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## LI-FI TECHNOLOGY: DATA TRANSMISSION THROUGH VISIBLE LIGHT

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### ABSTRACT

Li-Fi stands for Light-Fidelity. The technology is very new and was proposed by the German physicist Harald Haas in 2011. Li-Fi provides transmission of data through illumination by sending data through an LED light bulb that varies in intensity faster than human eye can follow. In this paper, the authors will discuss the technology in detail and also how Wi-Fi can be replaced by Li-Fi. Wi-Fi is useful for general wireless coverage within buildings while Li-Fi is ideal for high density wireless data coverage in confined areas where there are no obstacles. Li-Fi is a wireless optical networking technology that uses light emitting diodes (LEDs) for transmission of data. The term Li-Fi refers to visible light communication (VLC) technology that uses as medium to deliver high-speed communication in a manner similar to Wi-Fi. Li-Fi provides better bandwidth, efficiency, availability and security than Wi-Fi and has already achieved high speeds in the lab. In the present paper the authors will give a detailed study on Li-Fi technology, its advantages and its future scope.

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**Keywords:** *Light Fidelity; LED; VLC; Wi-Fi; Bandwidth.*

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### INTRODUCTION

Professor Harald Haas, the Chair of Mobile Communications at the University of Edinburgh, is recognized as the founder of Li-Fi. He coined the term Li-Fi and is the co-founder of pure Li-Fi. He gave a demonstration of a Li-Fi prototype at the TED Global conference in Edinburgh on 12th July 2011. He used a table lamp with an LED bulb to transmit a video of a blooming flower that was then projected onto a screen. During the talk, he periodically blocked the light from the lamp with his hand to show that the lamp was indeed the source of the video data. Li-Fi can

be regarded as light-based Wi-Fi, i.e. instead of radio waves it uses light to transmit data. In place of Wi-Fi modems, Li-Fi would use transceivers fitted with LED lamps that could light a room as well as transmit and receive information. It makes use of the visible portion of the electromagnetic spectrum which is underutilized. Li-Fi can be considered better than Wi-Fi because there are some limitations in Wi-Fi. Wi-Fi uses 2.4 –5 GHz radio frequencies to deliver wireless internet access and its bandwidth is limited to 50-100 Mbps. With the increase in the number of Wi-Fi

hotspots and volume of Wi-Fi traffic, the reliability of signals is bound to suffer. Security and speed are also important concerns. Wi-Fi communication is vulnerable to hackers as it penetrates easily through walls. In his TED talk, Professor Haas highlighted the following key problems of Wi-Fi that need to be overcome in the near future:

**a) Capacity:** The radio waves used by Wi-Fi to transmit data are limited as well as expensive. With the development of 3G and 4G technologies, the amount of available spectrum is running out.

**b) Efficiency:** There are 1.4 million cellular radio masts worldwide. These masts consume massive amounts of energy, most of which is used for cooling the station rather than transmission of radio waves. In fact, the efficiency of such stations is only 5%.

**c) Availability:** Radio waves cannot be used in all environments, particularly in airplanes, chemical and power plants and in Hospitals.

**d) Security:** Radio waves can penetrate through walls. This leads to many security concerns as they can be easily intercepted.

Li-Fi addresses the aforementioned issues with Wi-Fi as follows:

**a) Capacity:** The visible light spectrum is 10,000 times wider than the spectrum of radio waves. Additionally, the light sources are already installed. Hence Li-Fi has greater bandwidth and equipment which is already available.

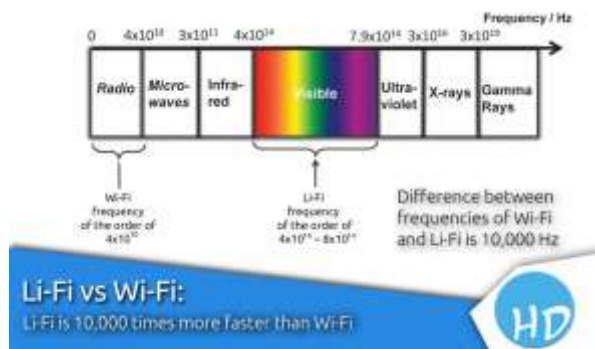
**b) Efficiency:** LED lights consume less energy and are highly efficient.

**c) Availability:** Light sources are present in all corners of the world. Hence, availability is not an issue. The billions of light bulbs worldwide need only be replaced by LEDs.

**d) Security:** Light of course does not penetrate through walls and thus data transmission using light waves is more secure.

Light	LEDs produce more light per watt than do incandescent bulbs
ON-OFF Time	LEDs can light up very quickly
Toxicity	Unlike fluorescent lamps, LEDs do not contain mercury
Free Band	Li-Fi makes use of a free band that does not need any licensing
High Speeds	It offers theoretical speeds in the order of Gigabits per second
Airlines	Li-Fi can be used safely in aircrafts without affecting airline signals unlike Wi-Fi
Healthcare	It can be integrated into medical devices and in hospitals as no radio waves are involved
Underwater	Wi-Fi does not work underwater but Li-Fi does and hence can be used for undersea explorations
Traffic Control	Li-Fi can be used on highways for traffic control applications. Cars can have LED based headlights and LED based backlights that can communicate with those of other cars and prevent traffic accidents
Street Lamps	Every street lamp can be converted into a free data access point

The applications of Li-Fi are derived from many of these benefits and will be studied in detail in later sections. Frank Deicke, who leads Li-Fi development at Fraunhofer Institute for Photonic Microsystems in Dresden, Germany, has said that Li-Fi can achieve the same data rates as USB cables which is challenging for wireless technologies such as Bluetooth and Wi-Fi. He also cites another advantage of Li-Fi being that the latency of Li-Fi is in the order of microseconds where as that of Wi-Fi is in the order of milliseconds. With the above benefits encouraging us to adopt this new technology, the actual need for Li-Fi can be confirmed from Cisco's Visual Network Index which suggests that user demand is increasing faster than gains in spectral efficiency. By 2015, traffic from wireless devices is expected to exceed that from wired devices. Such increases in network traffic require significant changes in how we think of wireless communication and Li-Fi may be the change that we need.



## II. WORKING OF LI-FI

### General Working Principle

Light emitting diodes (LEDs) can be switched on and off faster than the human eye can detect since the operating speed of

LEDs is less than  $1 \mu\text{s}$ , thereby causing the light source to appear to be continuously on. This invisible on-off activity enables data transmission using binary codes. Switching on

an LED is binary '1', switching it off is binary '0'. It is possible to encode data in light by varying the rate at which LEDs flicker on and off to give different strings of 1s and 0s. Modulation is so rapid that humans cannot notice it. A light sensitive device (photo detector) then receives the signal and converts it back into original data. This method of using rapid pulses of light to transmit information wirelessly is technically referred to as Visible Light Communication (VLC). The term Li-Fi has been inspired due to its potential to compete with conventional Wi-Fi. The VLC uses visible light between 400 THz (780 nm) and 800 THz (375 nm) as the optical carrier for data transmission and for illumination. Data rates of greater than 100 Mbps can be achieved by using high speed LEDs with adequate multiplexing. Parallel data transmission using arrays of LEDs where each LED transmits a separate stream of data can be used to increase the VLC data rate. Though the lights have to be kept on in order to transmit data, they can be dimmed to the point that they are not visible to humans but still be capable of transmitting data.

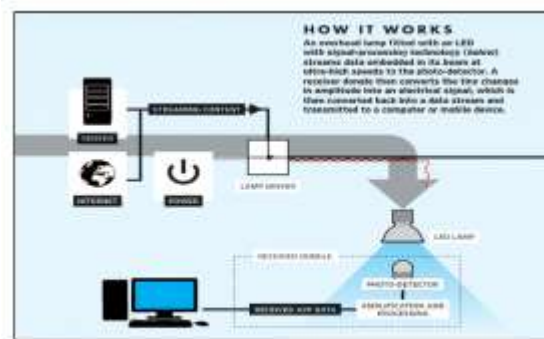


Fig-2: Working of Li-Fi

### 2.1 Technical Aspects and Modulation

VLC refers to any use of the visible light portion of the electromagnetic spectrum to transmit information. A VLC interest group is certified by the IEEE 802.15 with the final standard being approved in 2011. The standard of VLC specifies VLC consisting of mobile-to-mobile (M2M), fixed-to-

mobile (F2M) and infrastructure-to-mobile (I2M) communications. The main purpose of VLC is to focus on medium-range communications for intelligent traffic systems at low-speed and on short-range mobile to mobile and fixed to mobile communications at high speeds to exchange data. Data rates are supported from some 100 kbps up to 100 Mbps using various modulation schemes.

Li-Fi communication is modelled after protocols established by the IEEE 802 workgroup. It defines physical layer (PHY) & media access control (MAC) layer for VLC/Li-Fi.

The MAC layer supports 3 multi-access technologies: peer-to-peer, star configuration and broadcast mode. It also handles physical layer management issues such as addressing, collision avoidance and data acknowledgement protocols. The physical layer is divided into 3 types: PHY I, II, III and employ a combination of different modulation schemes.

In order to actually send out data by means of LEDs, it is required to modulate these into a carrier signal. The carrier signal consists of light pulses sent out at short intervals. The manner in which this is done depends on the modulation scheme employed.

Li-Fi systems use the following different modulation schemes:

**1. On-Off Keying (OOK):** The 802.15.7 standard uses Manchester coding so that the period of positive pulses is same as the period of negative ones, however this doubles the bandwidth required for transmission. For higher bit rates, run length limited (RLL) coding is used which is spectrally more efficient. Dimming is supported by adding an OOK extension which adjusts the aggregate output to the correct level.

**2. Variable Pulse Position Modulation (VPPM):** PPM encodes the data using the position of the pulse within a set time period. The duration of the period containing the

pulse must be long enough to allow different positions to be identified. VPPM is similar to PPM but it allows the pulse width to be controlled to support light dimming.

**3. Colour Shift Keying (CSK):** This is used if the illumination system uses RGB-type LEDs. By combining different colours of light, the output data can be carried by the colour itself and hence the intensity of the output can be near constant. Mixing of RGB primary sources produces different colours which are coded as information bits. The disadvantage is that it increases the complexity of the transceivers.

**4. Sub-Carrier Inverse PPM (SCIPPM):** This method is divided into two parts (1) sub-carrier part and (2) DC part. The DC part is used only for lighting or indicating. When there is no requirement for lighting or indicating, SCPPM (Sub-Carrier PPM) is used in order to save energy.

**5. Frequency Shift Keying (FSK):** In this method, data is represented by varying the frequencies of the carrier signal. Before transmitting two distinct values (0 and 1), there needs to be two distinct frequencies.

**6. SIM-OFDM (Sub-Carrier Index Modulation OFDM):** This is a new approach to transmission in which an additional dimension is added to conventional 2D amplitude/phase modulation (APM) techniques such as quadrature amplitude modulation (QAM) and amplitude shift keying (ASK). The key idea is to use the sub-carrier index to convey information to the receiver.

**2. LED as Light Source** The most important requirement for a light source in order to serve communication purposes is the ability to be switched on and off repeatedly in very short intervals of time. Due to their ability to be switched on and off rapidly, LEDs are suitable light

The most important requirement for a light source in order to serve communication purposes is the ability to be switched on and

off repeatedly in very short intervals of time. Due to their ability to be switched on and off rapidly, LEDs are suitable light sources for Li-Fi. LEDs offer many benefits over fluorescent lamps and incandescent lamps such as high efficiency, environment friendly manufacturing, flexibility of design, longer useful lifetimes and improved spectrum performance.

LEDs emit light when the energy levels change in the semiconductor diode. This change in energy generates photons, some of which are emitted as light. The wavelength of emitted light depends upon the difference in energy levels and the type of semiconductor material used to form the LED chip. Solid-state design allows LEDs to withstand vibration, shocks, frequent switching and extremes of environment without compromising their long useful lives of typically more than 100,000 hours.

The basic LED consists of a semiconductor diode chip mounted in the reflector cup of a lead frame that is connected to electrical (wire bond) wires, and then encased in a solid epoxy lens. The variations in data rate with the size of LEDs are very important in Li-Fi technology. Different data rates can be achieved with different sized LEDs. Normal sized LED bulbs can be reduced to micro-LEDs which handle millions of variations in light intensity. A micro-LED light bulb can transmit 3.5 Gbps and data rates of more than 10 Gbps are possible. The micro LED bulbs allow the light stream to be beamed in parallel thereby transmitting huge amounts of data in terms of Gbps.

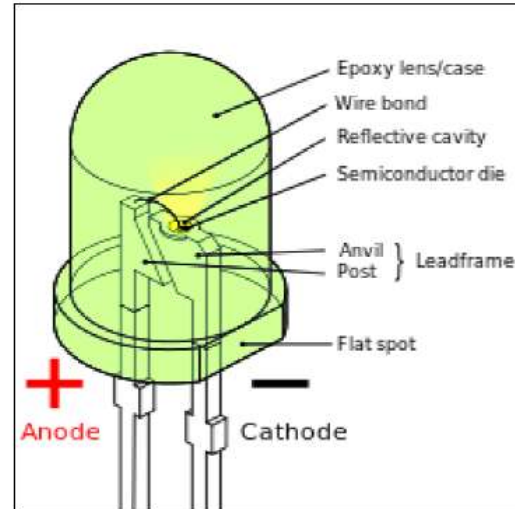


Fig-3: LED

### 3. Usage Models

Within a local Li-Fi cloud, several data based services are supported through a heterogeneous communication system. Initially, the Li-Fi Consortium defined different types of technologies to offer secure, reliable and ultra-high-speed wireless communication interfaces. These included giga-speed technologies, optical mobility technologies and navigation, precision location and gesture recognition technologies. For giga-speed technologies, the Li-Fi Consortium defined Giga Dock, Giga Beam, Giga Shower, Giga Spot and Giga MIMO models to tackle different user scenarios for wireless indoor and indoor-like transfers of data. Giga Dock is a wireless docking solution that includes wireless charging for smart phones tablets or notebooks, with speeds up to 10 Gbps. Meanwhile, the Giga Beam model is a point-to-point data link for kiosk applications or portable-to-portable data exchanges. Thus a two-hour full HDTV movie (5 GB) can be transferred from one device to another within four seconds.

#### 2.4 Implementation of Li-Fi:



The main components of a simple system based on Li-Fi are:

- i) High brightness LED which acts as the communication source
- ii) Silicon photodiode which serves as the receiving element

Data from the sender is converted into an intermediate data representation i.e. byte format and then converted into light signals which are emitted by the transmitter. The light signal is received by the photodiode at the receiver side. The reverse process takes place at the destination computer to retrieve the data back from the received light.

LEDs are employed as the light sources. The model transmits digital signal by means of direct modulation of the light. The emitted light is detected by an optical receiver.

Source Computer: Data Reading  
Module → Data Conversion  
Module → □ Transmitter Module  
Destination Computer: Receiver  
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The different components serve the following functions

### Comparison between Li-Fi and Wi-Fi

parameter	Li-Fi	Wi-Fi
speed	High	high
spectrum	10,000 times broader than that of Wi-Fi	Narrow spectrum
Data density	High	low
security	High security due to non penetration of light through walls	Less secure due to transparency
Reliability	Medium	Medium
Bandwidth	High due to broad spectrum	Low
Transmit/receive power	High	Medium
ecological impact	Low	Medium
Device-to-device connectivity	High	High
Obstacle interference	High	Low
Bill of materials	High	Medium
Latency	In the order of microseconds	In the order of milliseconds

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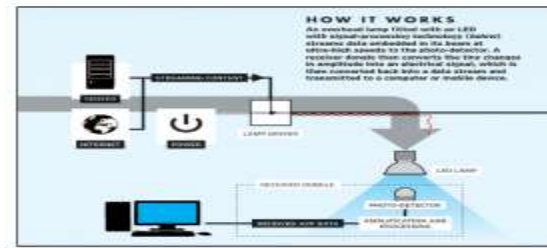


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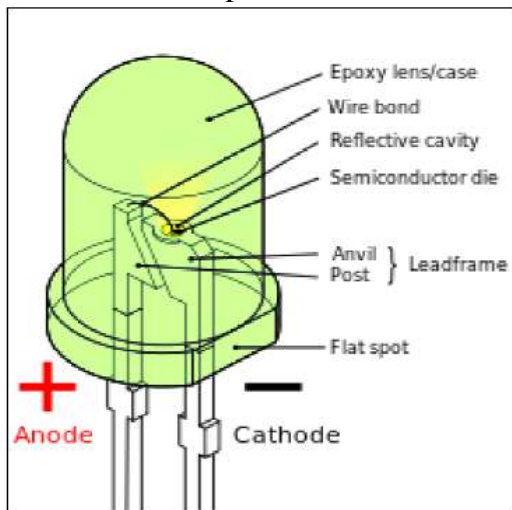


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Source Computer: Data Reading  
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Module → Data Interpretation  
Module → Data Display (GUI)

The different components serve the following functions:

Data Conversion Module – converts data into bytes so that it can be represented as a digital signal. It can also encrypt the data before conversion.

Transmitter Module – generates the corresponding on-off pattern for the LEDs.

Receiver Module – has a photo diode to detect the on and off states of the LEDs. It captures this sequence and generates the binary sequence of the received signal

Data Interpretation Module\_– converts data into the original format. If encryption was done, it also performs decryption.

### III. APPLICATIONS OF LI-FI

Li-Fi technology can find application in a wide variety of fields. A detailed discussion of its various applications is given below.

**(i) Medical and Healthcare:** Due to concerns over radiation, operating rooms do not allow Wi-Fi and even though Wi-Fi is in place in several hospitals, interferences from computers and cell phones can block signals from medical and monitoring equipment. Li-Fi solves these problems. Lights are an essential part of operating rooms and Li-Fi can thus be used for modern medical instruments. Moreover, no electromagnetic interference is emitted by Li-Fi and thus it does not interfere with any medical instruments such as MRI scanners.

**(ii) Airlines and Aviation:** Wi-Fi is often prohibited in aircrafts. However, since aircrafts already contain multiple lights, thus Li-Fi can be used for data transmission.

**(iii) Power Plants and Hazardous Environments:** Wi-Fi is not suitable for sensitive areas like power plants. However, power plants still require fast and interconnected data systems for monitoring grid intensity, demand, temperature etc. In place of Wi-Fi, Li-Fi can provide safe connectivity throughout the power plant. Li-Fi offers a safe alternative to electromagnetic interference due to radio waves in environments such as petrochemical plants and mines.

**(iv) Underwater Explorations and Communications:** Remotely operated underwater vehicles or ROVs work well except in situations when the tether is not long enough to fully explore an underwater area or when they get stuck. If instead of the wires, light were used then the ROVs would be freer to explore. With Li-Fi, the

headlamps could also then be used to communicate with each other, data processing and reporting findings back to the surface at regular intervals, while also receiving the next batch of instructions. Radio waves cannot be used in water due to strong signal absorption. Acoustic waves have low bandwidth and disrupt marine life. Li-Fi offers a solution for conducting short-range underwater communications.

**(v) Traffic:** Li-Fi can be used for communications between the LED lights of cars to reduce and prevent traffic accidents. LED headlights and tail-lights are being implemented for different cars. Traffic signals, signs and street lamps are all also transitioning to LED. With these LED lights in place, Li-Fi can be used for effective vehicle-to-vehicle as well as vehicle-to-signal communications. This would of course lead to increased traffic management and safety.

**(vi) GigaSpeed :** Li-Fi Consortium provides the fastest wireless data transfer technology presently available. Our current solutions offer effective transmission rates of up to 10 Gbps, allowing a 2 hour HDTV film to be transferred in less than 30 seconds. This can be extended to several 100 Gbps in future versions

**(vii) Smart Lighting:** Street lamps can in the future be used to provide Li-Fi hotspots and can also be used to control and monitor lighting and data.

**(viii).Mobile connectivity:**

Laptops, tablets, smart phones and various other mobile devices can interconnect with each other using Li-Fi, much like they interconnect today using Wi-Fi. These short range links provide very high data rates as well as increased security.

**(ix) Toys**

Several toys consist of LED lights and these can be utilized to implement low-

cost communication in order to build interactive toys.

#### **LIMITATIONS OF LI-FI:**

1) The main problem is that light cannot pass through objects, so if the receiver is inadvertently blocked in any way, then the signal will immediately be cut out. If the light signal is blocked one could switch back over to radio waves.

2) Reliability and network coverage are the major issues to be considered by the companies while providing VLC services. Interference from external light sources like sunlight, normal bulbs; and opaque materials in the path of transmission will cause interruption in the communication.

3) High installation cost of the systems can be complemented by large-scale implementation of VLC though adopting this technology will reduce further operating costs like electricity charges, maintenance charges etc.

4) We still need Wi-Fi and we still need radio frequency cellular systems. You can't have a light bulb that provides data to a high-speed moving object or to provide data in a remote area where there are trees, walls and obstacles.

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