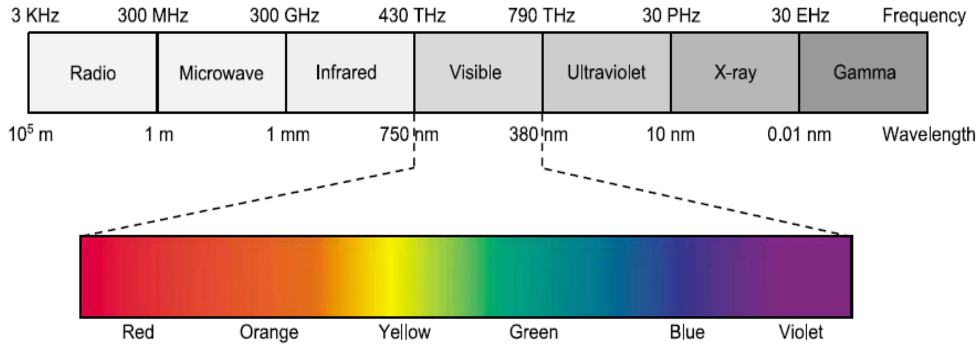

Figure.1. Wavelengths of visible light spectrum [2]

Light fidelity (Li-Fi) technology is a visible light communication (VLC) technique that utilizes light-emitting diodes (LEDs) for purpose of data transmission. Initially put forward by Harald Haas in 2011, it is capable of sending data at several gigabytes per second, which can be perceived as highly promising for the future Internet of Things (IoT).Yin Wang and Chen conducted a communication analysis utilizing visible light in 2015 and determined that Li-Fi, an advanced application of VLC, is a superior option. Its implementation prioritizes the establishment of fully networked wireless systems and can also be effectively incorporated into IoT systems. The remainder of this paper is structured in the following manner. Section II illustrates the working principle and related works of Li-Fi technology; Section III clarifies the IoT architecture; Section IV presents the integration of Li-Fi technology and IoT; Section V demonstrates the application areas and domains of Li-Fi technology; and Section VI provides the conclusion.

II. Light fidelity TECHNOLOGY

The term of Li-Fi has been embraced by some as a means of denoting a high-speed and cost-effective wireless networking technique that serves as the optical equivalent of Wi-Fi [3]. Notably, light is an essential component of our daily lives, thus, Li-Fi technology has the potential to be utilized wherever luminescence is present. Through the utilization of light for data transmission, the requirement for hotspots can be obviated. This presents a unique prospect to capitalize on an unutilized segment of the electromagnetic spectrum.

LI-Fi employs light emitting diodes (LEDs) for the purpose of transmitting data over short-range distances. As the operating speed of LEDs is less than 1 μs, they can be switched on and off at a rate that surpasses the detection capabilities of the human eye. This rapid on-off cycling results in the light source appearing to be continuously illuminated, which in turn facilitates the transmission of data through binary streaming.

A. *Working principle of Li-Fi technology*

According to the visual representation depicted in Figure 2, Li-Fi system is comprised of two key components: an LED Lamp that serves as the data transmitter and a photodetector that acts as the receiver of transmitted data. In order for the LED to function effectively, a lamp driver is required. The amplification and processing mechanisms are necessary for ensuring that the received signal from the photo detector is managed efficiently.

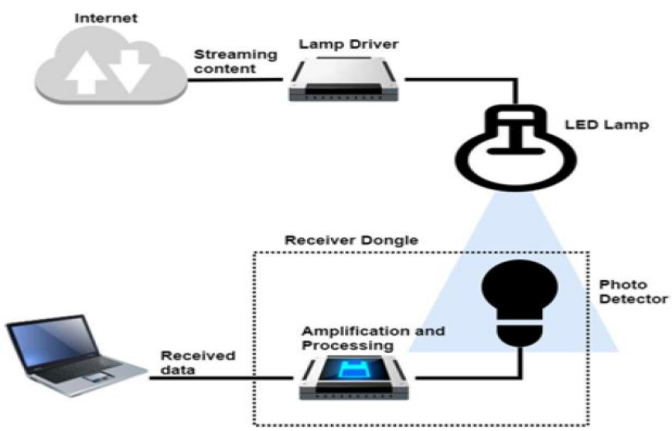

Figure.2. Li-Fi system overview [4]

Furthermore, that in Li-Fi working principle as illustrated in Figure 3, the light-emitting diode (LED) is employed to serve as the transmitter of light, while the photodiode is utilized as the receiver. To enhance the power of the received light, an amplifier is integrated into the system. Additionally, a modem is employed to facilitate the modulation and demodulation of the signal. The signal obtained from the photodiode is in analog form and is subsequently converted into digital form within the modem. Conversely, when the signal is ready to be transmitted, it is converted into analog form within the modem before being sent via the LED. Prior to the operation of the LED, a driver is employed to control the current flowing through it, thereby achieving the desired flickering effect. This flickering serves to function the LED in the context of data transmission, as it serves to convey a digital '1' when the LED is illuminated or ON, and a digital '0' when it is off [4].

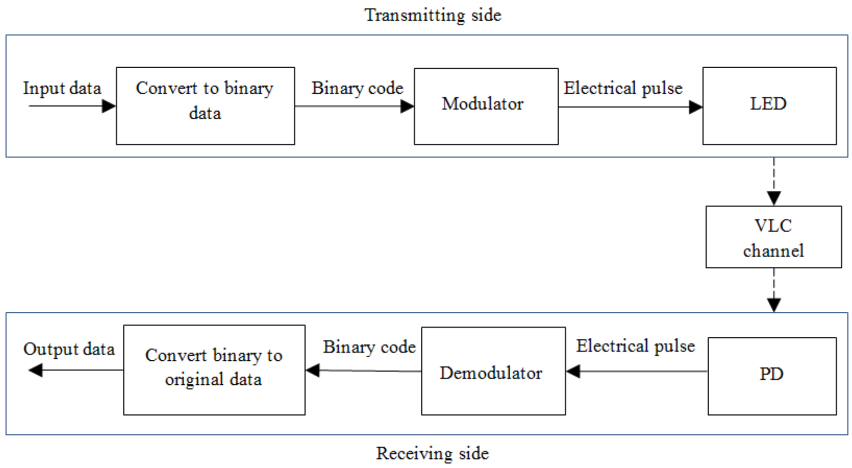

Figure.3. Schematic diagram of Li-Fi working principle

B. Related works

This part explains the previous studies about Li-Fi technology and the design requirements of VLC systems; thereby, researchers aim to examine requirements, including distance range, modulation techniques, external noise, and interference.

Manivannan et al. [5] this study demonstrated the implementation of indoor Visible Light Communication (VLC) through the utilization of the Optisystem simulation tool, which was used to essentially measure channel features of a white LED. The performance of the VLC system was evaluated through the examination of Quality factor and bit error rate (BER) values for a variety of date rates and link distances. The system was designed to provide a data rate of 2 Gbps for link distances up to 3 m, with the white LED serving as the source for communication. The modulation technique of non-return-to-zero on-off keying (NRZ-OOK), as investigated by Suriza et al. [6], this study demonstrates a high-speed capability for short-range distances and data transmission rates ranging from 400 kbps to 2 Mbps for an indoor suggested system.

Trung Ha Duyen et al. [7] this study presents an analysis of the performance of VLC system designed for a full-duplex transmission of text and image information through Light Emitting Diode (LED) lighting in the indoor environment. The authors investigate the transmitters and receivers of the designed system, which is capable of achieving a data rate of 161.2 Kbps with acceptable bit-error-rate at a distance of approximately 92 cm, thus facilitating real-time transmission of text and images in an indoor environment. Poulose [8] illustrated the concepts of line-of-sight (LOS) and non-line-of-sight (non-LOS). In the non-LOS scenario, there were two transmitter roles in two distinct propagation scenarios. The first scenario involved a single source as the transmitter, while the second scenario utilized two sources as the transmitter. In the former scenario, it was observed that the amplitude of the signal received was relatively lower in comparison to that of the line-of-sight signal. Selvendran et al. [9] conducted an investigation on the visible light communication (VLC) system utilizing Optisystem. The VLC system employs a white light emitting diode (LED) as the source, which is modulated by Orthogonal Frequency Division Multiplexing (OFDM) signal. The study explores the system design for various data rates and link distance ranges, establishing that the suggested system can achieves a data rate of 10 Gbps within a link distance of 2 m.

Mat et al. [10] investigated the performance of LiFi-IoT based on VLC for point-to-point topology, offering high-speed wireless data transmission for future network access. This topology has shown the possibility of achieving a high speed of approximately 1 gigabit per second. Aziz et al. [11] conducted an investigation to evaluate the efficacy of the VLC system. The findings indicate that, when considering both bit rates of 155Mbps and 622Mbps, the simulation of 1 user gave best result outcome compared to 4 users. The number of users plays a crucial role in system performance, and the results demonstrate that utilizing any form of Optical Code Division Multiple Access (OCDMA) multiplexing technique will inevitably cause the number of users to be limited to no more than four. Satea Hikmat and Ahmed Majid [12] examined the impact of bidirectional reflector on signal vulnerability in relation to five LEDs. The non-line of sight problem resulting from the walls of a conventional room measuring 5 × 5 × 3 m was examined. A data rate of 1-Gbps was supported by the proposed indoor system. The research findings indicated that the technology was capable of correcting reflected signals, thereby validating its effectiveness. Satea Hikmat and Walaa khalil [13] investigated the impact of weathers conditions on the end-users of a visible light communication (VLC) system. The proposed systems in this study; is designed as a VLC connected with fiber optic and free space optic channels ,which enables the transmission of various video sizes and an image at data rates range of 1, 2, and 3.5 Gbps . The performance evaluation of the proposed system validates its ability to overcome challenges in accordance with data transmission speed under severe weather conditions that significantly impact the transmission channel. Therefore, the proposed system provides a promising solution to ensure reliable and efficient data transmission in challenging environments. Table 1 presents a summary of previous studies of Li-Fi systems.

Table.1. Related works of Li-Fi technology

Authors	Year	Summary of the research
Manivannan et al.	2016	This study presented the application of indoor Visible Light Communication (VLC) system that designed to provide data rate of 2 Gbps for distances up to 3m, with a white LED as the source of communication.
Suriza et al.	2017	This study investigated NRZ-OOK modulation technique which is capable of high-speed data transmission for short-range distances. The suggested indoor system can achieve rates of 400 kbps to 2 Mbps.
Trung Ha Duyen et al.	2018	This study analysed the performance of a VLC system for transmitting text and image through LED lighting in indoor environments. The system can achieve a data rate of 161.2 Kbps with acceptable error rates at a distance of around 92 cm.
Poulose	2018	This study demonstrated the principles of line-of-sight (LOS) and non-line-of-sight (non-LOS). The signal amplitude was lower for non-LOS signals compared to LOS signals.
Selvendran et al.	2019	This study examined the implementation of the VLC system that utilizes a white LED with OFDM modulation technique. The proposed system can achieve a data rate of 10 Gbps within a 2 m link distance.
Mat et al.	2020	This study investigated LiFi-IoT performance using VLC for point-to-point topology. That has showed the capability for achieving high-speed data transmission up to 1 Gbps.
Aziz et al.	2020	This study examined the efficacy of the VLC system utilizing OCDMA technique. The simulation of 1 user gave better result results compared to 4 users for both bit rates of 155Mbps and 622Mbps
Satea H. Alnajjar and Ahmed Majid	2021	This research investigated the effect of bidirectional reflector on signal vulnerability for five LEDs. The proposed indoor system supported a data rate of 1-Gbps. The results showed that the technology could correct reflected signals, proving its efficiency.
Satea H. Alnajjar and Walaa khalil	2022	The research examined the effect of weather conditions on the visible light communication end-user system that can transmit different video sizes and images at 1, 2, and 3.5 Gbps. The proposed system proved capable of overcoming transmission challenges caused by harsh weather conditions.

C. Performance of Li-Fi technology

The enhancement of spectral efficiency and security in internet communication is a most important issue at present. The primary objective behind the development of Li-Fi networks is to addressing the limitations of Wi-Fi, which is insufficient for supporting multiple users. Li-Fi offers several advantages compared to conventional Wi-Fi, including higher data transfer rates and more security. Furthermore, it has the capacity to establish connectivity with a speed that exceeds Wi-Fi by 100 times, thus representing a significant advancement in communication technology [14]. Table 2 illustrates the distinct data transmission speeds between Li-Fi and Wi-Fi. Additionally Li-Fi performance depends on several factors such as the quality of the light source, the distance between the transmitter and receiver, and environmental factors like weather conditions. Table 3 depicts the characteristics distinctions between Li-Fi technology and Wi-Fi technology.

Table.2. Speeds of Wi-Fi and Li-Fi

Speed of Wi-Fi [4]			Speed of Li-Fi	
year	Standard	Data rate	Study	Data rate
1999	802.11b	11Mbps	[11]	155Mbps
1999	802.11a	54 Mbps		622Mbps
2002	802.11g	54 Mbps	[12]	1Gbps
2007	802.11n	72-600 Mbps	[5]	2Gbps
2013	802.11ac	433 Mbps -1.3 Gbps	[13]	3.5Gbps
2018	802.11ax	Under research	[9]	10Gbps

Table.3. Comparison of characteristics between Wi-Fi and Li-Fi [14]

characteristic	Li-Fi	Wi-Fi
Transmitter part	Light-Emitting Diode (LED)	Antenna
Receiver part	Light-Emitting Diode (LED)	Antenna
Inbuilt device	Under research and development	Wi-Fi Card/Chip
Average data transmission speed	More than 10Gbps (under research)	150-600 Mbps
Frequency band	1000 times of THz	2.4GHz
Data transmission	Bits	Radio waves
Range and coverage area	10 meters	The distance of transmission depends on power, antenna type, and varies between 20-100 meters.
Interference	Immune to radio frequency interference	Susceptible to interference from neighbour networks
Network topology	Point to Point	Point to Multipoint
Communication	Depend on Visible Light Communication	Depend on Radio Frequency Communication
Efficiency	More, LEDs are characterized with low energy consumption and high efficiency.	Less, Radio Base Stations consume a significant amount of energy.
Availability	Everywhere	Limited
Security	More security, due to the inability of light waves to pass through walls and cannot be intercepted by those outside the LED illumination.	Less security, due to the strong radio wave penetration, allowing anyone to intercept the communication.
Power consumption	Less	More
Environmental impact	Low	Medium

III. INTERNET OF THINGS

The Internet of Things (IoT) has the potential to interact with the environment in a variety of ways. IoT systems can be used to collect data from the environment, such as air quality, temperature, and other conditions. Subsequently, this data can then be used to make decisions or provide feedback to the environment. Similar to the robotic systems, Internet of Things (IoT) systems follow a cyclical paradigm of "Sense-Think-Act" to enable their interaction with the physical world. IoT devices are also capable of "communicating" via internet or network connections. The sensors embedded within these IoT systems serve as crucial physical inputs, allowing for the collection of data from the surrounding environment. The microcontroller within these systems is then able to analyze and interpret this data, enabling it to make informed decisions and respond to specific conditions through the system's outputs. The actuators represent the physical outputs of the IoT system that can do something in the environment. The transmission of information obtained from sensors or response received from actuators to the cloud is an indispensable requirement in the domain of Internet of Things. A gateway serves as the connection between IoT devices and the internet. In simpler terms, a gateway acts as a mediator that permits data transfer between two distinct networks. Essentially, a gateway serves as an intermediary means for the translation between two networks that utilize different protocols for communication. A typical example of a residential gateway is a broadband wireless router that connects various devices on the local area network (LAN) to the wide area network (WAN) managed by the internet service provider (ISP) through a modem. Edge gateways, as they are commonly known, are located at the periphery of a LAN and an ISP's WAN. Many communication technologies, such as Wi-Fi (802.11b/n/g/ah), Bluetooth low energy (BLE), ZigBee (IEEE 802.15.4), and LoRa network [15], enable IoT devices to establish communication with an appropriate gateway, which in turn connects to the internet and sometimes even provides device-to-device communication. Furthermore, The Internet of Things (IoT) enables physical objects to be connected together and exchange information without the need for human intervention. This allows for remote access and control of these objects. Figure 4 illustrates the IoT architecture.

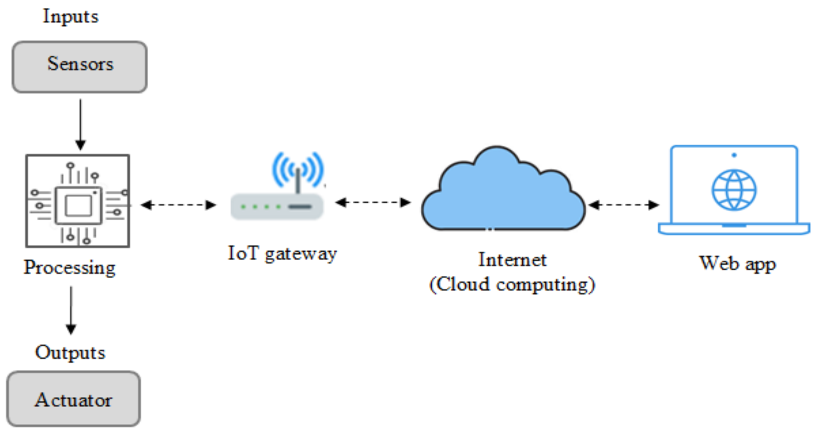

Figure.4. Internet of Things architecture

IV. INTEGRATION OF LI-FI AND IOT

Future applications of IoT are dependent upon advanced real-time processing in the cloud, to which mobile IoT devices are connected. The present radio-based communication infrastructure cannot easily provide high-bandwidth channels that meet the demands of the forthcoming 6th Generation networks[16]. Therefore, it is proposed to use optical wireless communication (OWC) via light fidelity (Li-Fi) that utilizes visible LED lighting to overcome Wi-Fi technology limitations.

A. *Advantages of utilizing Li-Fi technology in IoT systems*

- **Spectrum usage:** the discernible spectrum of light encompasses a scale that is 1,000 times greater than the entire range of radio, microwave, and millimeter wave radio spectrums. Consequently, wireless systems possess a substantial and unexploited reservoir of resources. It is expected that the current and future expansion of wireless data traffic will render the radio frequency spectrum inadequate in terms of offering adequate resources by 2025.
- **High speed**: high speed of data transmission rates of up to 10 Gbps can be easily reached [17].
- **Security:** the security holds significant importance in the connectivity of IoT. While transmitting or receiving a data stream, it is imperative to ensure that the IoT device or server possesses the appropriate authorization to send or receive the data. An IoT device becomes perilously vulnerable in the presence of an open port to the internet. Therefore, there is a dire need for end-to-end encryption between IoT devices. In contrast to the utilization of radio frequency waves by Wi-Fi, light waves cannot pass through obstacles, making it more secure and enabling better network access control.
- **Power consumption:** the transmission of data among Internet of Things (IoT) devices has been found to have a significant impact on both power and central processing unit (CPU) consumption. However, the utilization of light-emitting diodes (LEDs) as a low power component in Light Fidelity (Li-Fi) technology has led to a considerable reduction in power consumption [17]. As a result, Li-Fi is more energy-efficient than Wi-Fi, which is known to require intensive power. Moreover, the possibility of utilizing wireless battery charging and wireless internet simultaneously can be explored by employing solar cells as photodetectors.
- **Less interference:** Li-Fi technology employs signals of light frequency which are non-interfering to other electromagnetic signals [18]. The reason for this is the inability of light waves to pass through the walls, thus minimizing interference.
- **Safety:** the environmental impact of Li-Fi is low, and its safety for humans is ensured by the fact that light cannot penetrate the human body.
- **Availability:** Li-Fi everywhere, it can be utilized under water ,also it enables data connectivity within enclosed and regulated environments, such as airplane cabins, and hospitals , due to the light wave does not interfere with radio frequency waves.

B. *Challenges of implementing Li-Fi technology in IoT systems*

- **Line-of- sight (LoS) required:** signals based on visible light cannot penetrate through physical objects, which results in limited coverage of signal among multiple users. The inability of light to penetrate and spread among rooms is a disadvantage due to barriers like walls. These obstacles disrupt the signal's line of sight, causing obstruction to transmission. In practice, VLC mobile devices can experience misalignment of the receiver and transmitter due to unpredictable user actions, leading to data transmission loss [19]. Therefore, methods to provide line of sight alignment are needed for design and development.

- **Uplink and Radio frequency augmentation:** currently, VLC research focuses more on downlink operations compared to uplink. Uplink operation requires directional contact with the receiver, which can reduce throughput for mobile devices. To solve this, alternative communication types such as RF and infrared, which have the capability to facilitate the transmission of uplink data [20].

- **Ambient light noise:** in comparison to indoor LED utilized in VLC systems, sunlight has a substantially higher brightness during the day. Direct sunlight can cause photodiode saturation, which leads to damage [21]. Skylight alone has a much higher luminance than LEDs. Therefore, efficient photodetectors required for Li-Fi systems.

- **Coverage area and mobility:** the mobility of visible light communication systems poses a distinct challenge compared to RF, due to the presence of cellular technology. To implement standard VLC, infrastructure is required, as well as protocols for user mobility in both vertical handoff among the different networks (RF-VLC) and horizontal handoff within the same networks (VLC-VLC), where the use of VLC is complementary to RF networks [22].

V. APPLICATION AREAS OF LI-FI TECHNOLOGY

Li-Fi technology presents promising opportunities for improving connectivity, data transmission, and security in various application domains. The integration of Li-Fi technology with the enormous potential of IoT, presents new possibilities for enhanced connectivity and intelligent functionality in both indoor and outdoor environments.

A. Indoor applications

- **High-Speed Internet Access:** Li-Fi technology has the potential to provide high speed wireless internet connectivity within indoor spaces. By utilizing visible light as the medium for data transmission, Li-Fi can offer superior data transfer rates when compared to the conventional Wi-Fi. This makes it suitable for environments, such as offices, schools, and libraries, where a large amount of multimedia data like picture, video and audio requires to be transmitted with high speed.

- **Indoor Navigation and Positioning**: Li-Fi technology can be utilized for indoor positioning and navigation systems, much like the global positioning system (GPS). By strategically installing Li-Fi transmitters throughout a building, the position of Li-Fi-enabled devices can be tracked with accuracy. This feature is particularly beneficial in settings that necessitate precise indoor navigation, such as shopping malls, hospitals, and airports.

- **Smart Lighting Systems:** Li-Fi technology can be integrated with smart lighting systems to provide a dual functionality. In addition to providing illumination, LED lights that are equipped with Li-Fi technology can also facilitate the transmission of data to Li-Fi-enabled devices. As a result, this enables a seamless communication between lighting fixtures and other connected devices, thereby facilitating various applications such as smart homes and smart offices.

- **Secure Indoor Communication:** the utilization of Li-Fi technology provides an amplified level of security for indoor communication as a result of its inherent qualities. In contrast to wireless communication that relies on radio frequencies,

  Li-Fi signals cannot penetrate walls, making it considerably more difficult for individuals not authorized to intercept data. This feature renders Li-Fi particularly fitting for applications in which data privacy and security are of paramount importance, particularly in government facilities or financial institutions.

- **Indoor Environmental Monitoring:** Li-Fi technology can be utilized for indoor environmental monitoring systems. By integrating sensors with Li-Fi transmitters, data on temperature, humidity, air quality, and other environmental parameters can be collected and transmitted wirelessly. This information can be used for building automation, energy management, and ensuring optimal indoor conditions.

- **Medical Environments:** in the context of hospitals and healthcare centers, it is essential to continuously monitor the critical condition of patients, along with other crucial medical information. However, the utilization of radio frequency-based devices is strictly prohibited for certain healthcare applications that involve critical procedures, such as those performed in operating theaters and MRI scanners. In such scenarios, Li-Fi networks offer a potential solution for data exchange due to their minimal interference and promising capabilities.

B. Outdoor applications

- **Smart City Infrastructure:** Li-Fi can be integrated into outdoor lighting infrastructure to create smart cities. Streetlights equipped with Li-Fi technology can serve as data transmission points, providing high-speed internet connectivity to pedestrians, vehicles, and various IoT devices. This enables smart city applications such as intelligent traffic management, public Wi-Fi access, and environmental monitoring.

- **Public Transportation:** Li-Fi can be applied in outdoor transportation systems to enhance communication and connectivity. For example, Li-Fi-enabled buses, trains, or trams can offer passengers high-speed internet access during their commute. Additionally, can also be used for real-time information display at transportation hubs, providing travellers with up-to-date schedules, route information, and other relevant updates.

- **Outdoor Public Safety and Surveillance**: Li-Fi can enhance outdoor public safety and surveillance systems. By integrating LiFi technology into security cameras or sensors, real-time video feeds and data can be transmitted securely to monitoring centers or law enforcement agencies. This enables faster and more reliable data transmission, aiding in situational awareness, emergency response, and crime prevention.

VI. CONCLUSION

In conclusion, the integration of Li-Fi technology into the Internet of Things (IoT) holds significant potential for enhancing connectivity, data transmission rates, and security in IoT applications. The unique characteristics of Li-Fi technology, including high-speed data transmission, not passing through walls, and a good number of access points, make it a promising solution for development IoT applications.

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