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Research Article
New Trends in Wireless Communication: A Comparative Analysis and Study on Li-Fi and Wi-Fi Technology (Strength, Security, Privacy and the Future)

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Abstract

Background and Objective: Li-Fi is the next revolution of wireless technology. Light fidelity (Li-Fi) is a groundbreaking technology that utilizes visible light spectrum to unlock the capacity at which to transmit data at 10 times the speed of wireless fidelity (Wi-Fi). This study explores the similarities and differences between Li-Fi and Wi-Fi technology, while attempting to understand and study the factors of Li-Fi's strengths, security and privacy implications and what it means for the future of wireless communications. **Materials and Methods:** The data was collected from the previous studies on Wi-Fi technology and Li-Fi technology relating to their operational mechanism with wireless networking. Also features of Wi-Fi and Li-Fi network were investigated. In addition to above, a comparative study for Wi-Fi and Li-Fi was done to evaluate their performance relating to data transmission, strength, security and privacy. Also features of Wi-Fi and Li-Fi network were considered and compared for network efficacy. **Results:** Wi-Fi operates on the radio spectrum and uses radio waves to transmit data, unlike Li-Fi. Wi-Fi and Li-Fi both can provide optimum level services to work together to provide the users with the best speeds, allowing them to download larger files faster and stream movies with interruptions. **Conclusion:** The Li-Fi technology is now developed into a ubiquitous system technology with innovative networking capabilities for universal application to provide a variety of device platforms for high-speed internet communications. This study showed that Li-Fi technology is an appropriate alternative to Wi-Fi technology. Although Li-Fi technology does not use any radio frequencies, but it provides safer, greener and cheaper technology. This LI-Fi technology provides users with better security measures, capacity and availability as compared to Wi-Fi. The future implications of Li-Fi include its application in different fields such as industries, medicine, education and other regions requiring further exploration.

Key words: Light fidelity (Li-Fi), visible light communication (VLC), wireless fidelity (Wi-Fi), light emitting diode (LED), wireless communication, network security

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INTRODUCTION

Technology, more or less, is a highly rapid moving process which has helped the users not only to globalize but also to develop advanced technologies thus enabling people to accomplish more through wireless or wired networks. As a matter of fact, the quandary is that if more people utilize wireless networks proportionately that reduces the speed of the networks. Through Wi-Fi, there is only a limited time for the users to connect and quickly utilize the networks' speed. As per IEEE 802.11n, the maximum speed of Wi-Fi is up to 150 Mbps, which is not sufficient for accommodating a high number of users simultaneously. The increase in the number of users is mainly due to diversification to cloud technology and cloud storage which are being adopted by different infrastructures. The technical community has come up with a new concept of Li-Fi technology or light fidelity created by a German physicist named Dimitrov and Hass[1]. They defined the Li-Fi as a data set in the form of illumination taking the fiber out of fiberoptic by sending data through an LED light bulb varying in intensity faster than the human eye as reported by Poonam and Siddiqui[2].

According to Karthika and Balakrishnan[3], millions of cellular mast radio waves base stations are deployed into billions of cellular phones throughout the world at one time. They also stated that current mobile phones transmit close to 600 terabytes of data. Currently, the mobile users utilize wireless communication through radio waves and for wireless communication, the spectrum serves as an essential requirement. In order to resolve the issues of security, availability and scalability using LED lights, the Li-Fi was created for data transmission which is flexible and faster than Wi-Fi data transmission.

More conceptually, Li-Fi is a high speed, bidirectional and fully networked subsection of visible light communications (VLC) as described by Pandey *et al*.[4]. However, Li-Fi was developed for making data rates quicker than 10 Mbps and faster than Wi-Fi or Broadband connections. Since it is a new concept and still there is much to be learned. Keeping this concept in mind, the author chose to explore the strength, security, privacy and the future of Li-Fi technology as compared to these factors associated with Wi-Fi technology. There is still inadequate information neither to compare the two techniques, nor the implications that Li-Fi could have on cyber security. Besides, the global environment is experiencing an influx of cyber attacks and the introduction of new technologies has increased the significance of exploring these relevant factors. The main objective of the present study was to understand and study the factors of Li-Fi's strengths, security and privacy implications and what it means for the future of wireless communications.

Hase *et al*.[5] reviewed the basic concepts of visible light transmission, its difference from Wi-Fi along with its application in different areas, future challenges, usage and recent advancements over Wi-Fi. Bhavya and Lokesh[6] that extensive use of Li-Fi may overcome some of the hurdles during data transmission in Wi-Fi technology. They also tried to highlight the future scope of this new technology to determine the use of visible light as the carrier in data transmission and networking. In addition to that many investigators studied the Li-Fi technology in comparison with Wi-Fi technology for efficient data transmission and management for networking efficacy[7-10,1].

Wi-Fi technology: Wi-Fi is an essential wireless technology and a basic tool for the users to connect to the broadband internet. Its primary objective was to replace the Ethernet cable which was gradually shifted as the dominant carrier of wireless data. In 2013, according to statistics from the UK, Germany, Japan, Canada, South Korea and the US, Wi-Fi covered more than 70% of the total wireless traffic just on Android smart phones[11]. This traffic is mainly a combination of the long-standing development of global standards, on-going technological evolution, exploding network coverage and a wide range of user devices that connect to access points or hotspots.

Based on various standards, WLAN uses the synonym Wi-Fi that permits electronic devices to transfer and exchange data wirelessly over the network through internet connections using high-speed data. Wireless LAN is a set of terrestrial, low tier, network technologies for data communication. Apart of the IEEE 802.11 technologies, it is one of the most compatible technology to all the operating systems. The origin for Wi-Fi began in 1985 by a ruling from the U.S. Federal Communications Commission in which the bands of the radio spectrum at 5.8, 2.4 and 900 MHz were for unlicensed used. This permission the technology firms to started building wireless devices and networks. However, the lack of compatibility due to the fragmented industry remained a problem. According to a study of Alexiou *et al*.[12], by using the radio signal, this technology was spread over a wide range of frequencies that allowed the signal to be difficult to intercept and less susceptible to interference.

The Institute of Electrical and Electronics Engineers (IEEE) in 1997 developed the universal standard, 802.11. These standards initially allowed the transmission of maximum data

at 2 Mbps which increased to 600 Mbps. This was followed up by forming the formally named Wireless Ethernet Compatibility Alliance (Wi-Fi Alliance) in 1999 by the major companies to promote the new wireless standard. The new standard ratified over 2 years was able to operate in the Unlicensed National Information Infrastructure bands of 5.8 and 5.3 GHz and in the Industrial, Scientific and Medical (ISM) band of 2.4 GHz. Furthermore, with the introduction of high speed broadband, the popularity of Wi-Fi grew as more users were able to access the internet from their homes. Wi-Fi has remained the best way to share broadband links between computers and hotspots.

How Wi-Fi operates: The Wi-Fi consists of 802.11a/b/g IEEE standards of wireless for local area networks (WLAN). The IEEE 802.11a operates on 5 GHz band having a maximum speed up to 54 Mbps and cannot co-exist with other 802.11 standards. The IEEE 802.11 b is the original standard with a range of 100 m and high data rates of 11 Mbps which is widely deployed wireless network. The IEEE 802.11 g operates on the 2.4 GHz band with a data rate of 54 Mbps. Based on the findings of Banerji and Chowdhury[13], it only differs in the modulation technique and uses the orthogonal frequency division multiplexing (OFDM) that doesn't allow for 802.11b to pick up the signal. Wi-Fi operates in ad hoc mode when connected to an access point (AP). A comparison of IEEE 802.11a/b/g is presented in Table 1.

The architecture of IEEE 802.11 is composed of numerous components that interact to create a wireless LAN to support upper layers and station mobility transparently. According to Lee *et al.*[14], the primary cell of an IEEE 802.11 LAN is called a basic service set (BSS) consisting of a set of mobile or fixed stations. The Wi-Fi standard focuses on the bottom two levels of the OSI model, the data link layer and the physical layer. Mostly, Wi-Fi technology uses three logical units, namely the wireless medium, distribution system and the access point to facilitate the networking efficiently.

Using radio waves, Wi-Fi operates as a two-way radio communication, i.e. computer wireless adapter and wireless router. The first one translates the data into a radio signal using an antenna to transmit the data, while the second one receives and decodes the signal for sending the information to the internet using a wired physical Ethernet connection. There are several types of Wi-Fi that operate at different speeds on either multiple or single channels.

Li-FI technology: Among the various rapidly growing technologies during the 21st century's Li-Fi (Light fidelity) is one of the fastest technologies that can transmit data through LED light faster than before. According to a report by Dimitrov and Hass[1], a German professor, who created a subset of optical wireless communications (OWC) and visible light communications, which could replace data broadcasting or be a complement to RF communication. Gupta[15] stated that like Wi-Fi, Li-Fi is a wireless internet connection standard that operates on visible light waves rather than radio waves. Previously, Harler[16] invented pure Li-Fi that uses light bulbs as wireless routers. It is faster than the human eye can follow, Li-Fi transmits data through illumination, takes the fiber out of fiber optics, transmits data through a LED light bulb differing in intensity. Sharma and Sanganal[17] reported that Li-Fi is an optical version of Wi-Fi, that is considered a cheap and fast wireless communication system using visible light for data transfer. The main components of Li-Fi consists of a silicon photodiode and a transmission source. Based on visible light communication (VLC), Li-Fi uses visible light between 800 THz (375 nm) and 400 THz (780 nm), as an optical carrier for illumination and data transmission.

The LEDs are able to generate digital strings of different combinations of 1s and 0s, by switching on and off. By varying the flickering rate of the LED, it is able to generate a new data stream for encoding in the light. According to Sharma and Sanganal[17], the LEDs were used as a sender or source by modulating the LED light with the data signal. However, by adopting various multiplexing techniques, a high speed LED can achieve communication rates more than 100 Mbps. Using an array of LEDs, the VLC data rate can be increased by parallel data transmission. The emitter system for Li-Fi consisted of four primary subassemblies, such as enclosure, printed circuit board (PCB), RF power amplifier circuit (PA) and a bulb as described by Sharma and Sanganal[17].

Table 1: Comparisons of IEEE 802.11 a/b/g

Features	Wi-Fi 802. 11a/g	Wi-Fi 802.11b
Primary application	Wireless LAN	Wireless LAN
Frequency band	2.4 GHz ISM (g) 5, GHz U-NII (a)	2.4 GHz ISM
Channel bandwidth	20 MHz	25 MHz
Bandwidth efficiency	2.7 bps/Hz	0.44 bps/Hz
Radio technology	OFDM (64-channels)	Direct sequence spread spectrum
Encryption	Optional-RC4 (AES in 802.11i)	Optional-RC4 (AES in 802.11i)
Access protocol	Vendor proprietary CSMA/CA	Vendor proprietary CSMA/CA

All the subassemblies are housed in an aluminum enclosure, where the PCB controls the electrical outputs and inputs of the lamp and uses the micro-controller to manage the functions of different lamps. The solid-state PA generates the radio frequency (RF) signal and is guided into the bulb's electric field. Sharma and Sanganal[17], reported that at the core of Li-Fi, the emitter is the bulb subassembly embedded in a dielectric material where the bulb is sealed. "The energy from the electric field rapidly heats the material in the bulb to a plasma state that emits light of high intensity and full spectrum[17]. Figure 1 demonstrates the block diagram of the Li-Fi subassemblies.

When this approach was used, it provided various inherent advantages such as high luminous efficacy of the emitter, excellent color quality and high brightness in the range of 150 lm W^{-1} or more. The lamp life is about 30,000 h or more due to mechanically robust structure, without failure mechanisms and typical degradation linked by glass to metal seals and tungsten electrodes. In addition, the unique combination of digitally controlled solid state electronics and high temperature plasma provided a cost effective product of family of lamps with a scalability of over 100,000 lumens/package[17].

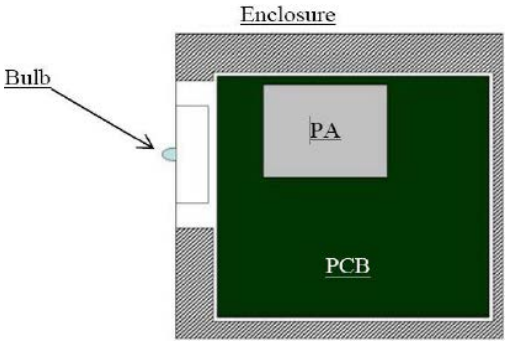

Fig. 1: Block diagram of Li-Fi sub-assemblies
Source: Gupta[15] and Sharma and Sanganal[17]

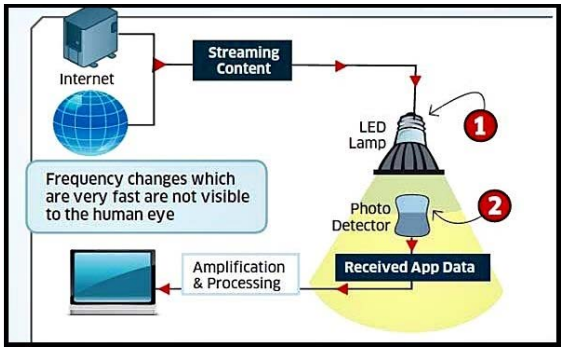

Fig. 2: Different phases for the operation of Li-Fi system
Source: Dimitrov and Hass[1] and Hase *et al.*[5]

How Li-Fi operates: Li-Fi is composed of a wide range of wavelengths and frequencies varying from ultraviolet to infrared through the visible spectrum. Li-Fi is comprised of gigabit and sub-gigabit class communication speeds for short to long ranges, bidirectional and unidirectional data transfers that use reflections, diffuse links, or line-of-sight and other methods. Unlike other communications, Li-Fi is not limited to laser technologies or LED that are used as access points instead of the internet of things (IoTs). The LEDs are the downlink transmitters that can produce an optical output to provide different levels of high speeds by the variations in the waves. The set-up of Li-Fi is simple i.e. If the LED is on, it is able to transmit a digital and a digital 0 is sent when the LED is off. According to, Chatterjee *et al.*[18], certain improvements can be made in the system using either an array of LEDs for parallel data transmission or a mixture of red, green and blue LEDs to alter the frequency of light with each frequency encoding a different data channel. Figure 2 shows the different phases of the operation of Li-Fi system.

Similar to the TV remote's infrared LED, the LED blinks when on and exchanges multiples of the data streams parallel at a higher speed in the LED's visible region. Using a portion of the electromagnetic spectrum, Li-Fi uses the transceiver-fitted LED lamps to transmit and receive data. In order to function Li-Fi, the system must optimize the use of LED and fluorescent light, line of sight (LOS) and the presence of light. Unlike Wi-Fi, LED utilizes a variety of lights, including visible or ultraviolet or invisible on the spectrum for data transfer. Presently, the luminous efficacy of LED lamps and luminaries is around 100 lm/W and expected to reach 200 lm W^{-1} by the year 2025 which will be higher than fluorescent lights (100 lm W^{-1}) and incandescent lamps (20 lm W^{-1}) Karthika and Balakrishnan[3]. The LED lamps are not only sustainable but also have a lifetime of 40,000 h, which is 40 times more when compared to incandescent lamps[3].

Kumar *et al.*[19] made advancements in Li-Fi technology reaching the data rates more than 500 Mbps started to bring ubiquitous high-speed rates. Singh[7] reported that Li-Fi technology is more advantageous than Wi-Fi and cellular phone wireless communication due to its visible light communication (VLC). The Li-Fi technology connection in an office is presented in Fig. 3.

Comparison of Wi-Fi and Li-Fi, Li-Fi is expected to measure 100 times faster than most of the Wi-Fi

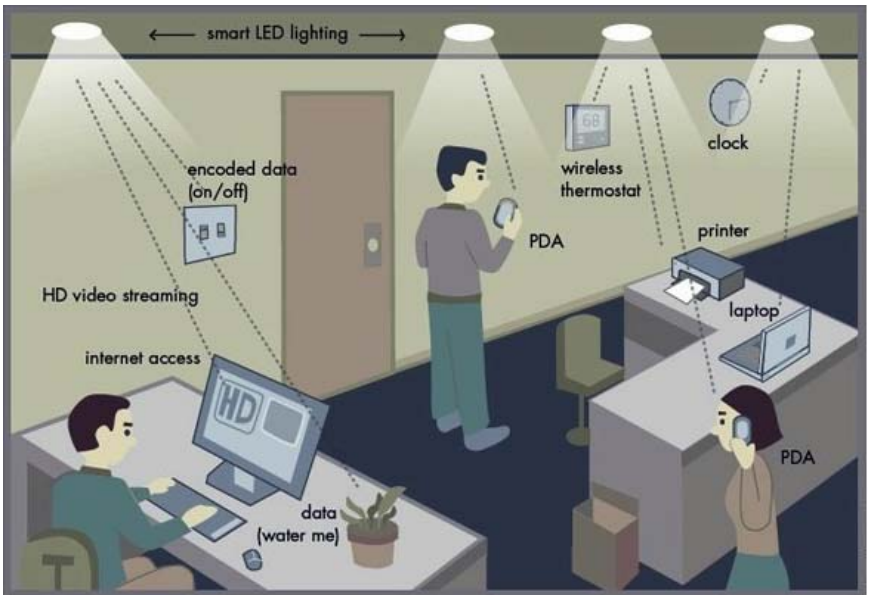

Fig. 3: An example of Li-Fi technology connection in an office
Source: Singh[7]

Table 2: Features of Wi-Fi and Li-Fi network

Features	Wi-Fi	Li-Fi
Name	Wireless Fidelity	Light Fidelity
Operates	Transmit data using radio waves on a radio spectrum	Transmit data using bits through visible light and infrared on ultraviolet waves
Equipment	Uses a Wi-Fi router	Uses LED bulbs, lamp driver and photo detector for complete Li-Fi system
Technology	WLAN 801.11 a/b/g/n/ac/ad standard compliant devices	IrDA compliant devices
Speed	Range of 54-250 Mbps	Range of 1-3.5 Gbps
Frequency	2.4, 4.9 and 5GHz	10x the frequency spectrum of the radio
Coverage	Up to 32 m	Up to 10 m
Interference	Nearby access points	Walls and other obstacles
Density	Comparatively Low	High

implementations by reaching speeds up to 224 Gbpsby Hadi[20]. The Li-Fi provides a new paradigm to supply unprecedented connectivity within the data-centric environment. But Wi-Fi (WLAN) serves as one of the most useable networks in homes and offices, small and large around the world. However, Wi-Fi provides many benefits for users due to its flexible data communications systems that are implemented primarily as an alternative to a wired local area connection. Using high frequency radio waves on a local-area network rather than communication between nodes, Wi-Fi is located in many areas. While, the users are able to share and receive data, gain internet access and access web applications with a possibility of many difficulties faced during the increased use of Wi-Fi. A comparison of LiFi and WiFi features is shown in Table 2.

The introduction of Li-Fi provided many resolutions to problems that plague Wi-Fi and other wireless networks such as reliability, scalability, security and privacy. In addition to the above, it offered human-friendly technology to the environment, high security for data transmission and faster and higher band widths using optical technology. Several vulnerabilities and the increased number of users leave Wi-Fi open to attacks that can affect the users in many ways. Although, Li-Fi is still in its initial stages of deployment but much research is needed to figure out the process which might be the prime alternative to Wi-Fi. On the other hand, the researchers have already started the process of bringing Li-Fi ubiquitous and high-speed technology to the market.

Strengths: Based on the findings of Karthika and Balakrishnan[3], Wi-Fi has numerous strengths that made it the prime alternative to wired connections. Because, Wi-Fi functions efficiently for general wireless coverage throughout public areas and buildings. Currently, Wi-Fi is able to transmit large amount of data at high speed which is 1000 times faster than standard LED only if the switches are turned on and off quickly. Karthika and Balakrishnan[3] reported that Wi-Fi allows

Table 3: Comparison of strengths between Li-Fi and Wi-Fi

Strengths	Wi-Fi	Li-Fi
Obstacle interference	Low	High
Device connectivity	High	High
Transmit/Receive Power	Medium	High
Reliability	Medium	Medium
Security	Medium	High
Data density	Low	High
Range	Higher range of coverage	Low range of coverage
Speed	Medium	High
Cost	Medium installation costs	Low installation costs
Usage locations	Within range of WLAN infrastructure	Anywhere where light is available (LED bulbs)

for cheaper deployment of LANs in historical buildings, outdoor areas and other spaces where cables cannot be run or not able to host wireless LANs. Overall, the Wi-Fi remained an economical networking option as the price of chip sets for Wi-Fi continues to drop and most laptops and PCs are fitted with wireless network adapters. The embedded Wi-Fi modules provide an easy way of wireless enabling any device that can communicate via a serial port, as they incorporate a real-time operating system. Wi-Fi allows for multiple access points in order to increase the overall network capacity, support for fast roaming, better range and network redundancy by defining smaller cells and using more channels. There are many limitations in Wi-Fi where the obstructions limit the range and the maximum speed is obtained only in proximity to the base station. Overall, the maximum speed decreases or increases depending on the signal quality and the magnitude of interferences due to the operation of more devices in the same locality. The comparison of strengths between Li-Fi and Wi-Fi is presented in Table 3.

Unlike Li-FI, Wi-Fi suffers from many fallacies including the issues with radio waves. The Li-Fi technology utilizes visible light communication technology which can acquire higher speeds of wireless communication. The Li-Fi is able to overcome the radio interference issues within confined areas or rooms using high-density wireless data coverage. Li-Fi utilizes light having bandwidth which is 10,000 times wider than radio waves. Karthika and Balakrishnan[3] reported that Li-Fi provides greater efficiency, as the LED lights are highly efficient and consume less energy thus making it a cost effective alternative for data transmission unlike Wi-Fi, Li-Fi can obtain different data rates by using different sizes of LEDs ranging from normal size LED bulbs to micro-LED. It is able to provide fast internet connectivity and servers from generating data rates up to 150 Mbps as described by Karthika and Balakrishnan[3].

While Wi-Fi can place a limitation on internet use, but Li-FI is not restricted by region. Because Li-Fi only works in the presence of a source of light and can generate speed more than 1 Gbps compared to the speed of Wi-Fi of 150 Mbps. Furthermore, Li-Fi depends on the visible light for data communication in the absence of any light in the room. This means that Li-Fi do not function outdoor in the absence of LEDs unless the sunlight is present outdoors. Also Li-Fi works in direct LOS but is interrupted if the line of sight is obstructed. According to latest research, the loss of reliability and network may be due to data transfer interference from external light sources such as opaque materials and normal bulbs[15].

Security and privacy: The radio waves, those can pass through the walls, pose one of the biggest problems to Wi Fi technology. This phenomenon allows misuse of radio waves by many users, thus making it the network susceptible to attacks. On the other hand, Li-Fi uses VLC unable to penetrate thick materials such as partitions and walls providing better security. Wi-Fi is challenged with security issues due to its simple access to the network. Previously, Wi-Fi tried to mitigate these security concerns by deploying WEP (Wired Equivalent Privacy), that uses CRC-32 checksum for integrity and stream cipher RC4 for confidentiality according to Alexiou *et al.*[12]. Wi-Fi also uses WPA (Wi-Fi Protected Access) and WPA2 in order to improve the problems of WPA by dramatically changing the keys of the system during its use. Besides, Wi-Fi is also able to improve the payload integrity by encryption and authentication to minimize outside attacks.

One of the major problems faced by Wi-Fi is its vulnerability to attacks such as piggy backing by providing a secure network, because external users can hack the wireless connection. The malicious users have the ability to monitor user activity and steal sensitive information by accessing files and taking control of the user's computer. Without the right security protection, restricted files can be accessed and shared, as well as susceptible to attacks such as, evil twin attacks, wireless sniffing, attacks from peer-to-peer connections, DDoS attacks and the inability to gain back control of the wireless network. As reported by US-CERT[21], Li-Fi technology is able to provide a safe and secure wireless

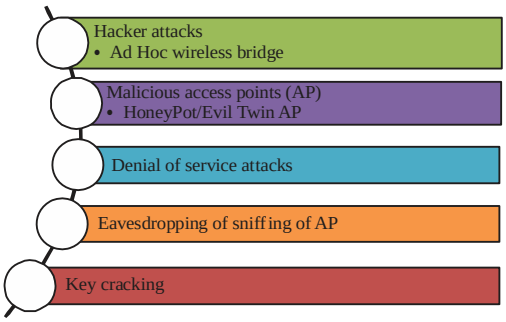

Fig. 4: Wi-Fi security threats

access. Based on the research studies and experience, the security threats of Wi-Fi network were developed by the author in the form of a diagram as presented in Fig. 4.

Data tied to an existing security system can be sent much faster than the conventional Wi-Fi. On the other hand, Li-Fi provides better profitability and productivity for organization by addressing the human element of security chain and minimizing the opportunity cost of information leaks. According to Dimitrov and Hass[1], "typical RF (radio frequency) solutions were avoided in many industries due to the penetrative and wide-spread nature of their coverage areas. This provided possible access outside the physical limitation of the intended user to compromise the network security according to Harler[16].

Future of Li-Fi: The potential of future use of Li-Fi depends on its application in educational systems, thus enabling them to provide better and quick internet access as an alternative to companies and educational institutions using Wi Fi. Because, Wi-Fi access is not available at operation theaters (OTs) due to radiation concerns and at hospitals due to interference with PC and mobile devices likely to block the signals used to monitoring equipment. Lights are considered as one of the most luminous factors in operation theaters where Li-Fi has the ability to delegate red light to priority medical data as stated by Rani *et al.*[22]. However, Li-Fi seems to be able to overcome these dangerous elements, controlling medical equipment and to access the internet, providing advantages to automated procedures and robotic procedures[3].

Li-Fi proved to be a potential alternative over Wi-Fi connections in airlines, chemical or petroleum plants and power plants due to its cost effective choice and the ability to overcome interference with the radio caused by RF waves[22]. According to a recent research, radio waves are quickly absorbed in water whereas the light can penetrate large distances and headlamps are used for communicating water as observed by Lakshmisudha *et al.*[23]. This also allows its future use in underwater ROVs and other underwater exploration. If there is light, Li-Fi connectivity is possible to be used in tunnels or subway stations where communication is needed in frequent dead zones and provide cheaper high speed internet access for emergency personnel[8]. Li-Fi is applicable for traffic management, making communication with LED lights of cars easier for managing traffic, reducing a number of accidents and the possibility of alerting drivers when vehicles are too close as reported by Sharma and Sanganal[17]. The potential of Li-Fi in the future is bright as it can be extended where Wi-Fi does not work efficiently.

CONCLUSION

It appears that Li-Fi technology is likely to be a potential and a viable alternative to Wi-Fi technology. Li-Fi seems to provide unlimited opportunities for cheaper, faster, safer and sustainable choice to radio based wireless. Although, Wi-Fi continues to be the dominant choice but this study explored the deficient areas of wireless technology. Li-Fi is being looked as a promising technology for providing resolutions to many challenges faced by Wi-Fi. Li-Fi is a viable and an upcoming competent technology to already established and developing technologies for its extension different platforms for wireless use.

Unless the spectrum can improve, provided Wi-Fi is able to keep up with the technological development, the shifts in paradigm provides opportunities for Li-Fi to be its replacement. Li-Fi with greater speed, will provide the users better security measures and utilize light as the primary source for data transmission where Wi-Fi and other technologies failed to accomplish. The future implications of Li-Fi include its application in different fields such as industries, medicine, education and other regions requiring further exploration.

SIGNIFICANT STATEMENTS

Li-Fi (Light Fidelity) is a groundbreaking technology that utilizes visible light spectrum to unlock the capacity at which to transmit data at 10 times the speed of Wi-Fi. Presently, it is developed into a ubiquitous technology with having an innovative networking capacity for universal application in order to perform high speed internet communications. Overall, Li-Fi technology can provide the users with better security measures, capacity and availability than Wi-Fi.

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