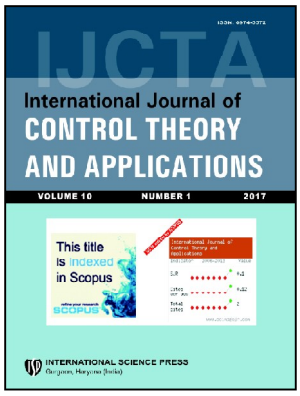

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Design and Implementation of LI-FI Prototype for Interference-Free Communication

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Abstract: **O**ver the past two decades, wireless communication is getting immensely popular all over the world to perform day to day activities. It has transformed the way people shop, educate themselves and transact online. Though mobile devices are equipped with friendly user interface, processing capability and adequate memory, a high speed network with sufficient bandwidth is a major concern. Recently, **V**isible **L**ight **C**ommunication (VLC) is identified as an interference free communication with high bandwidth. Visible light can be used not only to illuminate the room but also to provide the wireless data connectivity. **L**ight-**F**idelity (Li-Fi), a VLC concept, uses **L**ight **E**mitting **D**iode (LED) bulbs for sending signals and produces constant data transfer. By sending signals through LED at high speed, output can be achieved at high speed. Our LI-Fi prototype visualizes the future to be one where data transmission employs the use of eco-friendly LEDs that serve a dual purpose of lighting as well as bi-directional data transmission simultaneously. LEDs are the primary advantage of this technology as they are not expensive and adding Li-Fi will only add to their capabilities by providing a new purpose to them. Li-Fi serves as an alternative to Wi-Fi in term of less expensive and more traffic handling capacity. It will also reduce the use of Wi-Fi thus in turn reducing the radio waves that are slightly harmful to living beings.

Keywords: Li-Fi; LED; Optical wireless communication; VLC

I. INTRODUCTION

Communication is the basis for information sharing and defined as the exchange of information. Since the very beginning of time, humans have always felt the need to communicate with each other in order to share their experiences and thoughts. Speech is a good form of communication but is not effective for communication over distances. To communicate over distances, writing was used but it was not very effective as it required a lot of time to send and receive messages. The first form of quick communication was the basic wired communication in the 19th century that employed the Morse code to transmit alphanumeric data in the form of electrical signals. The telephone followed this, which allowed people to communicate over electrical wires called telephone lines. The telephone made it possible to communicate over distances using speech in real time. Further the invention of the radio was in the 20th century in which a message can be broadcasted to many people at the same time over a

distance. This marked the introduction of wireless communication. Radios work on radio waves and can travel over long distances. Since they travel at the speed of light, they are much faster than telephone lines. The end of the 20th century marked the birth of the **W**orld-**W**ide-**W**eb (WWW), which is a collection of interlinked hypertext documents accessed via the Internet that is a network of networks. At the same time Wi-Fi was an emerging technology that used radio waves to connect devices to a wired network within a specific region. Wi-Fi allowed devices to connect to the Internet wirelessly. With the rapid increase in population, the number of devices accessing the Internet is growing tremendously. To go about our daily lives, we are constantly reliant on the use of data transmission technologies to send and receive information. The currently available fixed bandwidth of Wi-Fi is rapidly being depleted as the networks are restricted to just a small part of the spectrum for data transmission. Wi-Fi technology uses radio waves, just a small part of the electromagnetic spectrum, and operates at frequencies ranging from 2.4 - 5 GHz with a limited bandwidth of up to 300 Mbps. Wi-Fi also faces vulnerability issues because it can penetrate through walls and hence can be targeted by hackers. Li-Fi technology aims to change this by providing more bandwidth that leads to higher transmission speed, and it does all of this at a cheaper cost. Harald Hass in 2011 introduced Li-Fi term in his demonstration of a Li-Fi prototype, see [1]. Li-Fi is based on the idea of transferring data by the use of the visible light spectrum. In this concept a LED is a *p-n* junction diode that emits visible light when a current is passed through it. Switching ON and OFF the LEDs at a very rapid rate can represent strings of 0's and 1's, here the OFF state represents a 0 and the ON state represents a 1. Further the variations in the flicker rate of LED can be used to encode data. The main advantage of using LEDs is that their intensity can be changed at such a rapid rate that the human eye can not able to notice this change. This means that every LED light source can act as a data transmission hub. This method of using rapid pulses of light to transmit information wirelessly is technically referred to as VLC, see Renzo et al. [2]. Jackson [3] highlighted the role of various Researchers of the University of Strathclyde in Scotland for bringing high-speed, ubiquitous, Li-Fi technology to market.

We observed that not much work has been done on the Li-Fi. However this technology can be the future technology. The objective of this paper is to give the details of the Li-Fi and propose a Li-Fi model. The rest of this paper is organised in the following way. Section II illustrates the working of Li-Fi. In Section III we give the significance of the Li-Fi over Wi-Fi technology. Further the construction of Li-Fi model is given in Section IV. Prototypes of the proposed Li-Fi model are reported in Section V. Some recent work and applications of the Li-Fi are presented in Section VI. Finally a conclusion and some future directions are discussed in Section VII.

II. WORKING OF LI-FI

Li-Fi is based on the principle of transmission of data using Optical Wireless Communication (OWC). It uses LED bulbs to transmit data. The specialty of LED bulbs is that they can be switched ON and OFF very quickly. The logic used is that 1 is transmitted when the LED is ON and 0 is transmitted when the LED is OFF. By turning the LED ON and OFF rapidly we can transmit data in the form of binary string. In Figure 1 we illustrate how a typical Li-Fi setup could be used to connect a device to the internet using visible light. In order for a signal to be transmitted there is an LED at one end which acts as a transmitter and a Light Dependent Resistor (LDR) or photodiode at the other end acting as a receiver. The data to be sent is first amplified and then sent to the LEDs. The LEDs transmit the signal by blinking at high speed. This flickering light signal is intercepted by an LDR or photodiode which converts the light energy back into the data signal. This data signal is then amplified and displayed on the receiver side.

III. SIGNIFICANCE OF LI-FI

Li-Fi technology is a light based wireless technology with great significance because it aims to replace the current wireless networks (Wi-Fi) as it is a superior technology. The frequency bandwidth offered by Li-Fi is about 300THz whereas that of Wi-Fi is only about 300GHz. This difference in bandwidth is something that can

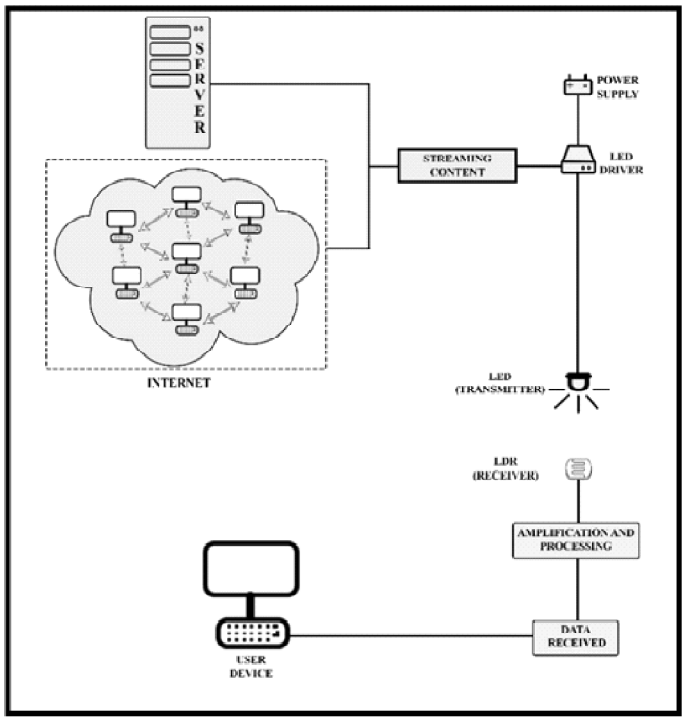

Figure 1: Working of Li-Fi

relieve the load due to which current Wi-Fi networks suffer. Li-Fi is advantageous over Wi-Fi as it can also be used in areas that are sensitive to electromagnetic waves. For an instance nuclear power plants, hospitals, aeroplanes etc. are some such places where Wi-Fi cannot be used due to the interfering nature of radio waves. Li-Fi on the other hand operates in the visible light spectrum and hence is safe to use in these places. Although Li-Fi sources would have to be kept on to transmit data, the bulbs could be dimmed to the point that they were not visible to humans and yet still functional [4]. Although direct line of sight is not necessary for Li-Fi to transmit a signal; light reflected off the walls can achieve 70 Mbit/s, see Gilliard et al. [5]. Li-Fi can also be considered as the optical version of Wi-Fi and an important component of the **I**nternet of **T**hings (IoT), in which everything is connected to the Internet. Huang et al. [6] integrated the Li-Fi technology and energy harvesting wireless sensor technologies to address the short-of-energy problem in the designing of next generation high performance buildings.

Li-Fi is also capable of removing the restrictions such as the security issues that Wi-Fi has. It has a strong security advantage because it cannot be accessed if the light does not reach the receiver. This means that Li-Fi can find applications in military areas where high security is required but Wi-Fi communication can be subject to being hacked. The fact is the Li-Fi system sends data using light rather than radio waves with 'Li-Flame' prototype that knows which light source is supposed to be receiving data from [7]. Light-emitting diodes can be switched ON and OFF faster than the human eye can detect, even though it is in fact 'flickering' [8]. Further as the visible light cannot penetrate through opaque surfaces such as, walls, solid-structures, etc. whereas Wi-Fi can be intercepted by someone present on the other side of the wall. The main advantage of Li-Fi is that it uses LEDs which are much cheaper to transmit data as compared to Wi-Fi Routers which consume more energy. In Table 1, we present the various aspects of Li-Fi and Wi-Fi in terms of different parameters such as speed, spectrum, bandwidth, security, data density, ecological impact, device-to-device connectivity, latency, obstacle interference and cost. This table exhibits how Li-Fi is a better technology over Wi-Fi:

Table I
Comparison of Li-Fi and Wi-Fi

Technology	*Li-Fi*	*Wi-Fi*
Speed	Very High	High
Spectrum	10,000 times wider than Wi-Fi	Narrow Spectrum
Bandwidth	High due to wide spectrum	Low
Security	Highly secure as light does not penetrate through walls	Less secure as it can be intercepted by anyone
Data density	Very High	High
Ecological impact	None	Low
Device-to-device connectivity	High	High
Latency	In the order of microseconds	In the order of milliseconds
Obstacle interference	High	Low
Cost	Low	High

IV. CONSTRUCTION OF LI-FI

The section deals with the construction of Li-Fi setup which consists of two circuits on each board, transmitter and receiver, see Figure 2. Note that both the circuits operate at 9V (1A) DC. Here a step-down (220V-9V) transformer that uses two capacitors, two diodes as a rectifier and IC 7805 to reduce the current to 1A, provides the input voltage. We prepared both the circuits and the details are discussed in the next sections.

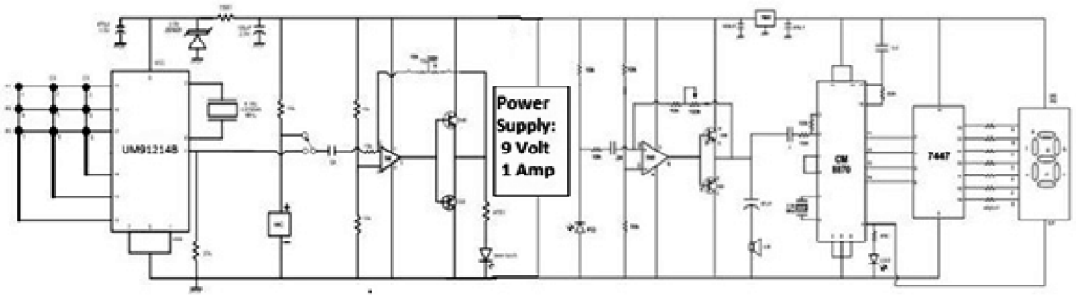

Figure 2: Li-Fi Circuit

(A) Transmitter

The transmitter circuit is divided into two parts: Analog Data and Digital Data. A two-way switch operates both the parts, one at a time. In Analog Data Transmission**,** the analog data signal is created by a piezoelectric mic that converts sound signal into electric signal. This electrical signal is further modulated with the help of 741 IC, and transmitted with the push and pull mechanism of two transistors. In Digital Data Transmission, decimal numbers are converted into binary using anode matrix keypad system with the help of UM91214B IC (Encoder) and a Crystal oscillator (3.5792 MHz). Both these types of signals are modulated and sent by the help of 741 IC and push and pull mechanism of two transistors to the LEDs to be transmitted.

(B) Receiver

In this part, a photo diode is used to determine the specific changes in the incoming photons, which are transmitted through the LEDs in the transmitter. A 741 IC is used to de modulated the signal received by the photo diode and send the signal for further processing. Both the analog and digital signals pass through the loud speaker. If the

data signal is digital, it produces a periodic tone based on the keypad number, and the data is then passed through CM8870 IC, which is a decoder. This decoder is used to decode the data signal into BCD format. This BCD data signal is then further passed to a 7447 IC that is a BCD to 7-Segment converter. The data signal from 7447 IC is passed on to a 7-segment display, which displays the data signal in decimal number format. If the data signal is analog, it produces audible sound through the loud speaker. It is to be noticed that the CM8870 IC does not accept the analog signal as it only accepts digital signals.

V. LI-FI PROTOTYPE

In this project while looking for advancements in LASER communication, certain problems such as point-to-point communication, direct line of sight, etc. were found. This was the motivating factor for the exploration of OWC technology and thereby Li-Fi. This included the construction of a proposed prototype (version 1.0). Further research led to the development of a new and advanced version of the first prototype. The proposed prototype of Li-Fi was based on a Simplex data communication where one device acted as a transmitter and the other as a receiver. We present this prototype in Figure 3, (a) is the transmitter and (b) is the receiver. The downside to this system is that data communication between the two devices was unidirectional. We then modified this version; details are given in the next section.

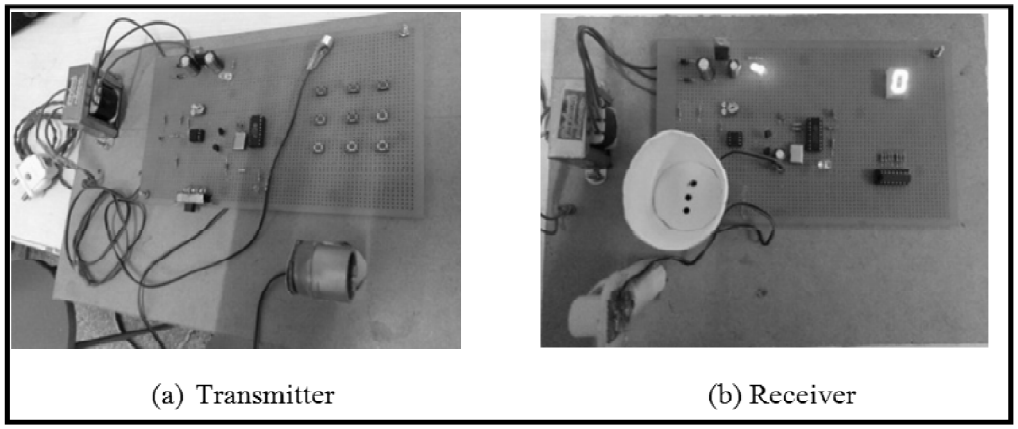

Figure 3: Li-Fi Prototype Version 1.0

(A) Li-Fi Prototype Version 2.0

In this new version of the proposed prototype, the circuit is modified and both the transmitter and the receiver are added onto a single board thereby producing Full Duplex communication. The advantage this provides is that it is able to achieve bidirectional communication between two devices thereby overcoming the disadvantages faced in the previous version of proposed prototype. Therefore now we were able to send and receive signals simultaneously. Figure 4 represent the Li-Fi prototype version 2.0.

Next we performed an experiment on the proposed prototype, and we found that it has coverage of 68.5cm in a well-lit room and 88cm in a dark room. This is the maximum distance between the transmitter and receiver at which a signal can be transferred. It is to be noticed that the new prototype also has an added a piece of hot glue stick on to the receiver. This acts as a translucent dense medium that intercepts and refracts the incoming light rays onto the receiver, thereby allowing the receiver to receive light falling on it from any direction. Figure 5 demonstrate the working of the new prototype version 2.0, Figure 5. (a) Illustrate the transmission of analog data signals from the right device to the left device. Notice that here we used the spectrum analyser to display a graph of the audio input in to the microphone of the transmitting device. So when analog data were then transmitted

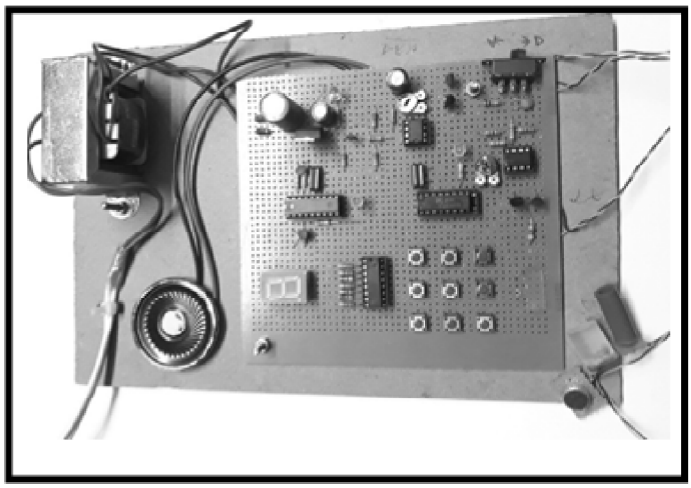

Figure 4: Li-Fi Prototype Version 2.0

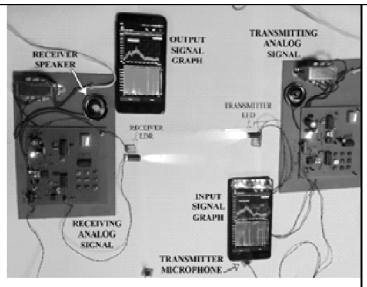

Fig. 5. (a) Reception of Analog Data

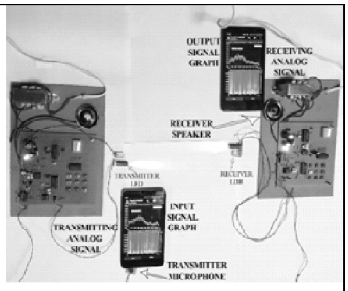

Fig. 5. (b) Transmission of Analog Data

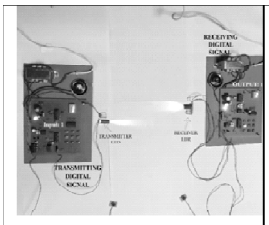

Fig. 5. (c) Transmission of Digital Data '1'

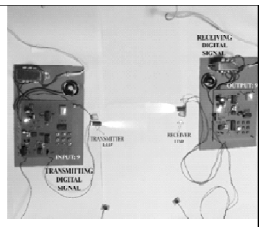

Fig. 5. (d) Transmission of Digital Data '9'

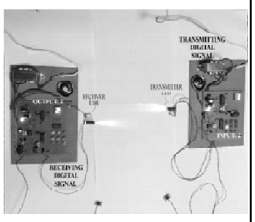

Fig. 5. (e) Reception of Digital Data '2'

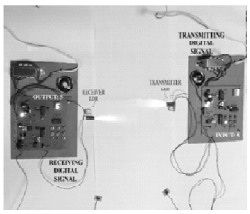

Fig. 5. (f) Reception of Digital Data '5'

Figure 5: Illustration of the proposed prototype

using the transmitter LED. The receiver LDR picks up this signal and outputs it through its speaker, which is then again displayed as a graph on the spectrum analyser. We found that the graphs of both the spectrum analysers almost identical. This means that the receiver speaker successfully receives the audio signal being picked up by the sender microphone. Further the Figure 5. (b) illustrates the same process as described above but this time the analog signal was sent from the left device to the right device. This is possible because the proposed prototype is a bidirectional device.

Figure 5. (c) (d) (e) and (f) demonstrate the transmission of digital data signals between both the devices. Here we used the anode matrix keypad to enter the desired digital data to be sent. Further 7-segment display was considered to display the digital data signal that has been received. In Figures 6 (a) and 6 (b), we explain the working of Transmitter and Receiver respectively illustrating the LI-Wi model.

Transmitter

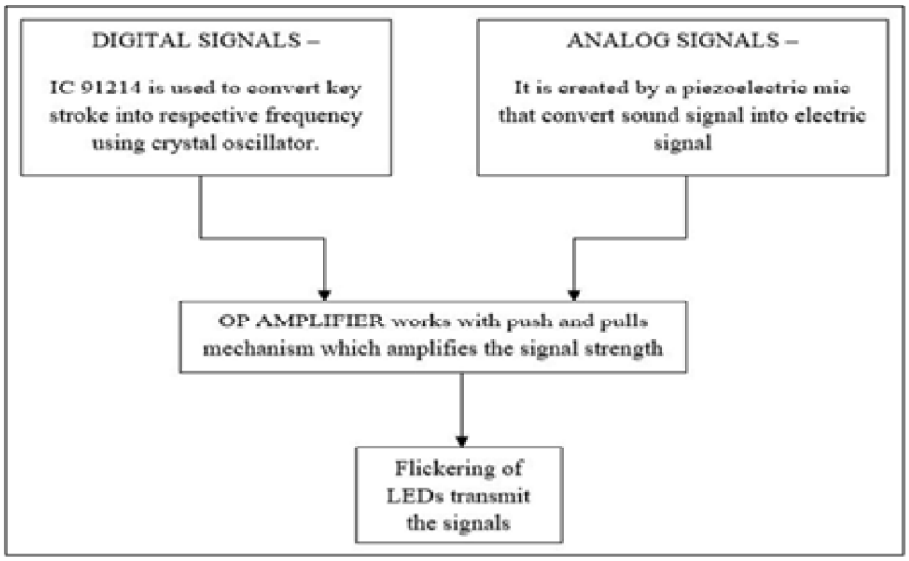

Figure 6: (a) Systematic Working of Li-Fi model (Transmitter)

Receiver

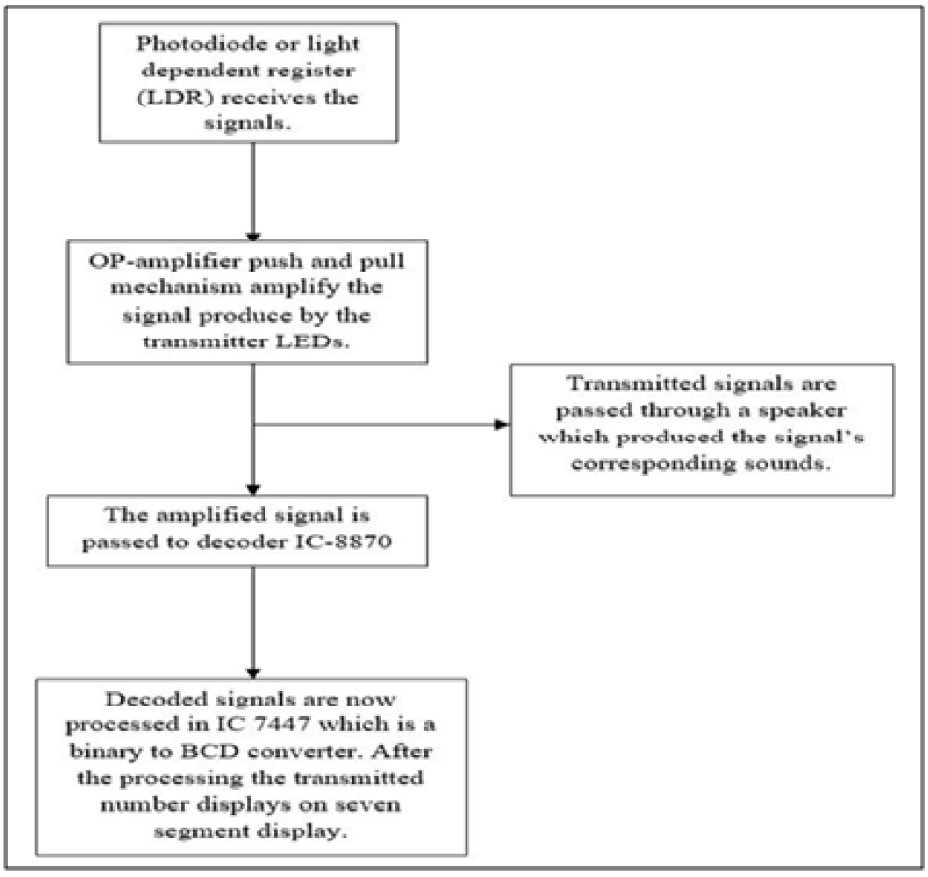

Figure 6: (b) Systematic Working of Li-Fi model (Receiver)

VI. APPLICATIONS

In this section we discuss various applications of Li-Fi technology in which the proposed Li-Fi model can be used.

(A) Patient Monitoring System

Patient monitoring in hospitals can be done using Li-Fi instead of Wi-Fi to avoid frequency interference with the human body. In their work Sudha et al. [9] considered the data from four sensors i.e. temperature, heartbeat, glucose, and respiration is converted into digital data using an analog to digital converter. This digital data is further sent to a microcontroller whose output is fed to a Li-Fi module which transmits the data. This data is picked up by a receiver which displays graphs for the given data using a computer. A copy of this data can also be sent to the concerned person through e-mail. As Li-Fi enabled LED bulbs communicate with the medical equipment in real-time, the bulb plays a role as a sensor that detect abnormal condition of the patients. As soon as the bulb receives emergency signal from the medical equipment, it broadcasts it to all connected client devices in the same network to notify such situation to doctors and nurses. The broadcasted message contains patient details such as patient id, room number, and equipment id to signal the client devices [10].

(B) Automated Traffic Control

Vehicle to vehicle communication is an effective solution that is used to prevent accidents. Here the Li-Fi technology can be used to send data between two vehicles which can further eliminate the need of complex wireless networks and protocols. In their work Abdulsalam et al. [11] considered the data that include information such as change in speed of the vehicle in front and warning of an oncoming vehicle at a T-junction. Figure 7 illustrate the proposed prototype, in which LEDs such as headlights, brake lights, traffic signals etc. are used accordingly as a transmitter for vehicle-to-vehicle communication systems. Here a camera is expected to be the receiver which have already been used for safety purposes in the automotive field and give the details of the following car such as vehicle id, vehicle speed, operating system of brake, left and right blinkers, distance between them and many more which provide an ease to the traffic management and the drivers. One may also refer to the work of Takai et al. [12] for more details in this regard.

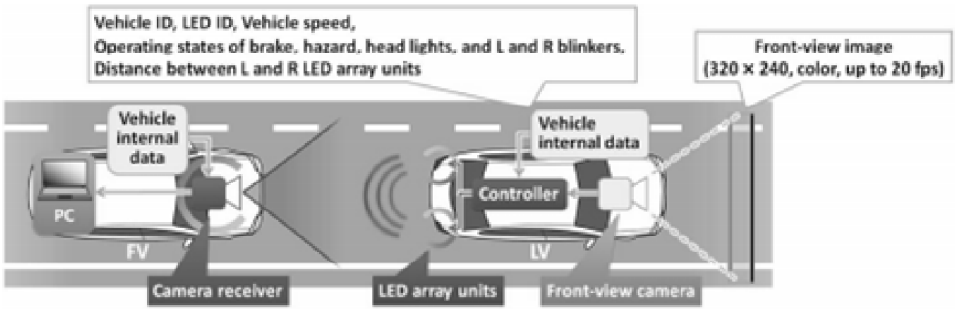

Figure 7: Block diagram of the optical V2V communication system [11]

(C) Automatic Billing System

Large supermarkets have a great variety of goods. Most of the customers find it difficult to stand in long billing queues which causes a waste of time. A Li-Fi transmitter can be integrated into each product. Similarly, mobile phone can also be integrated with a Li-Fi receiver via USB On-The-Go (OTG) communication in the shopping cart. Therefore the commodities chosen by the customers can be entered using mobile Li-Fi and the payment can

be processed in the mobile via online banking system. This may help to save both time and manpower required. Recently Thomas et al. [13] proposed the automatic billing system using Li-Fi, the block diagram is given in Figure 8. In the proposed procedure, the product which has transceiver, gets detail of the product including price, weight, company name etc. on the user's phone. Further the trolley which has attached to the Li-Fi shows the chosen product on the LCD display. Furthermore the products that are placed in trolley are displayed on the mobile for payment. The proposed system also triggered the alarm afterwards the paid products were checked at the gate using Li-Fi sensors and if any mismatch happens.

Figure 8: Block diagram of automatic billing system [13]

(D) Library Management System

In every library, books are not properly managed in the respective sections. To conquer this problem every book can be assigned with a transceiver of Li-Fi which is operated by the phone and gives all the details of the book such as price, author name, which section it belongs to and also the exact location of where it is placed in the library. The user just has to stand near the section of the book and type the book name, the book transceiver will automatically give details of the respective book. This application provides ease to the user as well as the library management system.

VII. CONCLUSION AND FUTURE WORK

Li-Fi has a lot of prospects to be worked upon to rise in the field of wireless communication. There are high possibilities that this technology will replace Wi-Fi but in order for that to happen, the limitations such as range need to be increased [14]. It would take time for Li-Fi to be as widespread as Wi-Fi. The initial costs and expenditure to implement this technology will be high but as it becomes more prevalent, the costs will go down. Due to the low power consumption of LEDs, Li-Fi is a green technology and is the way to go for a brighter future.

As the proposed prototype is based on simple bidirectional communication using Li-Fi, next level Li-Fi model is under the process to transmit the flawless data between computer systems. A hybrid network that uses both Li-Fi & Wi-Fi for communication will allow to have a reliable yet high speed connection. The high speed will be available while the user is in sight of the LEDs of the Li-Fi system and the network will be reliable as it will use radio waves to provide a lower speed using Wi-Fi when the user is not in sight of the LEDs.

In the current work, we noticed that while using Li-Fi, the transmitter LED is directly pointing toward receiver so the data cannot leak or get hacked by unauthorized users but if more than one user is accessing the same Li-Fi network simultaneously, there might be some kind of hindrance or interference between their data. For this problem, we can encrypt data and clock our transmitter LEDs at very high rate so every user receives the data swiftly and reliably, which is further area of research.

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