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Introduction

Wireless technologies (WiFi, WiMax, etc.) have evolved as heavily used routine phenomena in recent years. However, the expanding demand of wireless data has congested the radio spectrum. The shortcomings of the predecessor wireless technologies have been resolved through Li-Fi. Li-Fi technology is a new and noteworthy visible light communication (VLC) technology that makes use of light waves in lieu of radio technology for delivering data. Li-Fi was invented by Harald Haas from the University of Edinburgh, Scotland, back in 2011, when he demonstrated, for the first time, that by flickering the light from a single light-emitting diode (LED), large amounts of data could be transmitted than a cellular tower (Crew, 2015). Li-Fi technology is, in essence, a transition from illumination to communication, where one can connect to the internet by being within the range of an LED beam. According to Li-Fi Research and Development Centre (2016), the Li-Fi technology in the future will enable faster more reliable internet connections, even when the demand for data usage has outgrown the available supply from existing technologies such as 4G, LTE and Wi-Fi.

The Li-Fi movement

The usage of visible light as a means of wireless communication is not a new development. During antiquity, people used beacon fires, mirror reflections and light houses for communicating over large distances. The first use of electronic wireless communication through visible light media can be traced to the device "photophone" developed by A.G. Bell in 1880 (Bell, 1880). The photophone used solar radiation to transmit voice and data up to 200 m. Later on, various improvements were made to Bell's prototype using tungsten lamps with infrared lamps, mercury arc lamps and fluorescent lights (Groth, 1987). With the development of the LED technology in recent years as a low power-consuming lighting solution and with high longevity, the perception of using visible light for communication has become efficacious. LEDs have now evolved as a lighting source nearly for all lighting devices. Such lighting systems also have potential for high data transmission besides being used for illumination at the same time that justifies the high eligibility of LED lights for VLC (Sagotra and Aggarwal, 2013; Sevincer *et al.*, 2013). The concept of VLC through LEDs was the brainchild of Pang *et al.* (1999) in Japan in 1999 who put forth a framework of a VLC system executed on LED traffic lights that

provided open space, wireless broadcasting of audio messages. The first use of white LEDs for illumination and communication was carried out by Tanaka *et al.* (2003) in the early 2000s. Recent researches have revealed that high data transmission rates up to the range of a gigabit per second can be achieved. Moreover, to promote and standardize the VLC technology, various initiatives and groups have been established such as the Visible Light Communication Task group, Li-Fi consortium, HOME Gigabit Access (OMEGA) project and the Visible Light Communication Consortium.

Features of Li-Fi

High speed

Li-Fi works by trapping the intensity of light for communication and the light is diffused so fast that it is not noticed by the human eye. The speed of Li-Fi is relatively hundred times faster than the standard Wi-Fi download speeds. Li-Fi takes advantage of the perceptible light and binary code to increase download speeds exponentially. As information societies strive to adopt newer and faster technology solutions, Li-Fi has enormous potential to evolve as one of the primary means to transfer files over the internet. Table I presents a snapshot of the data communication speed of various technologies and how Li-Fi leads among all wireless technologies.

Security and reliability

Considering the fact that light is contained within the space it is used, there is no means through which transmission signals of Li-Fi can be gathered from outside sources. Li-Fi signals are basically confined to narrowly focused "beams" that do not travel through walls and there is non-interference with radio devices (Sawers, 2014). Because Li-Fi signals are unsusceptible to outside attacks, it is of great benefit for government and corporate entities to shield sensitive information from hackers.

Technology

Regardless of the monumental growth of the Wi-Fi technology in the past decades, it remains obstructed by the fact that it relies on microwaves in the 2.4 GHz and 5 GHz bands, a radio spectrum that is limited. In contrast, Li-Fi relies on the transmission of light that can be deployed in LED bulbs which will cover an entire office or home. A lighted LED bulb appears to throw a constant stream of light, but in reality, comprises millions of micropulses per second. Despite being challenged by Li-Fi, Wi-Fi will still remain relevant and widely utilized because wireless connectivity is currently the best option in public or outdoor settings. Li-Fi cannot function in an open environment (Sawers, 2014).

Working principle

Li-Fi involves data transmission by means of illumination which utilizes the fiber taken from fiber optics. The fiber is taken out while the data are sent through the LED which varies in intensity at a given rate so that it cannot be followed by the human eye. Some scholars have argued that Li-Fi is an optical version of Wi-Fi that is faster and relatively cheaper too. Data in the light are easily encoded by adjusting the flickering of LEDs on and off, leading to the generation of different strings of binary codes in the form of ones and zeros. The intensity of LEDs is adjusted in such a fast manner that it is unnoticed to the human eye and the data output appears to be constant. The working principle of Li-Fi has been shown in Figure 1.

Li-Fi is implemented using white LED light bulbs by a downlink transmitter:

- By fast variations of the current, optical output can be made to vary at extremely high speeds.
- An overhead lamp fitted with an LED with signal processing technology streams data embedded in its beam at ultra-high speeds to the photodiodes.
- A receiver dongle then converts the tiny changes in amplitude into an electrical signal, which is then converted back into a data stream and transmitted to a computer or mobile device.

Commercial Li-Fi products and applications

Li-Fi products use the lighting networks as wireless communication networks. OLEDCOMM is the first company to provide products that are based on Li-Fi technology. They provide CODELED bulbs which can be rented or purchased for small events. A variant of CODELED is MUSE that can be used in libraries and museums not only to provide internet access but also to guide users to accurate location of resources up to 10 cm. For higher data bit rates, LiFiNET can be used to provide connectivity to a larger area.

The applications of VLC are limitless; some of the useful applications are listed below.

Li-Fi can be used indoors for high density, more security, free unlicensed spectrums with a high level of radiofrequency (RF) noise and interference in the environment, such as, casinos, malls and coffee shops.

Li-Fi can be used in hospitals, particularly for new medical instruments, as Li-Fi is noise and interference free.

Light sources are installed in aircraft cabinets in abundance; therefore, Li-Fi can be used for smarter aircrafts, where this technology will never affect or interfere with the navigational system of the aircraft.

Li-Fi works perfectly well underwater unlike Wi-Fi. Therefore, it is possible to use it in underwater remote operations vehicle for rescues and exploring. As a pair, Li-Fi can be used for military operations in the underwater world.

In the past few years, some car makers have manufactured front-base LED light and rear LED lights, so Li-Fi could be potentially used for communication

Table I.
Comparative study of data communication through wired and wireless technologies

Wired		Wireless (Current)		Wireless (Future)	
Firewire	800 Mbps	WiFi	150 Mbps	LiFi	10 Gbps
USB 3.0	5 Gbps	Bluetooth	3 Gbps	Giga-IR	1 Gbps
Thunderbolt	20 Gbps	IrDA	4 Gbps	Wi-Gig	2 Gbps

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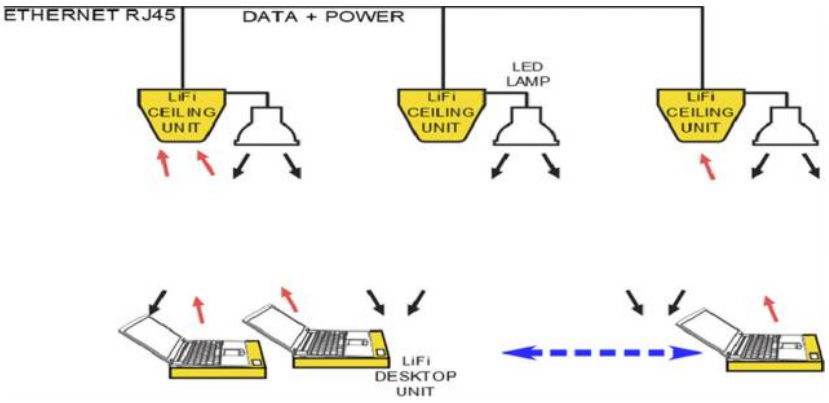
Figure 1. *Working principle and architecture of Li-Fi technology*



between vehicles and prevent accidents. Vehicles can communicate with traffic lights to receive important traffic management information.

There are millions of street lights around the world that can be used with Li-Fi-free hotspots to access the internet.

Li-Fi can be used in environments where RF is a major concern, such as power and petrochemical plants.

Challenges in Li-Fi adoption

Compared to radio-wave-based wireless communication, VLC through Li-Fi technologies has its own merits and demerits. The distances of communication and the rate of data transfer are two key issues critical to adoption of Li-Fi technologies. Through VLC, only up to 0.5 to 1 foot distances can be covered for communication purpose which is shorter in comparison to the radio-wave communication range. Moreover, the data rate through VLC media typically ranges from 1 KB/s to 10/s. Research is still being carried out to improve the rate of data transfer to GBs per seconds. The data rate in VLC is dependent upon the efficiency of LEDs or photo sensors at the receiver end which lowers the data rate. Although, these disadvantages may confine the application of LEDs in many areas, yet the line-of-sight property of data is especially beneficial across many avenues.

Conclusion

In the rapidly evolving world of data communication, VLC presents a stable, easy and faster mode of data communication. VLC takes a different approach as compared to other forms of data communications by using light which is available abundantly everywhere there is electricity and makes use of light's two most basic and most effective properties: speed and reach. Although VLC is still in its early stages of development, it can revolutionize the data communication field if its potential is effectively tapped. With dramatic developments in LED technology and scarce spectrum resources, there has been a growing interest in VLC, which can be termed as a positive step in this direction. But for progress to evolve in this technology, drawbacks must be acknowledged such as range, energy efficiency and costs to implement. Solutions to overcome these restrictions are necessary. VLC is an excellent method of communication and has the potential to be the prime mode of communication in the near future.

It may be quite some time before we will see Li-Fi being used on the same scale as Wi-Fi. Existing hardware would either need to be modified or replaced to use Li-Fi. This would be costly and time-consuming for businesses who wish to adopt Li-Fi technology. As Li-Fi gains traction and is more widely accepted and implemented, costs and inconveniences will become less of an issue. It is important to note that Li-Fi technology is a green technology that is environment-friendly, as it consumes far less energy. In addition, it can secure information better than radio, which has loopholes such as signal disturbances, leaks and interception. If the technology evolves, we will, one day, start seeing LED bulbs retrofitted and turned into hot-spots and access points for broadband networks in both homes and offices.

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