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A Technical Review on Visible Light Communication System

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Abstract

The implementation of communication system using visible light is the new fascinating trend in the communication field, where different colours and intensities are used to communicate. Since in late 1990s, communication has gained wide popularity and growth. Although communication had previously been hampered by interference and pre-existing difficulties, most of them use radio frequency (RF) communication, where information such as images and sounds are carried by radio waves. Radio frequency communication suffers from high latency and interference which added more to the arguments against communication technology and ultimately demanded a new method of communication by taking into consideration the advantage of the fast-switching characteristics of LEDs. To overcome the drawbacks of RF communication, Visible light communication (VLC) is adopted. This review article summarises the components, limitations, architecture, modulation techniques, and conclusions regarding the application of VLC.

Keywords: *Visible Light Communication (VLC), 6G, 5G, terahertz, Light-Emitting Diode (LED) & Optical Wireless Communication*

Introduction

In recent years, there has been a tremendous growth in the number of mobile phones around the world [1]. People are increasingly using smartphones, tablets, and sensors in their daily lives as they require constant communication, Internet access and sensing [2]In addition to the widespread adoption of powerful mobile phones that are always connected, the major computing revolution in this era is internet of things (IoT) [3] in which every gadget will have connectivity and processing abilities. Everyday appliances like televisions, microwaves, refrigerators, and automobiles will be connected round-the-clock, necessitating even more sources, either from the appliances themselves or from the network framework that supports them. Given this scenario, the growing crowding of the Wi-Fi-allocated EM spectrum band is a serious issue that has sparked interest from academia and industry alike. When there’s a high demand for wireless resources, Wi-Fi Spectrum [4] Crunch comes into the spotlight. As a result, the current framework does not have the capacity to support wireless communication. In fact, over the course of the past few years, the term "Wi-Fi Spectrum Crunch" has been used in the media a number of times, alarming both the academic sector and the industrial sector [5]As a result, new technologies which are Wi-Fi compatible, have been developed to avoid this problem. VLC is one of the new technologies that has a lot of potential for addressing the Wi-Fi spectrum crunch problem [6],[7]. In fact, the chances of collaborating with RF systems have increased interest in this type of wireless optical communication [8]. The possibility of working with frequencies that are significantly greater than those utilised by Wi-Fi gadgets is another point that draws researchers to this emerging field of study. These frequencies enable wireless communication at theoretical speeds in the terabytes per second [9].

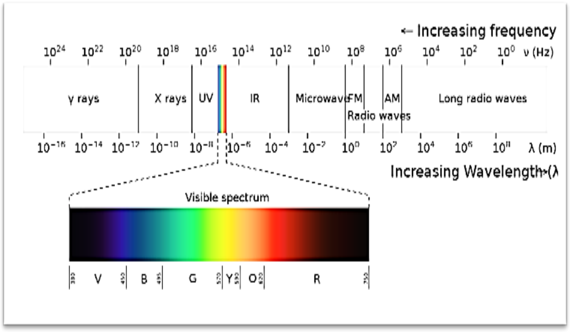

Fig.1: Visible Light Spectrum

In addition, new light-emitting technologies like LEDs [10] are gaining popularity and accessibility, opening up new avenues for OWC. Lastly, the growing attentiveness to and investigation of the visible light spectrum has resulted in many innovations that are currently available. One example is Li-Fi, which was introduced in 2011 and is currently being sold by VLC-focused businesses. A deep overview of VLC is presented in this paper. This review paper recalls the new applications of visible light communication for emerging regions also the open inquiries that may foster new research are been discussed here. In conclusion, we offer our contributions toward this technology. We go over the fundamentals of the optical spectrum and talk about how that part of the electromagnetic spectrum can be used for communication. We discuss the main factors that contributed to the rise in popularity of VLC over the past ten years and give a comprehensive understanding of how it came to be so. We provide an overview of VLC's architecture, which includes transmitters, receivers, and efforts to standardise it over the past ten years. In addition, we give a comprehensive description of the various modulation techniques and multiple access strategies used in the literature section. We also go into the area's application and difficulties. We provide a comprehensive analysis of the most widely used research platforms found in the literature. In the field of wireless technology, we offer a perspective on visible light communication's future. We have already observed many surveys about visible light communication in the past couple of years, from a wider angle to a more specific section, despite the novelty of visible light communication and the growth of new research in the technology.

Historical Background of VLC

Over the past few decades, the amount of mobile data traffic required to support a variety of services and devices used both inside and outside, such as high-definition television, various types of Internet connectivity, audio and video conferencing has increased tremendously. Additionally, as wireless communication technologies advance widely, the fourth generation of wireless networks now includes an increasing number of devices. The fourth-generation (4G) or fifth-generation (5G) wireless networks [11] must enable numerous communication connectivity options and a wide range of services for a large number of devices. This will necessitate widespread connectivity, increased security, high data rates, high positioning accuracy, low latency, and low battery consumption.

Modern RF-based wireless communication technologies (such as 4G and 5G) manage to maintain high levels of connectivity, offer high levels of location precision, and meet the varied quality of service (QoS) requirements of devices due to continually escalating bandwidth demands [12]Due to their extended lifespan and low power consumption, light-emitting diodes (LEDs) have received a lot of attention recently in the lighting industry. Compared to fluorescent bulbs, which have a lifespan of just approximately 10,000 hours, LEDs have a lifespan of between 30,000 and 50,000 hours. Additionally, commercial LEDs' luminous effectiveness is xpected to each 200 lumens per watt by 2020, which is significantly more than that of incandescent bulbs. In addition to the benefits outlined above [13], LEDs are used as emitters for VLC because of their rapid switching capabilities. The visible light spectrum used in VLC systems spans the wavelength range of 375 to 780 nm, producing a large amount of unlicensed bandwidth that is substantially larger than the RF spectrum. This makes it possible for VLC systems to offer indoor communications using wireless data transmission at high speed. As a result, LEDs can provide fast data rates for communication services in addition to simultaneous illumination in interior environments. The first article on VLC was published in 2000 by Tanaka et al. from Japan. They created visible light links using white LEDs and employed an amplitude-modulated visible light spectrum to establish a data channel without interfering with the LEDs' lighting capabilities.

A fundamental analysis of white LED-based VLC systems was given in the literature [14], which also described the core system model, the effects of reflection, and inter-symbol interference (ISI). Since then, every teacher and tradesperson has been watching the arrival of VLC systems powered by white LEDs with bated breath. The commonplace light ID system and, therefore, the commonplace VLC system were two specifications reported by the VLC association in Japan in 2007. The primary IEEE standard for VLC (IEEE 802.15.7) [15], [16], was adopted in 2011. To accommodate the assorted QoS necessities of devices, VLC has been highlighted as an achievable candidate technology for 4G or 5G networks. Because of the following key benefits [17], VLC can serve devices in indoor settings:

- high-speed transmission using the plentiful, unrestricted visible light spectrum
- cheap price because of the usage of the lighting infrastructure already in place
- ensure communication security as visible light signals cannot penetrate walls
- Using visible light positioning (VLP), high-accuracy localization for object tracking and navigation
- There is no interference with RF communications due to the different spectrum and no electromagnetic interference, making it suitable for use in electromagnetically sensitive environments (such as hospitals, airports, and gas stations)
- Using visible light as a source of energy to extend the battery life of low-power gadgets.

Given that wireless devices spend 80% of their time indoors, consistent with various studies, densely deployed light-emitting diode (LED) points are often utilised in access points (APs) to support high densities of indoor devices and supply a spread of services.

IEEE 802.15.7 specifically outlines three physical layer (PHY) modes that mix a spread of modulation techniques, like on-off keying OOK, VPPM, and CSK [18], which are samples of pulse position modulation techniques. The maximum supported rate for PHY II and PHY III is 96 Mbit/s. That may be an important increase on the far side of the most earned rate in laboratory tests. For example, a model was able to attain a knowledge outturn of 500 Mbit/s over a two-meter distance with outturn rates of 1.3 and 1 Gbit/s. The implementation included 3- and 10-meter distances. Furthermore, D. Tsonev and gallium nitride (GaN) LEDs [19] were used by et al. to create an approximately 3 Gbit/s VLC link over a 5 cm distance.

There are also a number of new standardisation initiatives connected to VLC, including IEEE 802.11b and ITUT G.9991 for high-speed indoor visible light communication, and others for several widely used standards and technologies in short-range wireless communication networks. As can be shown, VLC can achieve substantially greater transmission data rates (up to several GB/s) than the existing Wi-Fi technology (around 350 Mbps for IEEE 802.11n), even while Wi-Fi achieves longer transmission distances than visible light communication. In addition, because competing technologies (such as Bluetooth and ZigBee) have far lower data rates, they might not be able to achieve the demands for higher-speed transmission. Visible light communication systems based on LEDs provide a number of appealing benefits over RF-based indoor communication systems [20], including affordable front-ends, low power consumption, the absence of electromagnetic radiation, an abundance of unregulated bandwidth, and high security. In accordance with the abovementioned studies, VLC could be a crucial component of 5th generation networks to ensure the various QoS requirements of devices.

Architecture of VLC

The visible light communication system's two most important components, the transmitter and receiver, generally have three common layers [21]. These three levels are the physical, MAC, and application layers. The Visible Light Communication system's layered model is shown in Figure 2. Only two layers, the PHY and MAC, are specified in IEEE 802.15.7 for simplicity of usage [22].

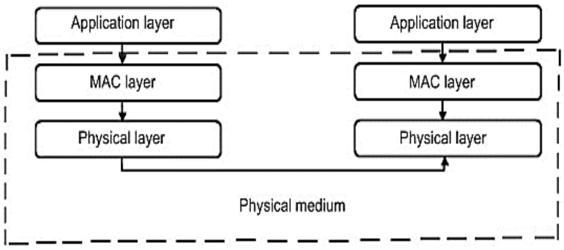

Fig. 1: Layered Architecture of VLC

A. *MAC Layer*

The Medium Access Control (MAC) layer [23] is responsible for the tasks, which include visibility, security, mobility, dimming, flicker mitigation techniques [24], colour function, generation of network beams if the gadget is a coordinator, and provision of a trustworthy link between peer MAC entities. Peer-to-peer, broadcast, and star topologies are supported by the MAC layer, as shown in Figure 3.

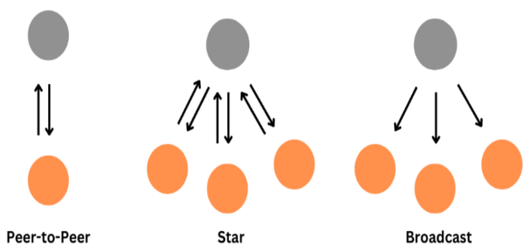

Fig. 2: MAC Topologies

Using a single central controller, the star topology's communication is carried out. As seen in Figure 3, the central controller serves as the means through which each node communicates with the others. As illustrated in Figure 3, one of the two devices interacting with one another is the administrator in the peer-to-peer system [25].

B. Physical layer

This layer gives the physical parameters of the node as well as its connection to the media. The main block design of the physical layer implementation for the VLC system is shown in Figure 4 [26].

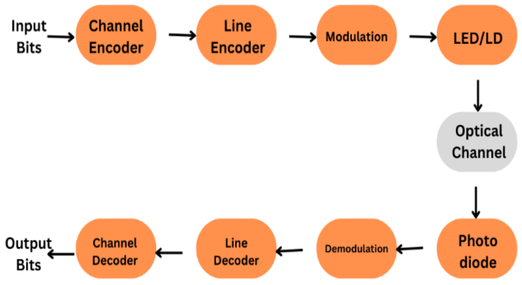

Fig. 4: Typical Physical Layer System model of VLC

In the first place, the channel encoder is utilized to handle the information bit stream (discretionary). Utilizing modern turbo codes, convolutional codes, and linear block codes can enhance the VLC system's performance. After the channel encoder, the encoded bit stream is created using the line encoder. Data is modulated using a variety of techniques, including ON-OFF keying, pulse position modulation, and pulse width modulation, among others, after line encoding. After that, it is sent to the LED for optical channel transmission. The bi-directional transmission is carried out using subcarrier multiplexing (SCM) and wavelength division multiplexing (WDM). In addition, Quadrature Amplitude Modulation (QAM) and Orthogonal Frequency Division Multiplexing [27] (OFDM) were used to boost the data rate. The light signal was captured by the receiver, which may be a silicon photo diode or a PIN photodiode[28]. Demodulation and line decoding were completed, and then the bit stream was routed through a channel decoder to create the output bit sequence. In IEEE 802.15.7, there are three different major physical VLC implementation types. PHY I, PHY II, and PHY III each have operating ranges of 11.67 and 266.6 kbps, 1.25 and 96 Mbps, and 12 and 96 Mbps, respectively. To address flicker reduction and DC balance difficulties, PHY I use convolutional and Reed-Solman (RS) codes[29] for outdoor usage, whereas PHY II offers run-length limited (RLL) codes for interior use.

C. Transmitter

LEDs have made solid-state lighting[30] a more recent technology. When it comes to reliability, power consumption, and luminous efficiency, LEDs have surpassed bright light sources. LEDs are 20 lm/W more energy efficient than incandescent bulbs. For visible-light communication[31], lasers and light-emitting diodes are used as the transmission sources. The LED should be used when a single device must perform both lighting and communication functions. One of the more appealing options for a source of visible light communication is white light generated by light emitting diodes and wavelength converters. The white light that the LEDs might produce can take on an assortment of spectra. The tetrachromatic, dichromatic, and trichromatic modes utilised to produce white light are depicted in Figure 5.

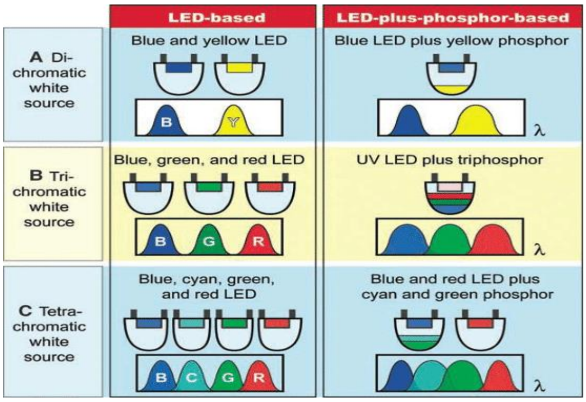

Fig. 5: White Light Sources based on LEDs

RGB (red, green, and blue) illumination is the most common method for creating white light from trichromatic LEDs. Utilizing an RGB LED for the production of white light is advantageous due to its large bandwidth and consequently high data rates. RGB LEDs' high-related complexity and challenging manipulation are disadvantages.

D. Receiver

An optical filter, an amplification circuit, and optical concentrators make up the standard VLC receiver[32]. The optical concentrator is a piece of equipment that is used to compensate for the attenuation caused by LEDs' beam divergence when they illuminate large areas. In the VLC receiver, a photodiode detects the light and converts it into photocurrent. The parameter specifications for VLC and infrared communication will change because of the different wavelengths. PIN diodes, silicon photodiodes[33], and avalanche photodiodes are utilised in VLC. A more prominent increase than a PIN photodiode is accessible with the torrential slide photodiode, yet at a massive expense. Since other sources of interference, such as sunlight and other lights, might interfere with the VLC, it is important to minimise the DC noise components in the received signal with optical filters. A photodiode in a VLC receiver normally receives VLC signals. A photodiode is preferable for a stationary receiver. However, in the case of mobility, an image sensor is utilised in place of a photodiode due to the increased field of view. Imaging sensors operate slowly and consume a lot of energy. As a result, when looking at photodiodes and image sensors, price, speed, and complexity should all be taken into consideration.

LEDs for VLC

The popularity of VLC has increased as a result of many factors. Among all of these, the use of LEDs to manipulate light waves stands out the most. LED bulbs have taken over as the primary visible light communication medium because of features like affordability. Additionally, the usage of LED light bulbs increased, incorporating a variety of settings that would make it useful to use light as a means of communication. As a result, this type of light source is commonly used in visible light communication systems. The LED is a node that produces light using electroluminescence and semiconductors. More precisely, materials that can partially conduct electricity are used to make LEDs. Additionally, a phenomenon known as electroluminescence occurs when an electric current flow through a substance. Between two semiconductors [37], there are electron holes, which occur when an atom is deficient in electrons. As a result, as electrons go through it, they cover the electron holes and, as a result, release photons. A particular hue is represented by the emission of light in the visible range, ranging from low to high frequencies. For example, red LEDs are typically made of GaAsP and have wavelengths in the range of 630 nm to 660 nm. The exponential expansion of LED lights nowadays has a variety of causes. This kind of light source has a number of well-known benefits, including low cost, durability, and energy efficiency. Residential LEDs can last 25 times longer and consume at least 75% less energy than an incandescent light bulb. Additionally, an LED bulb's light may be directed in only one direction. These benefits have led to the widespread usage of LEDs in a variety of products, including cell phones, cars, video displays, signage, and applications like visible light communication. The industry has benefited much from using this technology, and LED lights are clearly the way of the future for household illumination. The white-light LED is now the most widely used type of commercial LED light bulb. White LEDs are manufactured using two conventional processes, unlike other hues that are tied directly to semiconductor materials. The first technique creates white light using phosphor. A blue LED bulb coated with phosphor is used for this. A portion of the photons produced by the blue LED are transformed into yellow as they pass through the phosphor layer. White light is created by the combination of yellow and blue photons. The second way involves mixing the blue, red, and green outputs from RGB LEDs to create white light, which is accomplished using this technique [38]. The colour that is emitting from this kind of white LED may be changed. These two approaches differ in a number of ways, and each has its own set of benefits and drawbacks. Because it is less expensive and more effective than the RGB approach, the phosphor method is often more prevalent among LED light bulbs. However, the RGB LED tends to be more practical for Since visible light communication is controlled via light, the IEEE standard for visible light communication specifies a modulation technique that relies solely on the intensity of RGB LEDs [39]. A light-emitting diode is a semiconductor that was designed to serve as an optical source, as is common knowledge. LEDs may also convert light from an optical source into an electric one, though. In other words, a little-known fact that is becoming more and more common among VLC researchers is that an LED may also be used as a sensor. Because a little current that is proportionate to the light's intensity is created when the light is provided to the light-emitting diode, these light-emitting diodes can function as receivers. The term "photocurrent" refers to this phenomenon. An LED may be thought of as a selective photodiode since it detects a restricted wavelength range, unlike a photodiode, which has a wide spectrum response and can detect ultraviolet and infrared light. It is generally believed that an LED can detect light frequencies that are equal to or greater than those it emits. To put it another way: Blue LEDs can only detect blue light, while red LEDs can detect red, green, and blue photons. The spectral response often changes slightly toward the colour blue in the visible spectrum (higher frequencies). In contrast to the frequency of the emission, the spectral response of, say, green has a fairly narrow band. So, a green LED might not be able to detect green light. LEDs come in a variety of varieties, each with unique characteristics that make them suited for VLC applications. The area of the visible spectrum in which light is emitted depends on the material used to make the chip. The photon will consequently radiate at a certain wavelength, giving rise to a color. Compounds used in LEDs include gallium arsenide (GaAs) and gallium phosphate (GaP)[40]. The main categories of LEDs and their specifics are described below.

A. pc-LEDs (phosphor-converted LEDs)

They have a minimal level of complexity and are inexpensive. It has a blue LED chip with a phosphor coating covering it that emits some of the blue energy as white light while converting some of the remaining blue energy into green, yellow, and red. This type of LED's restricted bandwidth is a result of the delayed phosphor response [41].

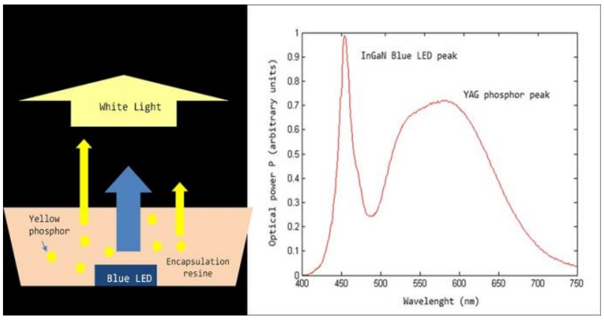

Fig. 6: pc-LED [41]

B. Multi-chip LEDs

These LEDs have a structure made up of three or more chips, each of which emits a different hue of light [42]. The various chips generally emit the RGB colours to produce white light. The flexibility to adjust the intensity of each chip to change the colour that is emitted is this sort of LED's primary benefit. It is significant to note that colour-shift keying, a sort of modulation, was developed specifically for this kind of LED.

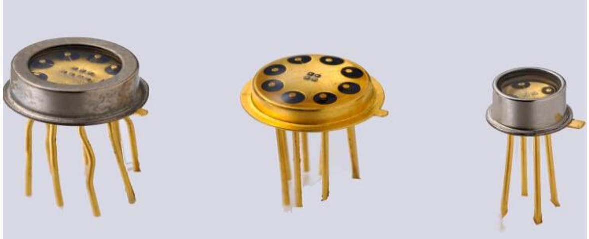

Fig. 7: Multi-chip LEDs[42]

C. Organic LEDs (OLEDs)

These LEDs are made of two conductors and a number of thin organic layers [43]. Light is produced when electric current is applied. They are frequently used on smartphone screens. The ability to create transparent and flexible gadgets is a major benefit of this kind of technology. This sort of LED is nevertheless less effective than other varieties in terms of frequency and endurance.

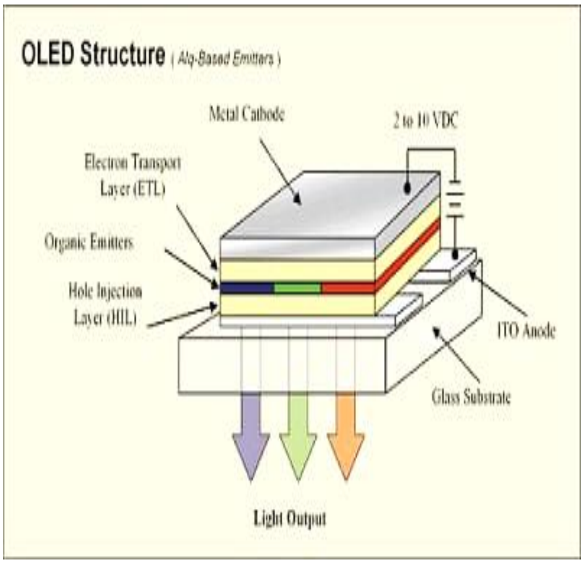

Fig. 8: OLED structure [43]

D. µ-LEDs

The µ-LEDs are typically connected in displays, allowing for high-density parallel communication that can reach extremely high speeds [44].

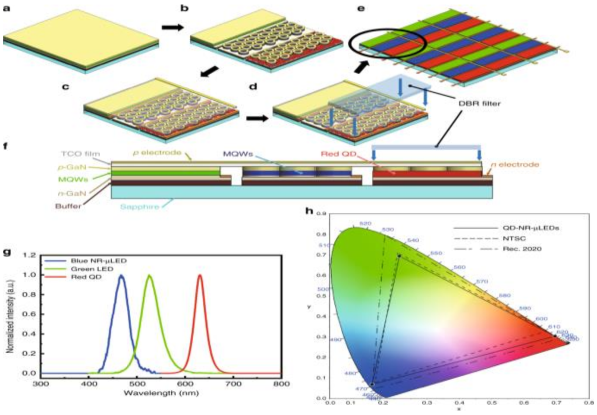

Fig.9µ-LEDs [44]

Benefits of VLC

VLC is an intriguing technology to supplement radio-based systems because of its various benefits [50]. These benefits result from the use of LEDs as transmitting devices as well as the utility of visible light as a high frequency carrier signal, on the one hand:

- It supports a wide bandwidth that goes beyond the bandwidth limitation of RF transmission.
- When the sender and destination are both in the same room's LOS, VLC communication performs best. A person in the adjacent room cannot eavesdrop on data being transmitted through VLC. It provides encrypted communication, in contrast to RF transmission.
- VLC sources are used for both communication and lighting due to their low power consumption. As a result, Visible Light Communication is a power-efficient technology.
- Light-based communication is used in VLC. As a result, Electromagnetic

radiation from Radio Frequency systems has no effect on it.

- It is simple to install and carries no health hazards for people.

Limitations of VLC

The limitations of VLC communication are as follows:

- Other light sources can interfere with Visible Light Communication
- Small coverage ranges are supported using VLC communication.
- The integration of Visible Light Communication with a wireless setup is difficult.
- The VLC system also has other issues, such as air absorption, shading, beams cattering, etc.
- Source and receiver must be direct to each other. As a result, non-LOS communication is difficult.

Additionally, the outside FSO channel adds significant attenuation, which inevitably reduces the power gathered by the sensor and, as a result, the transmission range of the Visible Light Communication system.

Applications of VLC

VLC has been seen as an appealing alternative for a wide variety of applications, whether indoor or outdoor, given all the benefits and limitations mentioned above [51]. Indoor positioning is a pioneering application of VLC from an industry standpoint [52]. The position may be determined with a centimetre of accuracy by employing the number of sources used for lighting the various rooms and hallways of a building as Visible Light Communication transmitters. This makes VLC an intriguing addition to Global Navigation Satellite System, which is typically unable to provide positioning in buildings. Additionally, VLC can guarantee the coverage of areas that would otherwise be impossible to cover due to restrictions on RF systems, such as those found in hospitals or mines, or because they are inoperable, such as those found under water. Beyond these specialized industries, the VLC community's main issue right now is creating a VLC-based home network solution. Few applications of VLC are discussed below:

A. Vehicle-to- Vehicle Communication

VLC can be utilized for vehicle communication for proper forward collision warning, pre-collision detection, computer-controlled brake lights, lane change warning, sign moving partner avoidance, right hand traffic sign violation warning, cornering speed warning, etc [53].

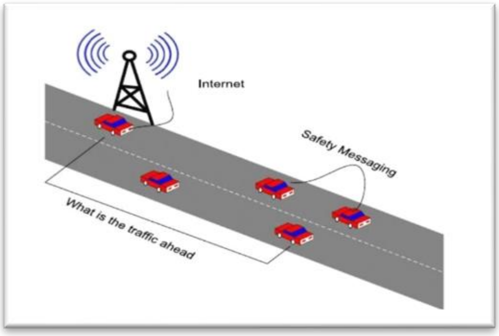

Fig.10: VLC for vehicular networks

B. Li-Fi

In 2011, Harald Haas first coined the term "light fidelity" (Li-Fi). Similar to Wireless Fidelity, Li-Fi is a two-way, fully integrated, high-speed VLC that communicates using radio waves [54]. Other radio frequency transmissions, such as those from pilot navigation systems, can interfere with wireless fidelity signals. Li-Fi could thus be a preferable choice in areas that are susceptible to electromagnetic wave radiation (such as aeroplanes). Internet of Things support is also provided via Li-Fi. Li-Fi is 250 times faster than ultrafast broadband, with rates up to 10 GB/s.

C. Underwater Communication

Radio Frequency waves don't travel pleasantly in ocean water because of its high conductivity. In this manner, verbal trade has got to be utilized in submerged communication systems[55]. The Unrestricted Remotely Operated Vehicle is another use of the VLC in submerged communication (UTROV).

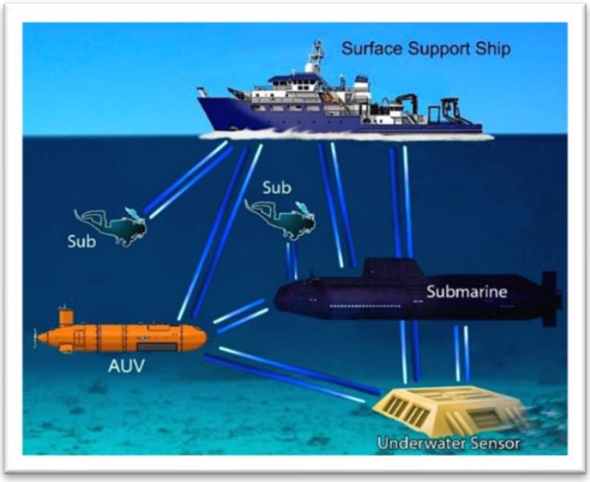

Fig. 11: Underwater communication

D. Hospital-s

VLC is a cutting-edge invention that uses visible light (400 nm–780 nm) as a transmission channel for data. Since transmitted light is constrained to the scope zone of the system, visible light communication poses less risk to human safety and is more secure against hackers. Additionally, it offers better data rates than traditional radio frequency-based developments in distant communication like Wi-Fi, Bluetooth, and WiMAX. As a result, the Visible Light Communication invention would be an excellent contender for clinical data transfer in healthcare. Furthermore, clinics are inside, where VLC would be ideal for proficient remote information administrations with no RF radiation.

Among the vital biomedical signal's ECG, EEG blood pressure are important.

- *HOSPI Robot*

In, a robot known as HOSPI was proposed to be used for transportation in hospitals

[56]. VLC does not interact with other equipment' radio waves; thus, it is likely to be converted to electromagnetic wave sensitive locations in hospitals (like MRI scanners). The robot's navigational sensor and a VLC connected to a building have been used to improve HOSPI's control machine.

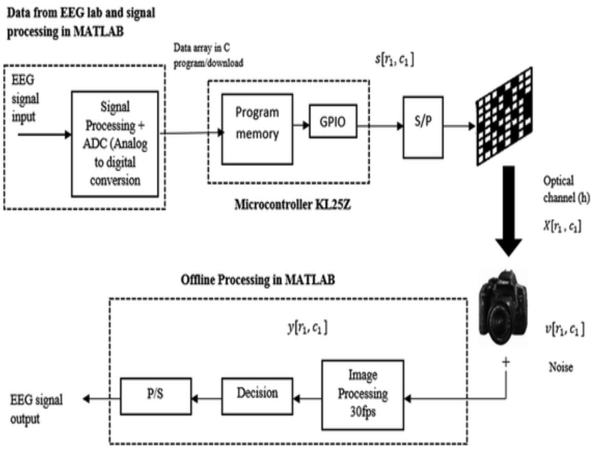

Fig. 12: Wireless EEG Signal Transmission Using Visible Light Optical Camera Communication

Conclusion and Discussion

This review paper presents the concept of visible light communication and its brief history. The basic architecture of visible light communication is described which includes transmitter as well as receiver section along with the importance of LEDs in VLC. Benefits, limitations and applications of VLC is also explained in this paper. This technology is harmless as compared RF and IR communication, so the future of communication is based on this technology only. Various advancements in this technology are being done by researchers so that results obtained could be better its limitations could be overcome in the future.

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