VLC Communication Technology: A Short Review

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Abstract

Because of the growing number of mobile devices and the demand for Internet services from them, particularly, streaming video, and online gaming, social media platforms, radio-frequency (RF) wireless networks have surpassed their capacity constraints. In addition, users inside of buildings account for 80% of all data traffic. As a result, consideration of new technologies for indoor wireless communications has begun. In this direction, Visible Light Communication (VLC) technology is developed which can give lighting as well as communication and serving as the best replacement to the Wireless networks based on radio frequency. Ultra-high data rates, communication channels that are secure, and absence of electromagnetic (EM) wave intervention are only a few of the major benefits of a VLC system, which enable a variety of applications. Therefore, this paper presents a review of the emerging VLC technology highlighting the VLC transmitter and receiver technology with different modulation schemes utilized. Further, this review also presents different application areas for VLC technology with open research challenges. Finally, the paper concludes by highlighting the future aspects for the VLC technology.

Keywords—Visible Light Communication, Modulation Techniques, VLC Transmitter, VLC Receiver, CSK, OFDM

I. INTRODUCTION

Visible light communication (VLC) systems is a wireless technology network that was developed in early 2000's [1-3]. This style of communication involves, a typical VLC communication system employs a camera with CMOS sensors or photodiodes as the receiver, and single LEDs or numerous Lighting with LEDs as the transmitter. Data is conveyed at a rate that is substantially faster than what the human eye can perceive, either by turning on and off the LED or by varying its intensity output.

Fig. 1 presents a basic block diagram for a typical VLC communication system. There are two main parts of the VLC communication system: (i) optical sender and (ii) optical receiver. A bit stream which is binary in nature drives the LED/LD after preprocessing and encoding, and electrical signals are converted into optical signals. Pre-processing is a technique used to compensate for signal deterioration induced by other channels. The equalization technique can be used to boost the LED's response bandwidth as well as its data transfer rate. Other channel losses, such as phase noise, can be compensated for by the receiver's post-equalization. The use of various techniques for modulating high-order coding that boosted both the transmission rate and the spectrum efficiency.

The evolution of VLC systems was initially motivated by instances of increasing transference speeds, and then by progressively complex transceiver configurations. Fig. 2 provides a timeline for milestones in the evolution of VLC. In its initial phase the VLC systems were able to achieve a throughput of 25MHz for white light component of LED [4] whereas for blue light component the throughput was increased to 14MHZ. Also, with the improvements made in technology a throughput up to 1Gbps was observed with the utilization of On-Off Keying (OOK) and OFDM technologies [5-7]. With the use of new Micro-LEDs made of GaN violet, current technology enables transmission speeds of up to 10 Gbit/s [8]. VLC systems finds applications in many fields including interplanetary communication, quantum communication, and LED-illuminated high-speed internet cables. In recent past, VLC adds a fresh viewpoint to the widely used field of computers, indoor VLC [9,10] System ID and positioning [11], communications within the vehicle [12], and communicating while underwater [11].

15

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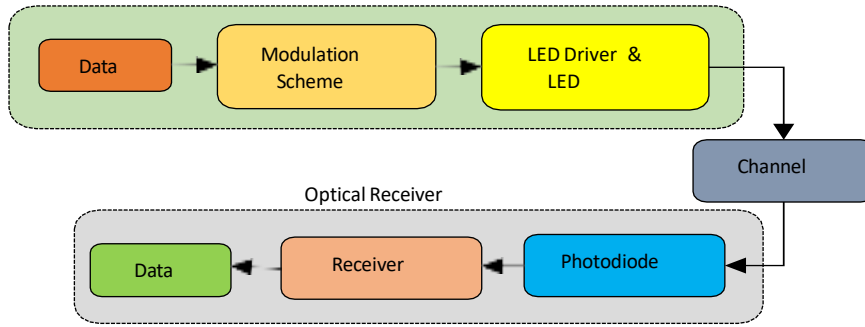
Optical Transmitter

Fig. 1. Block diagram of the VLC Communication Technology

With the advancements made in technology, VLC has gained immense popularity among researchers due to its application area. With the term "Visible light communication" or the keyword "VLC" in the paper's title or body is published years ago in many numbers of papers which is shown in Figure 3. From the exponential growth seen in Fig. 3 it is evident that VLC communication technology has a potential that encourages both academia and industry to invest in it.

This research describes a precise overview of the VLC communication system highlighting VLC transmitter and receiver technology, different modulation techniques with applications of VLC technology. Finally, we conclude the review with the open challenges to VLC and future works.

II. VLC TRANSMITTER & RECEIVER TECHNOLOGY

The transmitter in a high-speed VLC system is crucial for reaching a big data rate. A good VLC system's light source must have a powerful optical output, a wide bandwidth of modulation, high efficiency of energy conversion, a low operating voltage, a tiny form-factor, and an extended and lifetime. To achieve these characteristics mostly LD LED- based VLC systems are incorporated. Table I lists the most modern VLC systems with high-speed LD and LEDs highlighting the modulation and data rates for each light source.
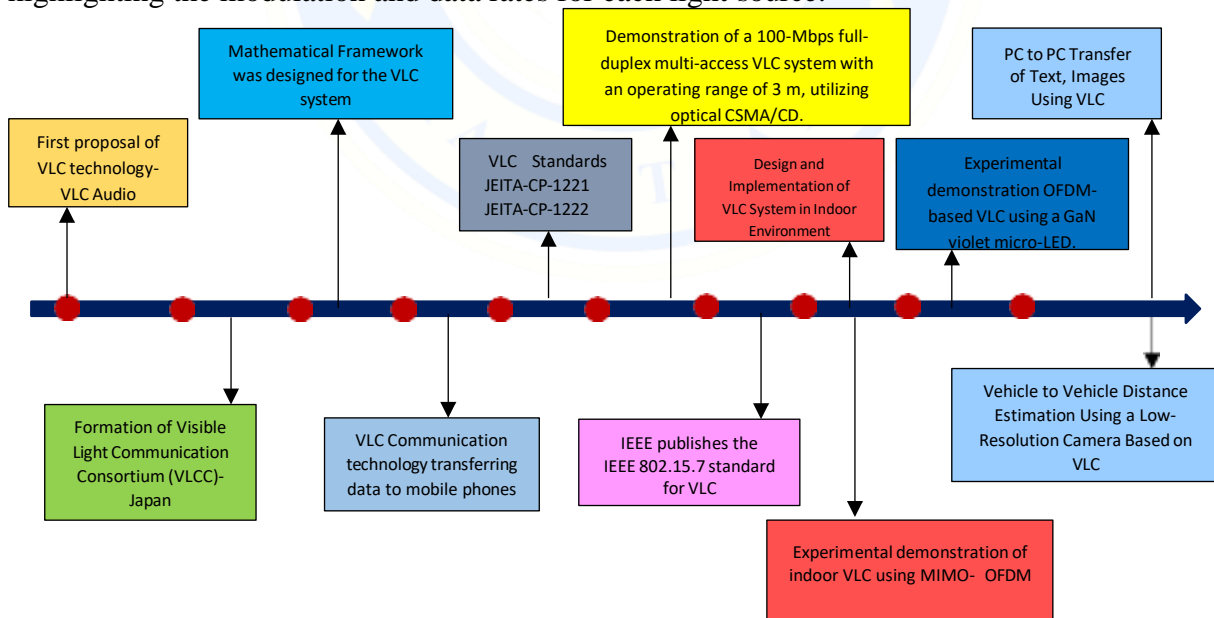

Fig. 2. Timeline of the VLC communication technology

Further, for VLC receiver there are few basic requirements that are required to be fulfilled. These are:

- The wavelength's responsiveness is adequate. For a given optical power which is incident in nature, the output photocurrent can be as high as feasible.

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16

- A high-speed broadband system can be constructed with reaction times that are quick enough.
- High-speed broadband systems can be used with a quick reaction time. To lessen the impact on the signal of the device, the degree of noise should be kept as low as feasible.
- The signal conversion technology has been designed to propagate without distortion using a suitable linear connection.
- Has a small size and a lengthy useful lifetime.

Also, Table II summarizes the different types of recently proposed VLC receiver technology indicating the bandwidth, responsivity and data rates for each VLC receiver.

TABLE I: RECENTLY PROPOSED VLC TRANSMITTER TECHNOLOGY

Sources of Light	Data Rate (Gbps)	Method of Modulation	Distance (m)
White phosphor [13]	1.1	MIMO OFDM	1
RGB- LED [14]	3.375	PAM-8	1
RGBYC-LED [15]	10.72	MIMO-OFDM	1
GaN u-LED [16]	5	OFDM	0.05
GaN Blue LD [17]	2.5	OOK	0.5
Blue LD [18]	18	OFDM	16
Violet LD [19]	26.4	DMT	0.5
Blue LD + phosphor [20]	4	OFDM	0.5
RGB-LD [21]	20.231	OFDM	1
RGBV-LD [22]	26.228	OFDM	2

III. VLC MODULATION TECHNIQUES

The brightness of flicker should not be perceived by users using the VLC modulation technique. According to [29], the flicker can lead to detrimental and significant physiological alterations in the human body. According to the IEEE

802.15.7 standard [30], to avoid harmful consequences, it is vital to alter the level of intensity of the light more quickly than the human eye can detect the blink, or faster than 200 Hz.
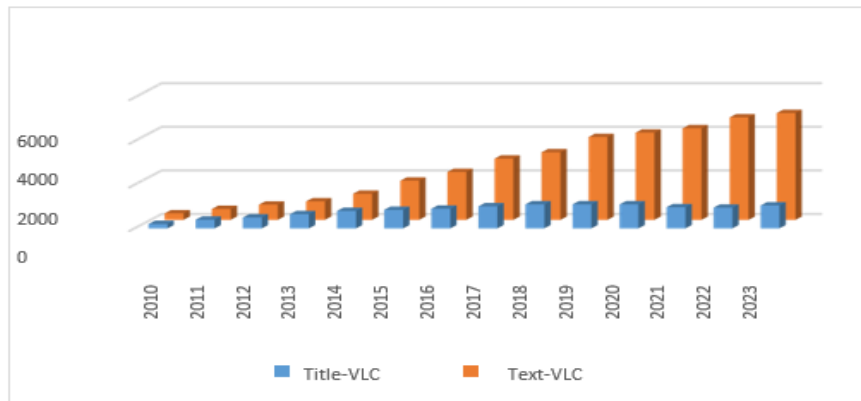

Fig.3: Analysis of "Visible light communication" or the keyword "VLC" in the paper's title

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17

TABLE II: RECENTLY PROPOSED VLC RECEIVER TECHNOLOGY

Type	BW	Data Rate	Responsivity	Chip Material
PD [23]	0.82	-	1.2	Triple Cation perovskite
SL-APD [24]	-	0.5 (PAM8)	-	Silicon
APD [25]	155	-	0.35	silicon
Micro-PD [26]	300	7.4 (OFDM)	0.11	Semipolar InGaN/ GaN PIN
Solar Cell [27]	0.114-0.586	DCO-OFDM	-	Triple Cation perovskite
APD [28]	890	2 (OOK)	0.45	silicon

This implies that the VLC Modulation technique should offer a better data rate while reducing flicker. In view of this, 5 modulation systems are utilized for the VLC communication system. Table III provides the comparison of these modulation techniques.

TABLE III: COMPARISON OF DIFFERENT MODULATION TECHNIQUES

Modulation Scheme	Data Rate	SNR	BER
OOK	Medium	Low	High
V-PPM	low	high	Medium
CSK	Medium	Medium	Medium
OFDM	Very high	high	low
PWM	Very low	high	low

A. On-Off Keying (OOK)

The basic principle involved in OOK modulation scheme is switching ON/OFF the lamp as per the input bits (i.e., 0 or 1). Although the LED indication is not totally off in the off state, step OOK's main benefit is the light intensity reduction. Though this technique is easy to implement still it suffers from problem associated with white light [31]. Lower data rates result when varied dimming settings are maintained. As a result of this problem, the majority of alternative modulation techniques use both pulse position and breadth position.

B. Variable Pulse Position Modulation (V-PPM)

V-PPM is comparable to PPM with the exception of the control that alters the value of the signal's frequency, expressing it as a linear value with the fundamental signal value, and emphasizing modulation design and decoding simplicity. Additionally, because many pulses are broadcast in each symbol-time, it is more spectrally efficient. Further, the capability of VPPM to multiplex with various amounts of dimming in a given frame is one advantage that can aid in achieving optimal resolution [32]. Also, the difficulty in achieving ideal duty cycles is one of VPPM's shortcomings.

C. Color Shift Keying (CSK)

It is feasible to create white LED lights by fusing various colours. There are two ways to do this: The first one is accomplished by combining blue LEDs and yellow phosphor. The disadvantage of this combination is that the yellow phosphor inhibits the responsiveness of the white LEDs.. The combination of blue, green, and red LEDs is the second way to achieve white, and it speeds up communication and the realization of the white colour [31]. Multiple-color LEDs are used to provide CSK modulation. Benefits of using CSK include: The final output colour is first assured by the colour coordinates. Second, whereas the output power of various light sources varies, that of the CSK light source is constant. The dimming of the CSK ensures that the overall power remains constant. Thirdly, the CSK supports the amplitude adjustments of both the digital and analogue converters.

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18

D. Orthogonal Frequency Division Multiplexing (OFDM)

This is one of the modulation techniques that is widely used because it has the ability to lessen the impact of multipath fading and conflicting symbol interference. Compared to the others, it is also the technique of multiple carrier modulation. This modulation method's ability to reduce interference from multipath fading is one of its enefits. It also simplifies the bipolar signals that must be converted into actual signals, which is the second benefit. One of the challenges with OFDM [32] is the nonlinear interaction between light and current. A key problem with OFDM-based modulation is its PAPR (peak-to-average power ratio) is high, which leads to clipping distortion and lowers system performance.

E. Pulse Width Modulation (PWM)

In this modulation system, the pulse widths are balanced according to the expected levels of dimming, and the pulses create digital pulses that are employed to capture the modulation signal. The data transmission happens when the LED is at its brightest. Notably, depending on the required dimming, the data rate can be adjusted as well as accommodated. According to researchers, the PWM frequency modulation technology can achieve a dimming level between 0% and 100%. One advantage of this plan is that it can attain the highest dimming level without changing the brightness of the light, obviating the need to define on and off levels. The fact that PWM's data rates are constrained to
4.8kbps [31] is one of its drawbacks.

IV. APPLICATIONS

VLC has numerous uses, including interstellar communication and quantum communication, and high- speed internet chains with LED lights. VLC also adds a fresh viewpoint to the widely used field of computers. This section discusses about different applications of VLC different applications of VLC in different fields.

A. Li-Fi

Li-Fi, like Wi-Fi, is a bidirectional visible light wireless communication system. These technologies give a superior solution in regions susceptible to radiofrequency radiation, for example, airplanes and in medical like hospitals by avoiding problems related to interference with other radio signals. This technology can offer multi-Gb/s connections.

B. Optical wireless communication in RF-restricted environments

In areas where RF communication is limited, VLC can be employed in a safe manner to facilitate the wireless communication technology. In hazardous circumstances, VLC is seen as a safe comparison to radio frequency communications. Furthermore, it is advantageous in applications where regular WLAN technology conflicts with specialized equipment in hospitals, etc.

C. Transportation

Outdoor intelligent transportation is a promising application of VLC technology. VLC is used in infrastructure for vehicle lighting and traffic lights to maintain efficient connections between vehicles and infrastructure. By leveraging VLC technology, it is possible to control road safety and traffic flow. These systems can also give lane- change alerts, cooperative forward collision alerts, pre-crash warnings, and other features. Furthermore, this strategy has the potential to increase transportation system safety and efficiency.

D. Underwater Communication

VLC technology can be effectively used in complex energy-consuming acoustic transceivers with low BW and high latency. VLC communication can easily provide much higher transmission BW with high data rates of around Gbps. VLC also can achieve short-range communications under sea sensors, underwater robots, etc. to communicate with one another or with the base station.

E. Indoor Localization

Since traditional GPS cannot operate inside of buildings, VLC-based localization is highly useful in interior environments [33]. The widespread use of LED lighting has special possibilities for indoor localization [34]. In uncommon environments like skyscrapers and

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19

subways, visible light can be utilized as an identification system. The visible light ID method is used to identify the location, which is usually the building and the space. Similar to this, hospitals, airports, and subways may all implement visible light identification systems. When the ID specifies the transmitter's coordinates, the system can be extended.

V. CHALLENGES

This section discusses potential techniques to improve the performance or VLC system technology's data rate. Different challenges and their potential solutions are discussed as follows:

i) Humans see flickering as fluctuations in light intensity. To prevent flickering in VLC, which could have harmful consequences on human health, lamps must be adjusted [84]. Blinking can occur between frames or even within them, based on the image size. The brightness difference between the frame bits is thought to be the cause of flickering within the frame, but the brightness difference between the frames is thought to be the result of the packet's sending and idle times. The service period of the pulse train is configured to monitor brightness during PWM, but when data speed is slow or there is a lot of idle time, the blink is more obvious compared to data time. As a result, developing modification ways to reduce flickering is an active study subject.

ii) Different luminance levels are necessary for different tasks, such as 30-100 lux for regular tasks and up to 1000 lux for strong illumination in offices. Therefore, the algorithms for opacity must be created to provide the required luminescence in a certain area.

iii) It's critical to evaluate the effectiveness of various coding for channel algorithms in VLC. Turbo codes with a lot of memory commands should be utilized for improved performance because VLC's bandwidth is too low. For element decoders, several decryption algorithms including Maximum a Posteriori (MAP), Log-MAP, and Max-Log MAP [35] must be confirmed and validated. Codes for linear block, like the (23,12,7) Golay code [36], can also be used to improve efficiency in VLC.

iv) The effectiveness of VLC systems is constrained by noise from ambient light sources. To reduce background noise, Manchester encoding was employed in [37] without active control or input. In [38–39], many methods to lessen noise in the background are suggested. To decrease background noise, Manchester and Hadamard encoding were used [40]. Networks for coding that use rectangular frame codes, turbo codes and coiled keys are used to boost the VLC device's performance. In comparison to codes for linear block and codes with convolutions, turbo also called accelerated codes perform better, but at the expense of a costly and challenging decoder. Since VLC's maximum bandwidth is limited, employing turbo codes is preferable. As a result, to reduce more noise efficiently, new codes should be devised than those already in use [41].

v) It's also a free search engine for examining the effectiveness of particular VLC's target junction rectifier. The performance, complexity, and cost trade-offs between various diodes with images, for example photonic silicon junction rectifier, PIN Photodetector, and photodiode failure, can be made in VLC. Although PINs are less expensive, having improved storage, and work well in more noise environments, avalanche optical diodes are still quite useful.

VI. CONCLUSION & FUTURE WORKS

This paper presents a review of VLC communication technology highlighting the VLC transmitter and receiver technology with different modulation schemes. Also, paper highlights the pros and cons of different modulation schemes utilized. Further, this review also presents the different application areas of the VLC communication technology with open research challenges to VLC. Also, the advancement of modules with lower energy production and consumption between the user device and communications infrastructure may affect overall system performance in terms of QoS and grade of service (GoS). as well as battery life, device efficiency, and lessening overheating, among other things. The advancement of highly spectral efficient signal processing techniques that will maximize the optical spectrum available for high throughput deployment, will be another area of research.

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20

Also, development of external noise-resistant systems using a variety of AI approaches that will revolutionize the VLC field among other prospective advances. This will also have an impact in the automation of the communications pathway to dynamically adjust the ambient interfering light sources, regardless of the application domain (inside or outdoor). In addition, this will lead to the creation of intelligent alignment of Li-Fi transceiver and monitoring modules to overcome LOS difficulties, effective source and detector designs to avoid saturation from background noise and light sources as well as the development of high-performance roaming/mobility algorithms for managing RF-VLC and VLC-VLC mobility.

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23