VLC and LIFI as Future of Wireless Transmission

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Abstract— Visible Light Communication (VLC) is a free-space advanced Optical Wireless Communication (OWC) technology that uses visible light (375nm-780nm) to transmit data across distances. VLC is much preferable than existing wireless technologies like Wi-Fi, Wi-Max, Bluetooth etc. in terms of security, data rate and cost. Conventional Wireless technologies use radio waves and this radio wave based technology is limited in bandwidth, interfered with signals of different electronic equipment and easily accessed or hacked by unauthorised users. To overcome these limitations, we can use visible light for transmitting data which can be referred as "Data Transmission Through Illumination". VLC uses white Light Emitting Diodes (LED), which transmit information by flashing light at speeds undetectable to the human eye. VLC covers a huge area in terms of its application. Light-Fidelity (Li-Fi) is a new VLC based technology that is proposed in late 2011 by prof. Harald Haas, uses illumination for internet data communication and will be implemented in a near future. The advantage of Li-Fi over present wireless systems is that the electromagnetic spectrum bandwidth used for visible light communication (VLC) of Li-Fi is 10,000 times greater than for electromagnetic spectrum bandwidth of radio frequencies for present wireless systems. As VLC is a relatively new concept in the field of data transmission, a lot of research is being done so that VLC can be used for various commercial purposes. It is found that not a lot research has been on the development of Li-Fi, so the possibilities are wide open. If this concept can be implemented successfully, it will surely bring a revolution in wireless data transmission. This paper presents an overview of VLC and the design of Li-Fi circuit and analysis of its performance over traditional wireless systems.

Key words: Li-Fi, Visible Light Communication

I. INTRODUCTION

The concept of using visible light as a communication medium is not a new one. In 1880, Alexander Grahm Bell invented a device called Photophone, which transmits signal through beam of light. In this device, he implemented sunlight and used a modulation mechanism of vibrating mirror on a parabolic mirror as a receiver.

Optical wireless communication is an emerging optical communication technology in which unguided visible, infrared (IR), or ultraviolet (UV) light is used to carry a signal. OWC systems operating in the visible band (375–780 nm) are commonly referred to as VLC. VLC uses LEDs that transmit information by varying the intensity of light at a speed which human eye cannot follow. There is a simple technique of data transmission through LEDs. If the LED is ON, digital signal 1 (logic high) is transmitted and if the LED is OFF, digital signal 0 (logic low) is transmitted. In this way encoding of data by changing the rate of flickering of LED is the basic principle of VLC. A receiver (either photodiodes or a digital camera) will detect the light coming from the transmitter and will interpret the signal. When the receiver detects light, it is represented as a logic high and when it detects no light at all from the transmitter, it is represented as a logic low. The advantages of using LED are- long life expectancy, high tolerance to humidity, low power consumption, and minimal heat generation lighting. VLC using LEDs can achieve the data transmission rate up to 500Mbits/sec. One important characteristic of LEDs is that they are semiconductor devices capable of fast switching with the addition of appropriate electronics. That is, the visible light emitted by LEDs can be modulated and encoded with information for broadcasting.

In this context, we can say Li-Fi can turn out to be a major implementation of VLC. In simple words, it can be said Li-Fi can be referred as optical version of Wi-Fi which will be faster, cheaper and more secured than existing wireless technologies. Data transmission through Li-Fi can actually meet up the exponentially increasing wireless traffic demand.

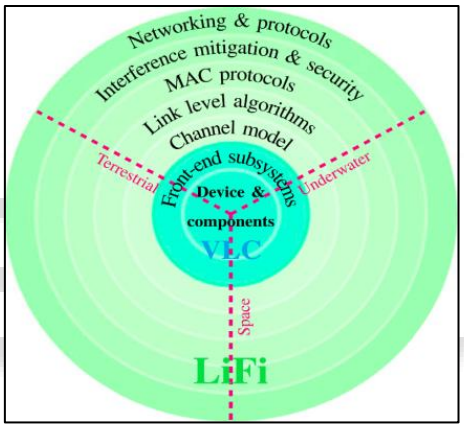

Fig. 1: Building Blocks of Li-Fi

II. DESIGN OF VLC SYSTEMS

A. Block Diagram of VLC System

In today's web-centric world, providing higher data transfer rates for multiple users over a secured network is a global concern. The internet access speed of the current wireless networks gets slow when multiple devices are connected. The present wireless networks use radio waves which is just a small part of the spectrum. As a result, the bandwidth available for internet access is limited. To improve the scenario Visible Light Communication has come into the picture. VLC operates in the visible region of the electromagnetic spectrum.

VLC has wide unlicensed bandwidth, enables communication in radio frequency (RF) sensitive environments, realizes energy-efficient data transmission, and has the potential to boost the capacity of wireless access networks through spatial reuse. It uses fast pulses of light to transmit signal wirelessly. VLC system consists of two main parts- 1) LED (Transmitter Section) which is used for both illumination and wireless transmission and 2) a silicon photodiode which shows good response to visible wavelength region serving as the receiving element.

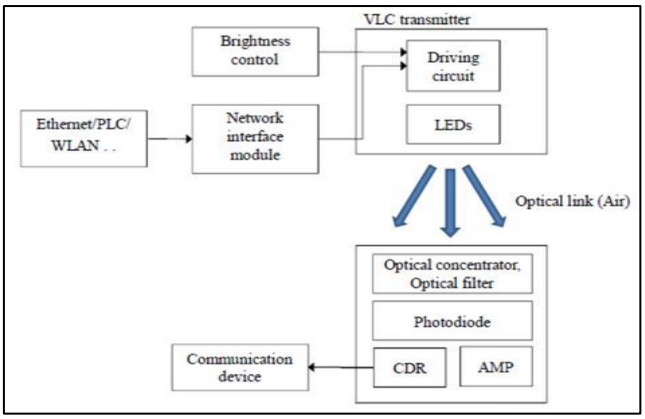

Fig. 2: Block Diagram of VLC System

B. Data Transmission through LED

The VLC system using LEDs as light sources has many distinctive features and high potential to be a ubiquitous (connected anytime anywhere) communication system. The purpose of the LEDs in the VLC system is to provide light to be used to transmit data. LEDs accomplish this by turning on which represents a logic 1 and turning off which represents a logic 0. In order to implement it successfully, the LEDs should be bright and capable of switching at a high frequency. By modulating the LED light with the data signal, the LED illumination can be used as a communication source. As the flickering rate is so fast, so the output in form of light appears constant and hence offering permanent connectivity. A data rate of greater than 100 Mbps is possible by using high speed LEDs with appropriate multiplexing techniques. VLC data rate can be increased by parallel data transmission using LED arrays where each LED transmits a different data stream. There are reasons to prefer LED as the light source in VLC while a lot of other illumination devices like fluorescent lamp, incandescent bulb etc. are available.

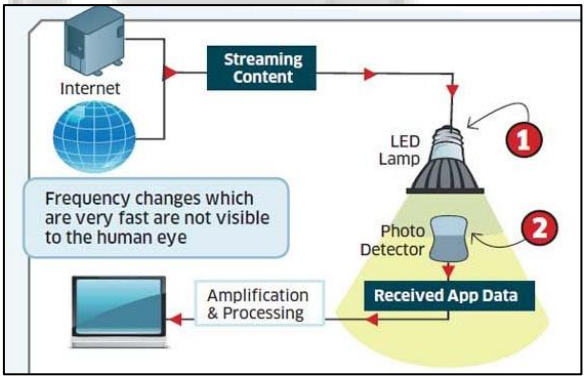

Fig. 3: Data Transmission through LED

In free space environment, the luminous intensity and transmitted optical power are the two basic characteristics of LED lights. The luminous intensity is used for expressing the brightness of an LED, while the transmitted optical power indicates the total energy radiated from an LED. The LED brightness and optical power will be one of the deciding criteria for the range of data communication in free space. Lastly, colour is important. Colour is not as important as the rest but choosing the right colour could affect how well the transmitter would perform with respect to the receiver. Transmitting a white light could result in issues, as the ambient lighting is also the same colour.

The alternative option is by means of red, green and blue (RGB) LEDs. The RGB solution is more preferable than phosphorous-based white LED to improve the data rate, since in the latter case, the slow response of the phosphors limit the modulation bandwidth whereas the power efficiency is reduced if combined with blue filter in order to reject the phosphorescent components. The RGB LEDs offer the possibility for wavelength division multiplexing (WDM) which further increases overall transmission capacity.

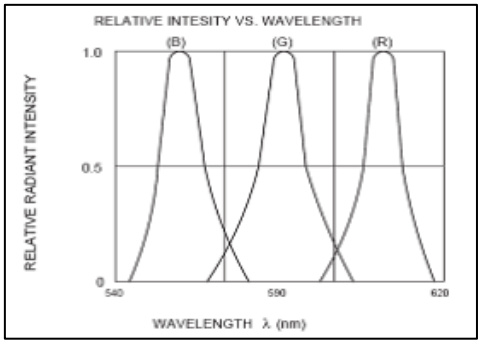

Fig. 4: RGB LED Spectrum

In order to choose the most optimal LEDs, the considerable important factors are shown in Table 1 below.

Category	Importance	Desirable	Undesirable
Brightness	1	> 10000 mcd	< 1000 mcd
Frequency Speed	1	> 1 MHz	< 100 KHz
Price (Unit Cost)	3	Less than $0.25	More than $1
Color	2		

Table 1: Important Requirements for selection of LED

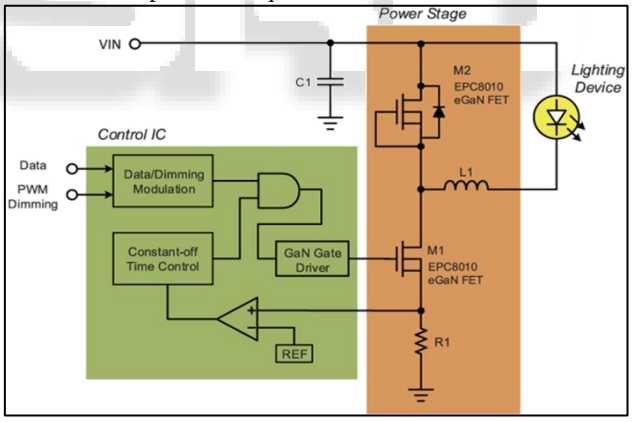

Fig. 5: Proposed VLC LED Driver Circuit

The proposed VLC LED driver is shown in Fig. 5. To solve the problem of low data rate, GaN power device has been utilized to replace the traditional silicon power device. Because of its high switching speed and low switching loss, the proposed driver achieves 10-MHz switching frequency, increasing the bandwidth of data transmission accordingly. The proposed structure includes diode-connected GaN power transistor as a rectifier. Instead of the traditional ultrafast recovery diode, the diode-connected GaN power transistor M2 featuring zero large reverse recovery charge has been used to increase the data rate and efficiency of the LED driver, leading to a system's efficiency of 80.8% at 1-Mb/s data rate. The M2 is OFF when the M1 is ON. Conversely, the M2 is ON while the M1 is OFF.

The constant off-time controlled loop is used to regulate the LED current stably for wide input voltage. In addition, there is a data/dimming modulation circuit to combine the PPM (Pulse Position Modulation) data with PWM (Pulse Width Modulation) diming signal for VLC and dimming applications. The predetermined pulse width is used to decide the dimming level in a modulation period, while at the same time the pulse position is used to determine if bit 0 or bit 1 happens. The data of bit 0 is represented by the pulse at leading edge of a modulation period. On the other hand, bit 1 is represented by the pulse at trailing edge. The gate driver of control IC with independent push and pull paths is used to prevent overvoltage or overcurrent damage on GaN power transistor. The overvoltage or overcurrent damage is due to high di/dt and dv/dt coming from the parasitic elements of transistor during switching interval.

C. *Photodiode Receiver Circuit*

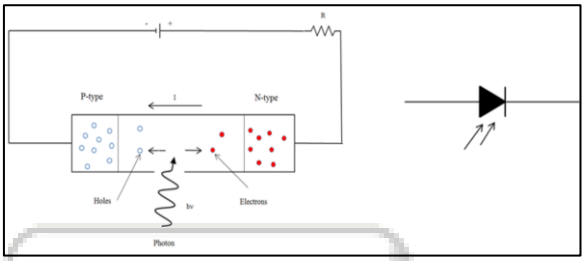

Fig. 6: Basic Biasing Arrangement and Circuit Symbol of Photodiode

A photodiode converts the incident light into the current. It works on the principle called Photo-conduction, whereas LED works on the principle of electro-luminance. The photodiode is a type of photodetector which converts the light to either current or voltage. Photovoltaic mode, also called as zero bias operation, occurs when no external voltage is given to the photodiode. The photo-current generated is fixed and also linearly dependent on the incident radiation level. In Photoconductive mode the diode is reverse biased (cathode positive and anode negative), which increases the depletion region width, reducing the junction capacitance. This results in faster response time. However, in this mode the effects of noise and dark current will be more.

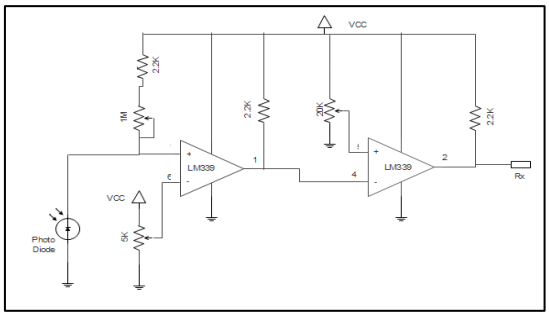

Fig. 7: Proposed Photodiode Receiver Circuit

Fig. 7 shows that Photo diode receiver circuit for data transmission. In Photo Diode Receiver circuit, LM339 is used as a comparator. LM339 had high gain and wide bandwidth. It is an open collector comparator. If the light illumination varies photo diode current also changes. In receiver have two stages. First stage photo detector current converts to voltage level. In second stage inverting amplifier inverts once to get original information.

D. *General System Architecture of VLC*

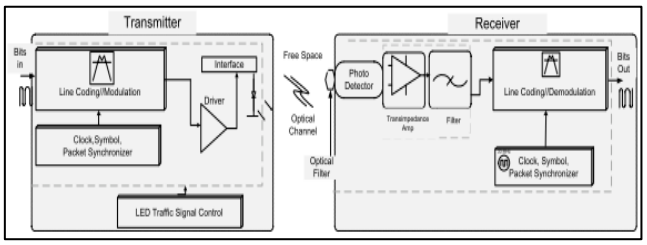

Fig. 8: Overall Architecture of a VLC System

The circuit diagram in Fig. 8 represents the overall system architecture of VLC. Devices such as laptop, mobile phones can be used for transmitting and receiving information signal. The transmitter part consists a modulator and a pulse shaper to switch the LEDs at the rate of data transmission. Because of high rate switching capabilities of LEDs, it is possible to extend its usage to data transfer in wireless communications systems. These dual properties make them modulation is intensity modulation (IM), in which the desired waveform is modulated onto the instantaneous power of the carrier. The optical driver is necessary to drive the emitter with sufficient power to obtain long distance communication. The optical signal is then detected and received by VLC receiving system front-end amplifier, whose gain is continuously adapted in order to reduce the effect of ambient and other background light sources. The most practical down conversion technique is direct detection (DD). The modulation method used must offer high robustness to background light. Similarly, the detector is characterized by the parameter, field of view (FOV). For a larger service area, a receiver with a wider FOV is preferable. However, a wider FOV leads to performance degradation because all received signals, including mostly undesired signals, are processed simultaneously. In addition the system will also need the protocol management unit and data/clock recovery block for the synchronization of received packets corresponding to the received power level. The data rate in VLC systems is limited by the switching speed of LEDs transmitter.

This dual function is based on the fast switching of LEDs and the modulation of the visible light waves for wireless communications. This system consists of a light source which emits light and data simultaneously. Data is sent between two or more terminals; in each terminal there is a receiver and an emitter. The emitter transmits data into free space, to be received by a receiver from a different terminal. At first, we modulate information into the luminance and then transmit the information by blinking LED. Next, we receive the information by capturing the blinking transmitter. A photodiode is generally applied as a light sensor. The VLC system, in fact, needs a complex channel characterization, modulation and coding schemes.

III. DESIGN AND WORKING PROCEDURE OF LI-FI

A. *Block Diagram of LI-FI*

Li-Fi is "A potential solution to the global wireless spectrum shortage". Li-Fi is a visible light communication technology, developed by the team of scientists including professor Haas at the University of Edinburg and deals with transfer of data through illumination by taking fiber out of optics by sending data through a LED light bulb. If this

technology is put into full-fledged practical use, every LED can be used like a Wi-Fi hotspot to transmit wireless data.

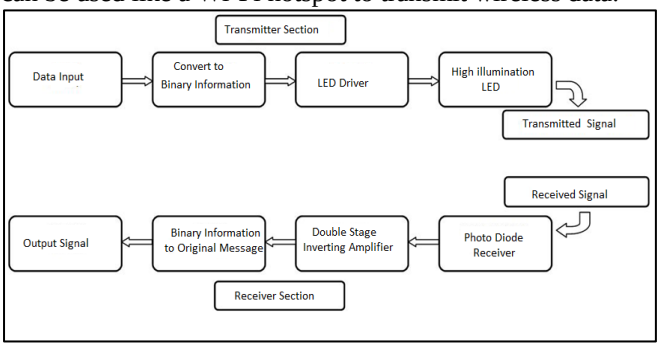

Fig. 9: Block Diagram of Li-Fi System

Fig. 9 shows the block diagram of Li-Fi design. In transmitter section the data input is converting to binary information and LED driver circuit drives the high illumination LED. In receiver section side, the photo detector receives the original information and getting amplified by the inverting amplifier. The binary information is converted to the Original data message and given to the output signal. This model should effectively be able to transmit data from one device to another using LED's, thereby establishing a LI-FI network in a localized environment.

Li-Fi is ideal for high density wireless data coverage in confined areas where there are no obstacles. The LI-FI is safer, cleaner and greener technology which is more efficient too for the future generations to create more value added services.

B. Constructions of Li-Fi

The Li-Fi emitter System consists of 4 primary sub-assemblies:

- Bulb (LED)
- RF power amplifier circuit (PA)
- Printed circuit board (PCB)
- Enclosure

The PCB controls the electrical inputs and outputs of the lamp and houses the microcontroller used to manage different lamp functions. An RF (radio-frequency) signal is generated by the solid-state PA and is guided into an electric field about the bulb. The high concentration of energy in the electric field vaporizes the contents of the bulb to a plasma state at the bulb's centre; this controlled plasma generates an intense source of light. All of these subassemblies are contained in an aluminium enclosure.

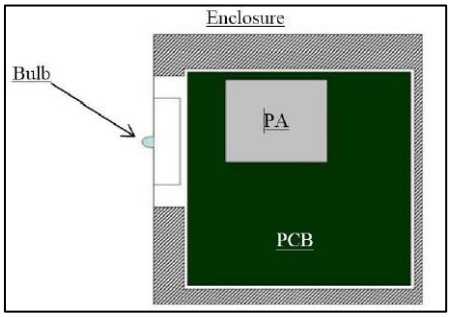

Fig. 10: Block diagram of Li-Fi sub-assemblies

At the central part of Li-Fi is the bulb sub-assembly where a sealed bulb is embedded in a dielectric material. This design is more reliable than conventional light sources that insert degradable electrodes into the bulb. The dielectric material serves two purposes; first as a waveguide for the RF energy transmitted by the PA and second as an electric field concentrator that focuses energy in the bulb. 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.

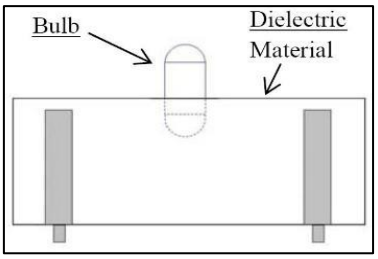

Fig. 11: Bulb Sub-Assembly

C. Circuit Design of Li-Fi

The Li-Fi system consists of mainly two parts, the transmitter and the receiver. The transmitter part modulates the input signal with the required time period and transmits the data in the form of 1‟s and 0‟s using a LED bulb. These 1's and 0's are nothing but the flashes of the bulb. The receiver part catches these flashes using a photodiode and amplifies the signal and presents the output.

1) Transmitter Circuit

A 4X3 matrix keypad is taken that transmits numeric data from 0-9,*, #. It is interfaced with keypad driver IC 91214 b which is also known as DTMF (Dual-tone-multi-frequency) tone generator. Each key has a different frequency that is made up of two frequencies one from low tone group from 697 Hz-941 Hz, and the other from high tone group from 1209 Hz-1477 Hz. The tone generated is a DTMF frequency which is converted from digital to analog form by this IC. The output of this IC is fed to the op amp 741c to prevent signal losses. This IC is further connected to push pull amplifiers. A two way switch is provided to select keypad or a microphone. If the switch is on, microphone is selected else the keypad is selected. A variable resistance is provided to adjust the amplification and sound of the speaker. At the output of the transistors a torch is connected to convert analog signals into light form. While on the other hand microphone converts sound to analog form.

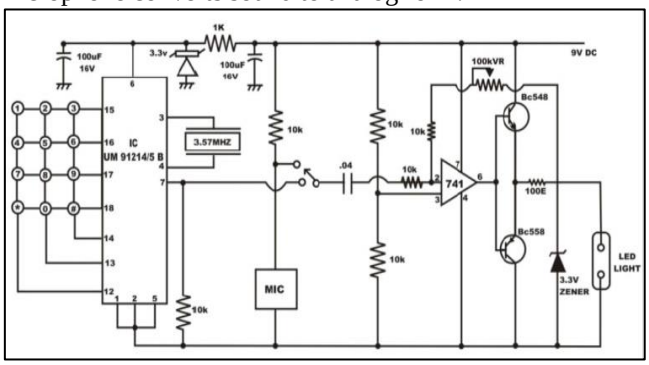

Fig. 12: Transmitter Circuit

2) Receiver Circuit

The signal received in the light form is detected by the photodiode which converts the light signal to analog form. The photodiode is connected to the op-amp to reduce distortion losses. The output of the op-amp is connected to the IC MT8870 which a DTMF receiver. Also the output of op-amp is connected to the speaker to convert output analog signal to sound form. IC MT 8870 converts the analog

signal to digital form and understands the frequency received and converts it into 4-bit BCD form for displaying on 16x2 LCD. Microcontroller ATMEGA8L is used to interface LCD and DTMF receiver. ATMEGA8L takes the BCD input from the DTMF receiver and displays it on the 16x2 LCD. IC 7805 is used, which is a voltage regulator that steps down 8V supply to 5V for the working of circuit.

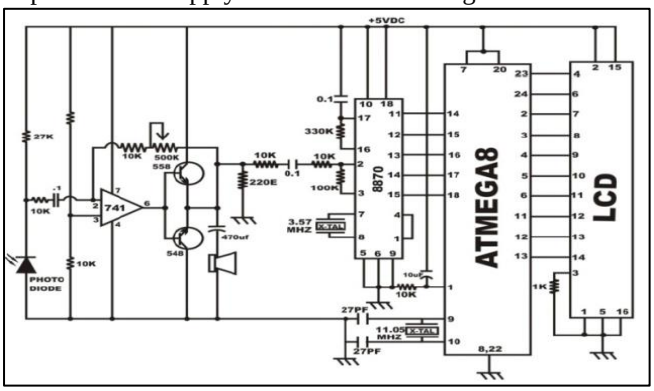

Fig. 13: Receiver Circuit

The LI-FI technology uses the light as their carrier medium for transmitting the data so that the space requirement is less. The System is controlled with Micro-controller that has been implemented using a AVR ATmega16 and thus reducing the time wasted by the system. In this presented prototype, LI-FI brings the data transfer rate to a great extent.

D. Working Procedure of Li-Fi

Data is transmitted in bi-directional way. This concept was implemented by using LEDs bulb as data source from data source computer after converting to stream of ones and zeros data at modem or transceiver. This light data was detected by the light sensor screen at in front of light source bulb and converted to original data and displayed move at user computer. Encoding of data by changing the rate of flickering of LED is the basic principle of Li-Fi. Li-fi uses two main section, transmitter and receiver, for reliable data transfer. Both transmitter and receiver use semiconductor diode, LEDs and photodetector diode respectively. A transmitter at one end of the communication link sends a modulated signal and then a receiver at the other end detects the modulated light, converts it back to Zeros and Ones, and decodes the digital messages and data.

1) Transmitter Section of Li-Fi

- Source Computer > Data Reading Module > Data
- Conversion Module > Transmitter Module

a) 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. It uses data converters and microcontroller unit as encoder or modulator.

b) Transmitter Module – generates the corresponding on off pattern for the LEDs by the help of driver circuit.

2) Receiver Section of Li-Fi

- Destination Computer>Receiver Module >Data
- Interpretation Module > Data Display (GUI)

a) 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 and boosts this received signal by using amplifier.

b) Data Interpretation Module – detects and decodes or converts data into the original digital signal format with the help of microcontroller unit. If encryption was done at transmitter, it also performs decryption.

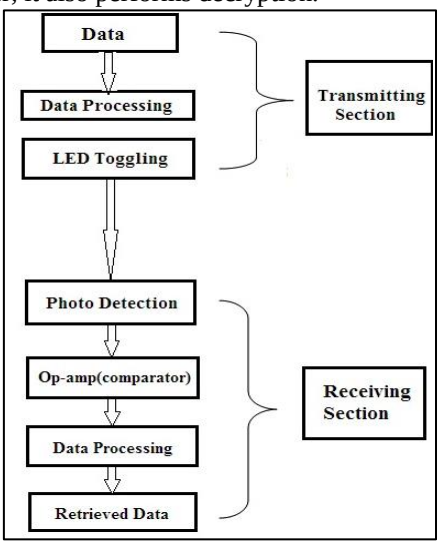

Fig. 14: Flowchart of Li-Fi Operation

IV. Application and Future Scope of Li-Fi

A. Application of VLC and Li-Fi

1) Health technologies

For no longer time now medical technology would lag behind the rest of the wireless world. Till now operating rooms did not allowed Wi-Fi over radiation concerns, and there was also a whole lack of dedicated spectrum. Also if Wi-Fi is implemented in many hospitals, interference from cell phones and computers can block signals from monitoring equipment. Thus Li-Fi solves both problems: lights are not only allowed in operating rooms, but tend to be the most intended fixtures in the room.

2) Airlines

Airline Wi-Fi wants captive audience to pay for the "service" of dial up on the plane. And also they are very expensive. Passengers will soon be offered a "high-speed like" connection on some airlines. Li-Fi could easily introduce that sort of speed to each passengers reading light. It would be interruption free to and from other wireless signals on the board.

3) Power Plants

Wi-Fi and many other radiation or radio waves are bad for sensitive areas like those of power plants especially the atomic power plants. Nuclear power plants need fast, inter-connected data systems to monitor things like demand, grid integrity and core temperature. Proper monitoring can save huge benefits in terms of energy and economy obviously. Li-Fi could offer safe, abundant connectivity for all areas of these sensitive locations. This would be cost effective as well as would improve upon the current implementations solutions.

4) Under sea working

Underwater Rovers, also called toys of treasure seekers, operate from long cables that supply their power and allow them to receive signals from their pilots above. ROVs work efficiently until unless they got stuck somewhere or if the search area is huge. If made wireless and replaced with light — say from a submerged, high-powered lamp— then they would be free to explore more. They can also communicate with each other via headlamps, process intermediate data

autonomously and periodically refer back to the surface, all the while obtaining their next batch of orders from the source.

5) Information Delegation

If any town is hit by earthquake and an average resident is not aware of such disastrous situations and precautions to be taken. Until they pass under a street light, they won't be aware of the emergency broadcasts. It should be remembered with Li-Fi, we're online only till its light. Subway stations and tunnels, common dead zones for most emergency communications, pose no obstruction and could opt to provide cheap high speed web access to every street corner.

6) Various Other Areas

Can be used effectively in the places where it is difficult to lay the optical fiber cable. In operation theatres Li-Fi can be used for modern medical instruments. In traffic signals Li-Fi can be used to communicate with the LED lights of the cars. All of the street lamps can be transferred to Li-Fi lamps to transfer data. In aircraft Li-Fi can be used for data transmission. It can be used in petroleum or chemical as well as in nuclear plants where other transmission or frequencies could be hazardous.

7) Learning

The classroom can be far more interactive with real-time interconnectivity between 500 devices.

8) GPS usage

Satellite navigation has been one of the most important technological advances of the last 50 years. No matter how good the systems get, they still don't work where we spend the majority of our time: the great indoors. Tools have been devised that cleverly use Wi-Fi triangulation and "hybrid" GPS (say, GPS coordinates combined with sensor data from a compass, pedometer, and accelerometer), but these are inaccurate and generally unreliable. A company called Byte Light is trying to change this situation with a system that uses LED lighting to provide devices with accurate location data. Byte Light's indoor location system works by controlling the pulses of LEDs so they work in a certain pattern. This pattern is not detectable to the human eye (it's working in the range of a hundreds of hertz), but can be picked up by the camera in a smartphone or tablet. Using the data gleaned from the LED modulation, the device works with an app and performs client-side calculations to figure out where it is within the structure. Wi-Fi isn't needed so networking is not a problem, and the calculations are performed on the device, so everything happens quickly.

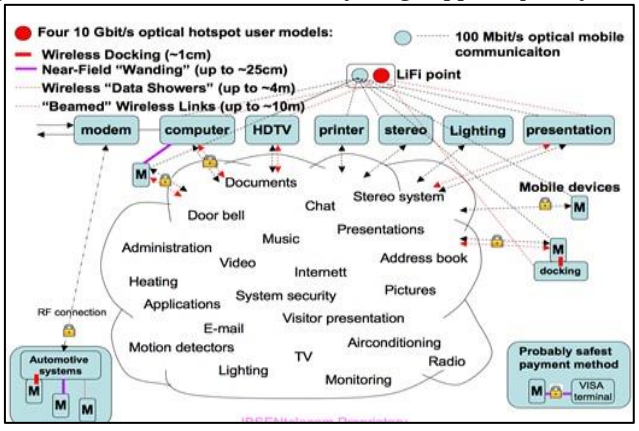

Fig. 15: Applications of VLC and Li-Fi

V. Conclusion

The issues of shortage of radio frequency can be tackled easily with only limitation being that it works in direct line of sight of light. There are no dead ends to technology and science. Now both light and radio waves can be used simultaneously to transfer data and signals. The use of li-fi technology gives a very golden opportunity to replace or to give alternative to the radio based wireless technologies. As the number of people and the access of internet is increasing on such a large scale accessing internet through wi-fi will soon be insufficient as the usage is increasing but the bandwidth remains the same. As network traffic will increase it will result in lowering the speed of accessing the internet thus more increasing prices. Li-Fi is the upcoming and on growing technology acting as competent for various other developing and already invented technologies. Hence the future applications of the Li-Fi can be predicted and extended to different platforms and various walks of human life.

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