Scope and Challenges in Light Fidelity(LiFi) Technology in Wireless Data Communication

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Abstract*— Light Emitting Diodes(LED) are used in different areas of everyday life. The advantage of this device is that in addition to their lightening capabilities, it can be used for data transmissions as well. In the present study, the authors have made an exhaustive study on technology of Li-Fi and its applications in transferring data from one computer to another computer. The authors have also made study on advantages as well as disadvantages of using Li-Fi in transferring data from one computer to another computer. The massive use of Li-Fi may solve some bottleneck of data transmission in Wi-Fi technology. Finally the authors have also tried to explore the future scope of this new technology for using visible light as the carrier in data transmission and networking.

***Keywords*— LED, Li-Fi technology, Wi-Fi technology, data transmission, Visible light**

I. INTRODUCTION

All of us have increasingly become dependent on the internet some way or the other. It is impossible to think of a day in our lives, when we are not "connected" to the "net". We are using the internet for a variety of purposes, chief among them being sharing of data. In scenarios where we want to transmit data quickly and efficiently, low internet speeds can be quite annoying.

In 2011, Professor Harold Haas from the University of Edinburgh in the UK, suggested an idea called "Data through illumination" [4]. He used fiber optics to send data through LED light bulbs. Light modulation certainly is not a new concept, but Haas is looking to move things forward and enable connectivity through simple LED bulbs. With Li-Fi, we can connect to the internet simply by being within range of an LED beam, or we could conceivably transmit data using our car headlights. The ramifications of this are huge, especially with the internet of things in full swing and the much mooted spectrum crunch expected to bite increasingly hard in the coming years.

LI-FI is a new technology which uses visible light for communication instead of radio waves. It refers to 5G Visible Light Communication systems using Light Emitting Diodes as a medium to high-speed communication in a similar manner as WI-FI [6]. It can help to conserve a large amount of electricity by transmitting data through light bulbs and other such lighting equipments. It can be used in aircrafts without causing any kind of interference. LI-FI uses light as a carrier as opposed to traditional use of radio waves as in WI-FI and this means that it cannot penetrate walls, which the radio waves are able to. It is typically implemented using white LED bulbs at the downlink transmitter [1]. By varying the current through the LED at a very high speed, we can vary the output at very high speeds. This is the principle of the LI-FI. The working of the LI-FI is itself very simple—if the LED is ON, the signal transmitted is a digital 1 whereas if it is OFF, the signal transmitted is a digital 0. By varying the rate at which the LEDs flicker, we can encode various data and transmit it.

Li-Fi is no longer a concept or an idea but a proven technology, albeit still at its infancy. Already, several experts in the field of communication have attested that Li-Fi technology would soon become a standard adjunct to Wi-Fi. That is, until its inherent limitations could be overcome. Since it is light-based, its major drawback is that it won't be able to penetrate solid objects such as walls. Though it could also mean privacy for the personal user, it also questions its use for large-scale delivery of data transmissions.

But despite its drawbacks, researchers all over the world have been going all-out in further developing this new technology. A research was initiated by a consortium of universities that includes the Universities of Cambridge, Oxford, St. Andrews and Strathclyde in Scotland. It is led by Professors Martin Dawson, from the Institute of Photonics, and Harald Haas, from the University of Edinburgh. The goal of the consortium is to eventually make every illuminated device, such as televisions, lamps, road signs, and commercial ad boxes, transmit data to gadgets such as mobile phones.

At the University of Strathclyde, researchers have begun earnest efforts at bringing this new technology to market. Their biggest accomplishment to date is the development of LEDs that are a thousand times smaller than the smallest commercial LED. Dubbed micro-LED or micron-sized LEDs, these newer models are merely 1μm^2 (square micrometres) in size. This means that 1,000 more lights could be fit into the same space as a typical LED. In addition to its size, micro-LEDs can flicker 1,000 times faster than commercial LED. Thus, in theory, a bank of 1,000 micro-LEDs flashing 1,000 times faster could transmit data a million times faster than that of an average LED. At the moment, the potential advantage of micro-LEDs for Li-Fi use is staggering.

While Li-Fi technology by itself is already incredible, having increased its data transfer speed that is comparable to fibre optics is what makes this new technology a major issue. Imagine having a light source that not only provides light but also networking capability at astonishing speeds. Or a home television that communicates with every other gadget around, including the ability to project your smart phone's display onto it for easy presentation to large groups. Or highways lighted by Li-Fi, providing motorists with real-time traffic and weather news as well as internet access to all devices inside. The possibilities seem endless, and the potential is much broader than at first thought. With all the support pouring in, it won't be long now before Li-Fi becomes an everyday technology.

Professor Haas has founded a company called *PureLIFI* to carry on work in the field of this new technology. The company's mission statement is: *"PureLiFi seeks to resolve the global struggle for diminishing wireless capacity by developing and delivering technology for secure, reliable, high speed communication networks that seamlessly integrate data and lighting utility infrastructures and significantly reduce energy consumption."*

Li-Fi signals are confined to narrowly-focused 'beams' that do not travel through walls. Moreover, LED lights are natural beam-formers, which makes it easier to create separate uplink and downlink channels, which essentially means more secure internet browsing, given that both channels have to be 'intercepted' if someone did manage to coerce their way into the same room as us. The LI-FI allows us to network via a desktop photosensitive unit that works in tandem with an off-the-shelf, unmodified light fixture. The desktop unit has infrared LEDs to communicate in the uplink channel. The LI-FI delivers a capacity of 5Mbps in the uplink and downlink channels, covering a range of up to three meters. It is worth noting here that it has been shown that speeds of upto 10Gbps has been proven with LI-FI too.

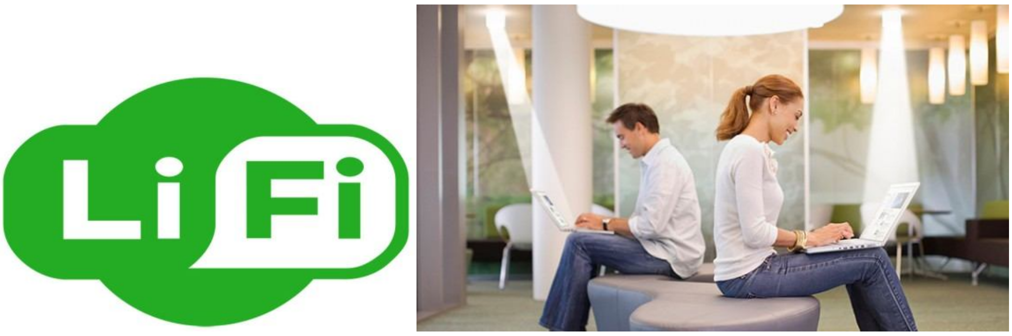

Fig.1 Demonstration of wireless Li-Fi Data transmission

II. THE LI-FI TECHNOLOGY

A. Overview of LI-FI Technology

LI-FI stands for "Light Fidelity". The technology uses an LED light bulb that varies in intensity faster than the human eye can follow to send data through illumination [3]. The light that zips data across the Internet's backbone used to stop a long way from the data's final destination but now it goes all the way to our homes. The LI-FI technology takes the last step and takes the light all the way to the computer or TV, projecting it through the air over the last few meters and only converting it to an electronic signal at the end.

Since LI-FI uses visible light instead of radio waves as the medium of communication, LI-FI is considered as the optical version of WI-FI. LI-FI is an important component of the Internet of Things (IoT), in which everything is connected to the internet. LED lights are used as access points in case of IoTs.[5] Such indoor optical wireless probably wouldn't replace Wi-Fi, but with a potential for data rates of 3 terabits per second and up, it could certainly find its uses. Wi-Fi, by contrast, tops out at about 7 Gb/s. And with light, there's no worry about sticking to a limited set of radio frequencies. If someone is in the optical window, he will have virtually unlimited bandwidth and unlicensed spectrum.

With the increasing use of Wi-Fi, the existing radio frequency is getting blocked slowly and simultaneously, there is an increasing number of people who want to connect to the internet. Wireless radio frequencies are getting higher, complexities are increasing and RF interferences continue to grow [6]. The LI-FI technology helps us to overcome these problems. LI-FI uses the Visible Light Communication (VLC). Visible light communication is a data communications medium which uses visible light between 400 and 800 THz (780–375 nm). VLC is a subset of optical wireless communications technologies. The technology uses fluorescent lamps (ordinary lamps, not special communications devices) to transmit signals at 10 kbit/s, or LEDs for up to 500 Mbit/s. Low rate data transmissions at 1 and 2 kilometres (0.6 and 1.2 mi) were demonstrated. Specially designed electronic devices generally containing a photodiode receive signals from light sources, although in some cases a cell phone camera or a digital camera will be sufficient.

The image sensor used in these devices is in fact an array of photodiodes (pixels) and in some applications its use may be preferred over a single photodiode. Such a sensor may provide either multi-channel communication (down to 1 pixel = 1 channel) or a spatial awareness of multiple light sources.

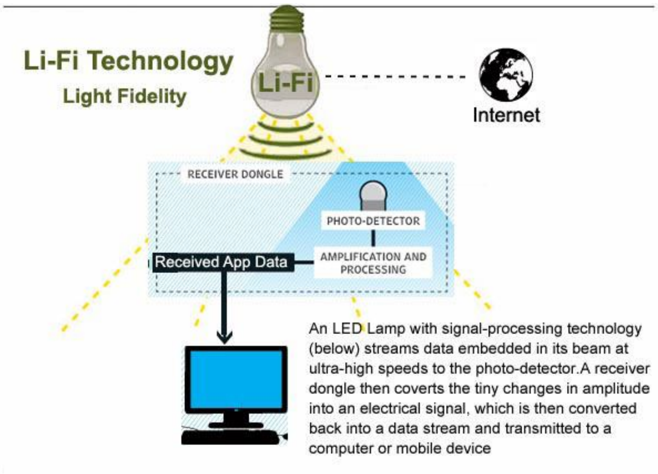

Fig.2 Li-Fi Technology

B. Working Principle of LI-FI

This technology is based on the Visible Light Communication which uses the visible light for data communication. In VLC, we use a source of illumination which can not only produce illumination but also send information using the same light. So we can say that VLC is illumination along with communication.

Now imagine a torch which we might use to send some sort of a signal, maybe morse code. We can do so manually by switching the torch ON and OFF repeatedly. But in this case, we may not be able to use the torch as an efficient source of illumination, so we cannot strictly consider it as VLC as per our definition. Now suppose we switch the torch ON and OFF very quickly using a computer system. In this case, due to the rapidity of the motion of switching between ON and OFF states, the torch appears to be ON constantly, and additionally, we also cannot "see" the data being transmitted. We would, of course, need a receiver.

Literally, any form of information that can be sent using a light signal that is visible to humans could be considered to be VLC, but by our definition we should be able to see the light, but cannot "see" the data. So although there seems to be no universally agreed definition of VLC, we can at least agree what we mean by VLC [7].

The sending of the data in the above mentioned manner has been made possible by the widespread use of the LED bulbs. These bulbs can be switched ON and OFF very rapidly thus permitting us to send the required data via light. The rapid adoption of LED light bulbs has created a massive opportunity for VLC. The problem of congestion of the radio spectrum utilized by Wi-Fi and cellular radio systems is also helping to create the market for VLC [7].

Fig.3 Li-Fi Bulb

C. Description of the Working Process

LI-FI uses white LED bulbs at the downlink transmitter. Normally, a constant current is applied across the LEDs to use them. But by varying the current very fast, the optical output can be made to vary at very high speeds. This is property used in a LI-FI setup. If the LED is ON, we transmit a digital 1 and if it is OFF, we transmit a digital 0. We can easily transmit data by switching the LEDs ON and OFF very rapidly. Thus, we need some LEDs and a controller which can code data into those LEDs in order to set up the system. Now, by varying the rate at which the LEDs flicker, we can encode the desired data and thus transmit the data very easily. We may also make certain improvements to the system by using an array of LEDs for parallel data transmission and or using a mixture of red, green and blue LEDs to alter the light's frequency, with each frequency encoding a different data channel. Theoretically, speeds of up to 10Gbps can be achieved using such a system.

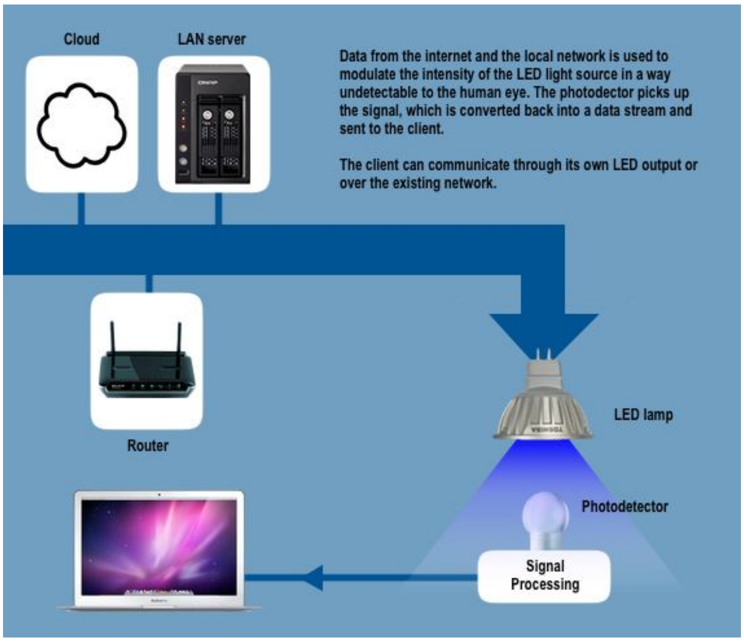

Fig. 4 Li-Fi and Internet

D. Modulation Techniques Used in LI-FI

Since LI-FI uses visible light for sending data, it is necessary to modulate the data into a signal which can be transmitted. These signals consist of light pulses. Some of the common modulation techniques used in LI-FI are discussed below:

(a) **OFDM:** Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional *single-carrier* modulation schemes in the same bandwidth.

(b) **OOK:** On-off keying (OOK) denotes the simplest form of amplitude-shift keying (ASK) modulation that represents digital data as the presence or absence of a carrier wave. In its simplest form, the presence of a carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero. Some more sophisticated schemes vary these durations to convey additional information. It is analogous to unipolar encoding line code. It is very easy to generate and decode but is not very optimal in terms of illumination control and data throughput.

(c) **PWM:** Pulse-width modulation (PWM) is a technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. Pulse Width Modulation transmits the data by encoding the data into the duration of the pulses. More than one bit of data can be conveyed within each pulse.

(d) **PPM:** Pulse-position modulation (PPM) is a form of signal modulation in which M message bits are encoded by transmitting a single pulse in one of possible required time-shifts. This is repeated every T seconds, such that the transmitted bit rate is bits per second. It is primarily useful for optical communications systems, where there tends to be little or no multipath interference.

(e) **SIM-OFDM:** Sub-carrier Index Modulation OFDM is a technique which adds an additional dimension to the two dimensional amplitude/phase modulation technique i.e., Amplitude Shift Keying (ASK) and Quadrature Amplitude Modulation (QAM). SIM uses the sub-carrier index to convey information to the receiver. Unlike the traditional OFDM technique, the SIM-OFDM technique splits the serial bit stream into two bit sub-streams of the same length.

E. New Digital Modulation Techniques for VLC and LI-FI

(a) As described in [8], the researchers have developed a new digital modulation technique which can be used in optical wireless communication using incoherent LEDs. The basic principle which is used in this technique is Intensity Modulation (IM). Depending on the variation in the intensity of light, the information is varied. As a consequence, the signal that modulates the LED strictly has to be positive and real valued (power can never be negative or complex). In contrast, higher order, capacity achieving modulation techniques used in radio frequency (RF) systems require bi-polar and complex signals. The use of higher order modulation techniques such as M-level quadrature amplitude modulation (M-QAM) is essential to achieve data rates that are close to the Shannon capacity limit. Therefore, the key question in optical wireless communications is how to map bi-polar and complex valued signals into uni-polar (positive) and real valued signals without offsetting the bit-error performance. The proposed technique achieves the first goal, i.e., the mapping of bi-polar to uni-polar signals, in a way that the it outperforms existing methods such as DCO-OFDM (direct current optical - orthogonal frequency division multiplexing) and ACO-OFDM (asymmetrically clipped optical – orthogonal frequency division multiplexing).

(b) As discussed in [9], the VLC and LI-FI systems which use the indoor lighting systems often require high average optical powers in order to provide adequate illumination. This can cause high-amplitude signals common in higher-order modulation schemes to be clipped by the peak power constraint of the LED. And lead to high signal distortion. The researchers have developed the *Hadamard Coded Modulation (HCM)* to achieve low error probabilities in LED-based VLC systems needing high average optical powers. This technique uses a fast *Walsh-Hadamard transform (FWHT)* to modulate the data as an alternative modulation technique to orthogonal frequency division multiplexing (OFDM). HCM achieves a better performance for high illumination levels because of its small peak to average power ratio (PAPR). The power efficiency of HCM can be improved by reducing the DC part of the transmitted signals without losing any information. The resulting so-called DC-reduced HCM (DCR-HCM) is well suited to environments requiring dimmer lighting as it transmits signals with lower peak amplitudes compared to HCM, which are thus subject to less nonlinear distortion. Interleaving can be applied to HCM to make the resulting signals more resistant against inter-symbol interference (ISI) in dispersive VLC links.

F. Use of OLEDs to Control Light to Boost LI-FI Bandwidth [9]

Getting better control of the light emitted from organic LEDs (OLEDs) could lead to faster links between the Internet and mobile devices, according to a Scottish researcher.

Anyone who has tried to use the Wi-Fi on a crowded airplane or a packed hotel conference room knows it can be maddeningly slow; there usually isn't enough bandwidth . Some researchers, notably Harold Haas, head of the mobile communications group at the University of Edinburgh, have proposed an alternate system—Li-Fi—which rapidly flickers room lighting to send signals. To get even more bandwidth out of such a system, it would help if there were an easy way to break the light up into different colors, using individual wavelengths to send different signals.

Ifor Samuel who heads the organic semiconductor optoelectronics group at the University of St. Andrews in Scotland described a method his team has developed for making patterned OLEDs for a Li-Fi system at the fall meeting of the Materials Research Society (MRS) in Boston in December. The idea, he explained to the MRS audience, is that the signal would be created by high-speed CMOS chips that alter the blue light coming from an array of small, nitride-based LEDs. OLEDs on top of the LEDs would act as a color conversion layer, multiplexing the signals into other colors.

Because OLEDs are malleable, it would be easy to imprint a diffraction grating into them. Such gratings could control the direction in which the signal was sent. That could be useful, in slower-speed communications where controlling direction is more desirable than a high data rate, to provide increased security or reduce power consumption.

To that end, his team has developed gratings with periods comparable in size to the wavelengths of visible light—about 300 to 400 nanometers. One method for making such gratings is called solvent-assisted *micromolding*, which would allow a grating to be built directly into an OLED. The polymer that makes up the OLED is coated with a solvent, and then pressed against a mold containing the grating pattern. The solvent causes the polymer to swell while it dissolves away a thin layer. Once the solvent dries, the now-patterned light-emitting polymer can be lifted away from the mold and used to construct an OLED.

Another technique they've used is *nano-imprint lithography*, which involves creating a stamp, pressing it into a photo-resistor, and then using ultraviolet light to expose the photoresist in particular areas, forming the grating.

One problem is that OLEDs emit a fairly broad spectrum of light, and different wavelengths will pass through the grating at different angles, forming a rainbow. To minimize this, the team searched for OLEDs with very narrow emission characteristics. OLEDS constructed with the rare earth element europium offer narrow emission, but they are not very efficient. The team has managed to raise the efficiency—the amount of input energy that comes out as light—to 4.3 percent. Another option is to add quantum dots, which have narrow emission spectra, as a color conversion layer in the OLED, Samuel says. The underlying OLED would cause the dots to emit the desired color of light.

Still the work could help make Li-Fi a success. The ability to control the output of OLEDs might have applications in medicine as well. Controlling the phase and the wavefront of light would allow researchers to adjust the depth to which it penetrates tissue, which could aid both in diagnostics and in treatments that, for example, use light to activate a drug.

III. ADVANTAGES OF LI-FI OVER WI-FI

- Li- Fi uses light rather than radio frequency signals so are intolerant to disturbances.
- VLC could be used safely in aircraft without affecting airlines signals.
- Integrated into medical devices and in hospitals as this technology doesn't deal with radio waves, so it can easily be used in all such places where Bluetooth, infrared, Wi-Fi and internet are broadly in use.
- Under water in sea Wi-Fi does not work at all but light can be used and hence undersea explorations are good to go now with much ease.
- There are billions of bulbs worldwide which just need to be replaced with LED's to transmit data.
- Security is a side benefit of using light for data transfer as it does not penetrate through walls.
- On highways for traffic control applications like where Cars can have LED based headlights, LED based backlights, and they can communicate with each other and prevent accidents.
- Using this Technology worldwide every street lamp would be a free data access point.
- The issues of the shortage of radio frequency bandwidth may be sorted out by Li-Fi.

IV. SCOPE AND CHALLENGES OF LI-FI TECHNOLOGY

Although there are a lot of advantages of LI-FI, there are still certain challenges which need to be overcome.

- LI-FI requires Line of Sight.
- If the apparatus is set up outdoors, it would need to deal with changing weather conditions.
- If the apparatus is set up indoors, one would not be able to shift the receiver.
- The problem of how the receiver will transmit back to the transmitter still persists.
- Light waves can easily be blocked and cannot penetrate thick walls like the radio waves can.
- We become dependent on the light source for internet access. If the light source malfunctions, we lose access to the internet.

TABLE-I

COMPARISON OF LI-FI AND WI-FI TECHNOLOGIES

	LI-FI	WI-FI
SPEED	1-3.5 Gbps	54-250 Mbps
RANGE	10 meters	20-100 meters
IEEE STANDARD	802.15.7	802.11b
SPECTRUM RANGE	10000 times than WI-FI	Radio spectrum range
NETWORK TOPOLOGY	Point-to-Point	Point-to-Multi Point
DATA TRANSFER MEDIUM	Use light as a carrier	Use radio spectrum
FREQUENCY BAND	100 times of THz	2.4 GHz

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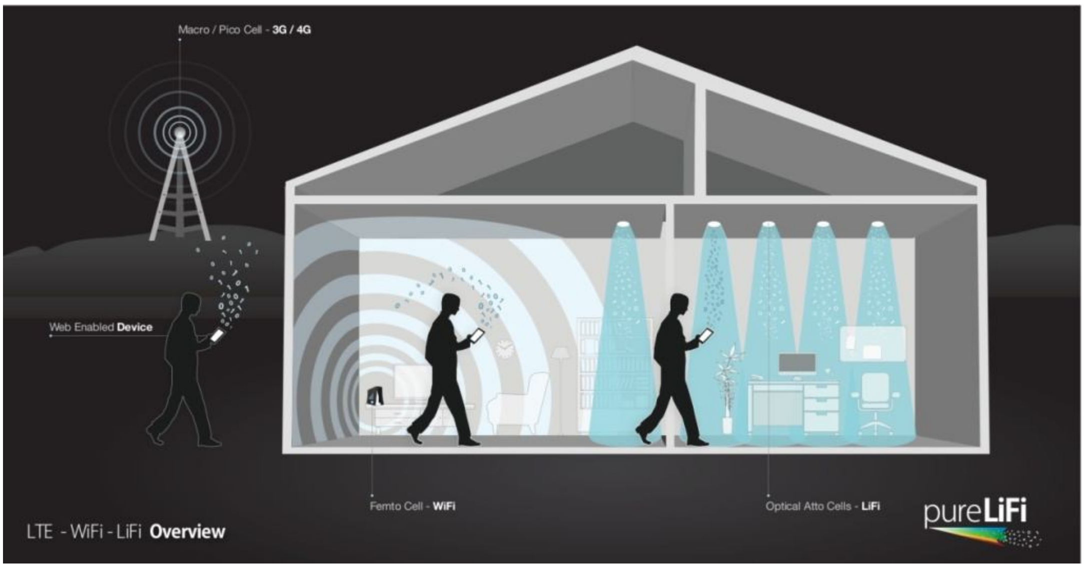

Fig. 5 Difference between LI-FI and WI-FI

TABLE-II

COMPARISON OF LI-FI AND WI-MAX TECHNOLOGIES

	LI-FI	WI-MAX
IEEE STANDARD	802.15.7	802.16a
SPEED	100 times faster than Wi-Max	100 times faster than WI-FI
RANGE	10 meters	30-100 meters
FREQUENCY BAND	100 times of THz	2-11 GHz
TECHNOLOGY USED	Light Fidelity	Microwave
NETWORK TOPOLOGY	Point-to-Point	Point-to-Multi Point
SPECTRUM RANGE	10000 times than WI-FI	10-66 GHz

V. APPLICATIONS OF LI-FI

The LI-FI system finds a variety of uses in many fields from access to internet by the general public using street lamps to auto-pilot cars which communicate through their headlights.
Moreover, in areas such as medicine and aircrafts where WI-FI cannot be used, LI-FI is an alternative which can provide faster data access rates. Some of the applications are discussed below:

(a) **Education System:** LI-FI can replace WI-FI in educational institutions and provide faster internet speeds. All the people can make use of the same speed as has been designated.

(b) **Medical Applications:** WI-FI is not allowed operation theaters because they can interfere with medical equipments. Moreover, their radiations pose risks for patients. LI-FI uses light and hence can be used in place of WI-FI.

(c) **Internet access in aircrafts:** The use of WI-FI is prohibited inside airplanes because they can interfere with the navigational systems of the plane. The users get access to very low speed internet at high rates. Thus, LI-FI is a safe alternative to WI-FI in aircrafts since it uses light and can provide faster internet access.

(d) **Underwater applications:** Underwater ROVs (Remotely Operated Vehicles) operate from large cables that supply their power and allow them to receive signals from their pilots above. But the tether used in ROVs is not long enough to allow them to explore larger areas. If their wires were replaced with light — say from a submerged, high powered lamp — then they would be much freer to explore. They could also use their headlamps to communicate with each other, processing data autonomously and sending their findings periodically back to the surface [11]. LI-FI can even work underwater where Wi-Fi fails completely, thereby throwing open endless opportunities for military operations.

(e) **Disaster Management:** In times of natural calamities such earthquakes, LI-FI can be used as a powerful means of communication since it uses light which unlike RF is not obstructed by walls or other such things.

(f) **Radio broadcast:** A large amount of power is required by radio masts in order to broadcast and this makes them quite inefficient. LEDs on the other hand require very low power to operate and this means that LI-FI also uses very little power.

VI. CONCLUSION AND FUTURE SCOPE

LI-FI is an emerging technology and hence it has vast potential. A lot of research can be conducted in this field. Already, a lot of scientists are involved in extensive research in this field. This technology, pioneered by Harald Haas, can become one of the major technologies in the near future. If this technology can be used efficiently, we might soon have something of the kind of WI-FI hotspots wherever a light bulb is available. It will be cleaner and greener and the future of mankind will be safe. As the amount of available bandwidth is limited, the airwaves are becoming increasingly clogged, making it more and more difficult to get a reliable, high-speed signal. The LI-FI technology can solve this crisis. Moreover, it will allow inter access in places such as operation theaters and aircrafts where internet access is usually not allowed. The future of LI-FI is GI-FI. GI-FI or *gigabit wireless* refers to wireless communication at a data rate of more than one billion bits (gigabit) per second. In 2008 researchers at the University of Melbourne demonstrated a transceiver integrated on a single integrated circuit (chip) that operated at 60 GHz on the CMOS process [12]. It will allow wireless transfer of audio and video data at up to 5 gigabits per second, ten times the current maximum wireless transfer rate, at one-tenth the cost. Researchers chose the 57–64 GHz unlicensed frequency band since the millimeter-wave range of the spectrum allowed high component on-chip integration as well as the integration of very small high gain arrays. The available 7 GHz of spectrum results in very high data rates, up to 5 gigabits per second to users within an indoor environment, usually within a range of 10 meters [12]. Some press reports called this "Gi-Fi"[13][14]. It was developed by Melbourne University-based laboratories of NICTA (National ICT Australia Limited), Australia's Information and Communications Technology Research Centre of Excellence.

Fig.6 Logo of Gi-Fi

It's estimated that the Li-Fi market will be worth more than $6 billion by 2018, according to analysis by MarketsandMarkets. Haas is well aware of the need for many more players in the space for it to be viable, and he's hoping Scotland will be central to this drive [15].

TABLE-III

COMPARATIVE STUDY OF LI-FI USAGE

Region	2012	2013	2014	2015	2016	2017	2018	CAGR% (2013-2018)
North America	29.58	92.23	203.91	418.36	824.50	1,343.09	1,940.42	83.9
Europe	24.89	80.67	180.80	374.43	743.68	1,228.60	1,769.48	85.4
APAC	33.09	106.80	233.35	470.03	905.34	1,442.79	1,992.12	79.5
ROW	8.52	27.41	60.49	118.22	217.55	337.24	436.01	73.9
Total	96.08	307.12	678.54	1,381.04	2,691.08	4,351.72	6,138.02	82.0

Source: MarketsandMarkets Analysis

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