

Visible Light Communication: A Short Review

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Abstract

This work presents a general and introductory review of visible light communication. Visible light communication or VLC refers to wireless communications using a spectral range from 380 to 780 nm for the transmission of information. This part of the optical-electromagnetic range presents some advantages to current wireless radio frequency technologies, as well as several challenges to its development and application. Different visible light communication systems have been developed for indoor, outdoor, domestic, and industrial fields where the luminaire performs two tasks: general lighting and data transmission, since this type of communication has important and valuable applications. Recently, research has been performed to improve each functional block's performance that composes this kind of communication system. The incursion VLC poses challenges such as LED bandwidth limited by the carrier lifetime, the LED-Driver Linearity, it's up-link; the general lighting infrastructure to the internet; and the dimming and general lighting performance. It is concluded that the incursion of Visible Light Communication into the already extended spectrum of wireless communications systems will complement and make it less harmful to our environment as international regulation has helped to improve this technology substantially.

Keywords: *Optical wireless communication; Visible Light Communication; VLC; lighting emitting diode; photodiode; modulation.*

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Comunicación con luz visible: una breve revisión

Resumen

Este trabajo presenta una revisión general e introductoria de la comunicación de luz visible. La comunicación con luz visible o VLC (por sus siglas en inglés) se refiere a las comunicaciones inalámbricas que utilizan un rango espectral de 380 a 780 nm para la transmisión de información. Esta parte del rango óptico-electromagnético presenta algunas ventajas para las tecnologías de radiofrecuencia inalámbrica actuales, así como varios desafíos para su desarrollo y aplicación. Se han desarrollado diferentes sistemas de comunicación de luz visible para el ámbito interior, exterior, doméstico e industrial, donde la luminaria realiza dos tareas: iluminación general y transmisión de datos, ya que este tipo de comunicación tiene importantes y valiosas aplicaciones. Recientemente, se han realizado investigaciones para mejorar el desempeño de cada bloque funcional que compone este tipo de sistema de comunicación. El VLC de incursión plantea desafíos como el ancho de banda de LED limitado por la vida útil del operador, la linealidad del controlador de LED, su enlace ascendente; la infraestructura de iluminación general a internet, y el rendimiento de la iluminación general y de atenuación. Se concluye que la incursión del VLC en el ya extendido espectro de los sistemas de comunicaciones inalámbricas complementará y hará menos nociva para nuestro medio ambiente, ya que la regulación internacional ha ayudado a mejorar sustancialmente esta tecnología.

Palabras clave: Comunicación óptica inalámbrica; Comunicación con luz visible; VLC; Diodo emisor de luz; Fotodiodo; Modulación.

1. Introduction

Optical Wireless Communication (OWC) refers to the generating wireless link using electromagnetic waves in a spectral range from infrared (IR) up to ultraviolet (UV) including the visible light spectrum (VIS). The distance transmission of the optical link defines the application field and the spectral range used in the communication (Uysal & Nouri, 2014). The Ultra Short-Range applications are defined in cover ranges of millimeters and micrometer. This type of communication is used in super computers where conventional transmission channels such as copper waveguides are replaced by optical links for both inter and intra-connection between chips. The short distance range OWC applications are defined in the range of tens of centimeters. Its application is focused on wireless networks of the body area or Wireless Body Area Network (WBAN), biosensors are wirelessly connected to a central computer through waves located in the visible spectrum. This type of ranges is also applied to communication in Wireless Personal Area Network (WPAN) in order to generate links between different kind of devices such as TV-SmartPhone or SmartPhone-SmartPhone. Medium distance range applications are defined in the order of meters, and used in Wireless

Local Area (WLAN), which currently works with WiFi in RF range. Visible spectrum is used in this type of link because the existing general lighting infrastructure can be used to carry out the transmission. Long distance range applications are links with communication distance of a few kilometers. These application are high-speed links applied in the WLAN-WLAN interconnection, and are currently evaluated for the connection between the end user and the high-capacity fiber optic infrastructure. Finally, the Ultra Long Range applications with links greater than 10.000 km for Earth-Satellite or Satellite-Satellite connections (NASA, 2013).

Visible Light Communication (VLC) refers to wireless communications using a spectral range from 380 to 780 nm for the transmission of information (O'Brien, Zeng, *et al.*, 2008). The light sources used in VLC are based on solid-state devices, LED, OLED, and PLED. The principal feature of these light sources is switching capacity at high speeds; this feature modulates the light source for sending data using visible light as a transmission medium while a certain area is illuminated. VLC has several advantages concerning the Radio Frequency (RF) wireless communications. For example, free use of the visible spectrum, increasing security in communication, the greater optical bandwidth (near to 300THz) compared to the available RF spectrum (near to 300 GHz) (Rajagopal *et al.*, 2012), and null electromagnetic interference (Monteiro & Hranilovic, 2014). Besides these advantages, this technology has gained attention due to the high demand for mobile data services in the urban city center (Uysal & Nouri, 2014), which has led to the saturation of the spectrum in radio frequencies. However, this emerging technology faces challenges such as bandwidth increasing, the LED-Driver non-linearities, the generation of uplink, and the VLC impact on general lighting performance, among others. During the last 15 years, academic works related to the improvement of LEDs for VLC, new VLC modulations, drivers, commercial products, business alliances, and normative documents related to VLC have been developed for indoor applications. In January 2009, IEEE held the inaugural meeting for IEEE 802.15.7, the normative document that defines the physical (PHY) and media access control (MAC) layers for short-range optical wireless communications using visible light.

This paper presents a general review of visible light communication. Section 1 shows the advantage and disadvantages of the VLC against RF. Section 2 presents the main application fields of the VLC for indoor systems. Section 3 depicts the main components of the VLC system. Section 4 introduces recent developments related to implementing the VLC systems for indoor applications. Finally, section 5 focuses on the main challenges that this technology faces.

2. VLC vs RF Aspects

The VLC technology, as well as infra-red OWC, has several advantages. RF communication works on a frequency range between 30kHz to 300GHz, while OWC occupies a spectrum between 120THz (near Infrared) and 780THz (short wavelengths of the visible spectrum), occupying approximately 670THz of the spectrum (Dimitrov & Haas, 2015), therefore a much broader spectrum is available for OWCs. Specifically, the VLC 300THz is available. A large amount of spectrum imposes high-speed transmissions, which is the main advantage of the OWC. On the other hand, the RF spectrum is regulated and controlled by local and international authorities, such as cellular operators, television, or microwave point-to-point links. The spectrum of optical communications is not licensed, which facilitates the development of applications and reduces implementation costs (Uysal *et al.*, 2016).

Another aspect is that communication systems based on OWC present greater robustness concerning electromagnetic interference since this phenomenon does not occur within this range. Conversely, RF communications must handle this issue (Morgan, 1994; Chow, 2015). Regarding the coverage distance, wireless RF communications can pass through any obstacle between the transmitter and the receiver. Even though they attenuate the propagation of the waves, these wireless systems support vast communication distances. For OWC and VLC, communication is limited and confined to the illuminated space, mostly requiring a line-of-sight (LoS) for good communication. This fact has two advantages for indoor applications: the reduction of interference between devices and easy control of the users who can use the link. The last one improves the security of the transmission but limits OWCs since they are not applicable when mobility services are required.

Table 1. Comparison between VLC and RF technology

Property	VLC	RF
Bandwidth	300Thz (theoretical)	300GHz
EMI	No	Yes
Line of sight	Yes	No
Standard	Beginning	Matured
Power consumption	Relative to the lighting power.	low, Medium
Visibility security	Yes	No
Infrastructure	LED Illumination	Access Point
Mobility	Limited	Yes
Coverage Distance	Narrow Short	Wide

Source. Adapted from "Optical wireless communications: system and channel modelling with Matlab®" by Z. Ghassemlooy, W. Popoola, and S. Rajbhandari (2019). Copyright 2019 by CRC press.

The use of the VLC presents a solution for providing communication services since it is a low-cost technology and energy consumption is decreased. Since it already has the LED infrastructure for lighting, it is not necessary to implement or develop new devices that fulfill the function of antennas. The light source already fulfills this task. On the other hand, the construction cost of VLC systems is cheaper than RF systems, and the complexity of the VLC modulators/demodulators and optical antennas is more straightforward than the specialized devices used for RF communications (Rajagopal *et al.*, 2012). Table 1 shows a summary of some comparative aspects between RF and VLC.

3. Applications

There are several applications where communications are performed with visible light; some track vehicle-to-vehicle communication, location-based services, personal and local area networks, and areas where RF is not permitted. These applications are explained in detail below.

3.1. Indoor Positioning by LED

The typical indoor positioning system based on GPS, IR, RFID, Bluetooth, WLAN, or ultrasound presents problems due to system instability, long response time, low accuracy, and low precision (Allycan Mapunda *et al.*, 2020), (Zhang *et al.*, 2013b). Therefore, the VLC is emerging as an attractive technology for indoor positioning systems using lighting equipment (Rahman *et al.*, 2011; Afzalan & Jazizadeh, 2019). The authors (Pham *et al.*, 2019) presented an indoor positioning system based on VLC and reported an experimental accuracy of 2.56 cm. In (Wang & Shen, 2019) presented a prospective study of machine learning algorithms applied to VLC-based indoor positioning systems. Li *et al.* (2018) presented an indoor position system, where a smartphone camera was used as a VLC receiver, coding information data in the on-off keying format.

3.2. Wireless Personal Area Networks

High demand for mobile data services has motivated using VLC technology in Wireless Personal Area Networks (WPAN) (Chi *et al.*, 2020). It aims to increase the bandwidth and data rate connection. In this type of computer network, the connection can be made among devices such as computers, phones, printers, tables, or a higher-level network, where the typical maximum data transfer rates are between 400 and 700 kbps and communications distances typical of 10 m (Halsall, 2006). The working group IEEE 802.15 develops Personal Area Network standards for short-distance wireless networks. In the Omega project, their VLC demonstration consists of the VIDEO HD signal transmission to four video players through Ethernet stream and by the modulation of driver current to 6 high-power LED lamps (O'Brien, Faulkner, *et al.*, 2008).

3.3. RF Area

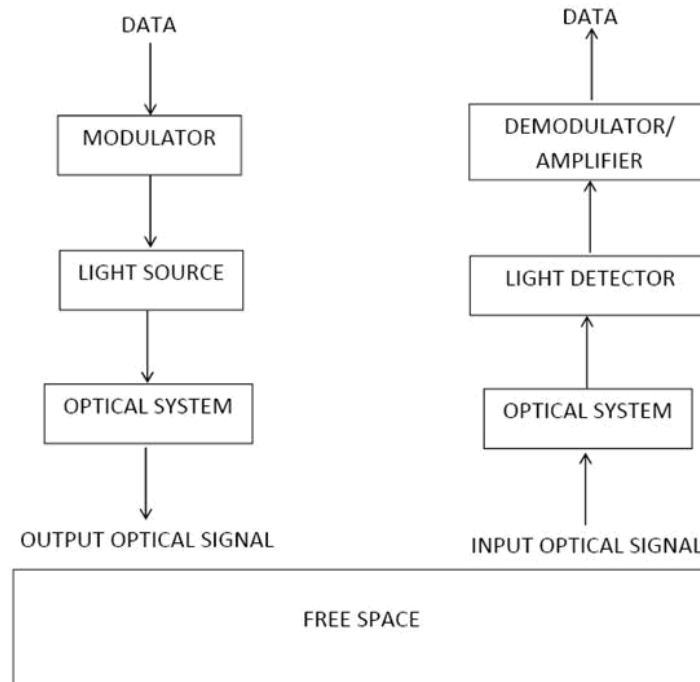
There are areas where the use of radio frequency is forbidden (*e.g.*, hospitals). There are reports describing device malfunction related to electromagnetic interference due to cellphones. Electromagnetic interference is the unwanted reception of electromagnetic (EM) waves in medical devices, in which either analog or digital signal in instruments is altered (Lapinsky & Easty, 2006). This issue is avoided in VLC since it does not generate electromagnetic interference (Kumari *et al.*, 2021). Other RF-free areas include airplane lights that can interfere with aircraft navigation systems (Alsulami *et al.*, 2020) and explosion risk areas (Bradby, 2008).

3.4. Vehicle to Vehicle, and Vehicle to Infrastructure

With the introduction of LED technology to traffic signals, vehicles lamp, and transport systems, many intelligent vehicle safety applications have been developed (Shaaban *et al.*, 2021). The U.S. Department of Transportation developed the Vehicle Safety Communications Project. The National Highway Traffic Safety Administration March 2005 presented the report of the result for the Identify Intelligent Vehicle Safety Applications; some of them were violation warning and curve speed warning, left turn assistant, stop sign movement assistant, lane change warning, cooperative forward collision warning, precrash sensing, and emergency electronic brake lights, among others. In the case of a traffic signal violation warning, the lighting road infrastructure transmits the vehicle to the state of the road so that drivers can be assisted while traveling. The project defined the requirements for each application, the transmission mode, minimum frequency, allowable latency, data to be transmitted and received, and maximum required range of communication (The CAMP Vehicle Safety Communications Consortium, 2005; Zadobrischi *et al.*, 2019).

4. A Basic VLC System

Figure 1. Functional diagram block of VLC system



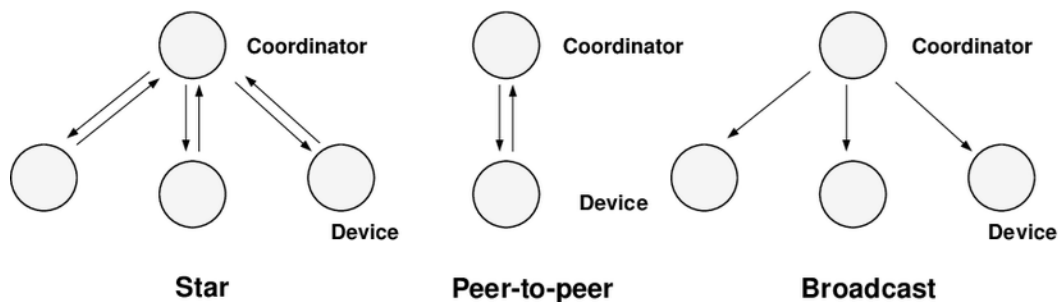
Source. Author's own.

The VLC is a type of data communication where the transmitted signal is an electromagnetic wave in the visible range propagated in free space. A typical VLC system applied to general lightning is illustrated in Figure 1. A basic optical wireless system consists of a light source, a propagating medium such as free space, and a light detector. Data is sent via digital or analog signals through an electronic circuit that modulates the light source. The light output passes through an optical system, such as filters, lenses, or reflectors. Subsequently, light travels through free space and is received by a light detector composed of concentrating lenses, color, and noise filters. The light detector generates an electric signal which will be decoded to recover original information (Elgala *et al.*, 2011).

4.1. IEEE 805.15.7 Standard

The IEEE Standard for local and metropolitan area networks in section 15.7 defines PHY and MAC layers for short-range optical wireless communications using visible light in optically transparent media (IEEE, n.d.). Aspects such as data rates to support multimedia services, mobility of the visible link, compatibility with lightning infrastructure, interference, noise from ambient light, and eye safety regulations are considered in this standard. The standard defines three types of devices for VLC: infrastructure, mobile, and vehicle; each is applied in three topologies: peer-to-peer, star, and broadcast, as shown in Figure 2.

Figure 2. Supported MAC topologies at IEEE 802.15.7



Source: Adapted from "IEEE Standard for Local and metropolitan area networks--Part 15.7: Short-Range Optical Wireless Communications" (IEEE Standards Association, 2019, p. 22).

Table 2. Description of the PHY layer for IEEE 802.15.7.

	Data Rate	Modulations
PHY I	Low: tens of hundreds kbps	OKK, VPPM
PHY II	Moderate: tens of Mbps	OKK, VPPM
PHY III	Moderate: tens of Mbps	CSK

Source. Adapted from "IEEE Standard for Local and metropolitan area networks--Part 15.7: Short-Range Optical Wireless Communications" (IEEE Standards Association, 2019, p. 233).

4.2. Modulation Techniques

Studies and developments made for VLC have allowed the writing of the IEEE 802.15.7 standard, which was introduced to standardize the different communication schemes for visible light modulation techniques (Gao, 2013). This standard includes three modulations: On-Off Keying (OOK), Variable Pulse Position Modulation (VPPM), and Color Shift Keying (CSK). Table 2 shows the classification of these modulation schemes according to the data rate supported. Other modulations are compatible with the VLC principle, such as Orthogonal Frequency Division Modulation (OFDM). OOK is the simplest because, in this modulation, the data is represented as the presence or absence of light; therefore, it can transmit one bit. Although the complete modulator scheme includes encoders for non-return to zero and Manchester (Singh, 2015), the IEEE standard 802.15.7 Section 2 recommends Manchester codes (IEEE, n.d.). VPPM utilizes the basic principle of OOK modulation but adds a variation of the pulse duration; the pulse duration can be used to control the emitted power of the light source. For the multisubcarrier modulation, the information is represented in one another orthogonal carriers. The sum of these carriers generates the transmitting signal.

There are several schemes for multi-carrier modulations proposed for VLC (Lin *et al.*, 2018; Durukan *et al.*, 2019), and the optical OFDM is one of them (Deepa & Mathur, 2019; Zhang *et al.*, 2021; Singh, 2015). The basic idea of OFDM is to divide the transmission spectrum into orthogonal narrower bands, thus achieving sub-channel overlaying (Zhang *et al.*, 2021). There are two types of OFDM modulation: DCO-OFDM and ADC-OFDM (Khalid *et al.*, 2012; Ntogari *et al.*, 2011; Elgala *et al.*, 2007). Another multi-carrier scheme is the CSK. This modulation sends the information by configuring several colors in the luminaire and using these colors as symbols are mapped the bits of information. By controlling the intensity of RGB components, the luminaire chromaticity point is defined (Monteiro & Hranilovic, 2014; Singh, 2015). Finally, a Metameric Modulation, unlike CSK modulation, does not change the chromaticity point that the light source emits, it uses different color gamuts to transmit information (Butala *et al.*, 2012).

4.3. Light Source

The development of lighting helped to the emergence and improvement of light source technology in aspects such as cost, low power, high light efficiency, high color quality, and increased lifetimes (Malacara, 2002). LED lighting is currently the most used solid-state lighting technology, applied to industrial and domestic areas, indoor or outdoor architecture, and traffic control, among others (O'Brien, Zeng, *et al.*, 2008). Light sources based on solid-state devices, such as LED, Organic Light-Emitting Diode (OLED), and Polymer Light-Emitting Diode (PLED), have shown to be future technologies with great advantages in their performances. One of these advantages is the rapid on-off commutation ability, which allows transmitting data using the light as a carrier signal.

Radiative recombination of electron hole pairs in the depletion region allows LED to generate light when a p-n junction is biased in the forward direction (Agrawal, 2003). This phenomenon is called spontaneous emission. LED spectrum depends on the wavelength of the photons emitted in a radiative recombination event, which is determined by band gap energy. LEDs are made of different semiconductor materials, and each material has a characteristic band gap energy (E_g). The principle of coating phosphor layers is based on the absorption and re-emission of light. The absorption of blue light (excitation) causes the phosphor layers to emit a specific color (Agrawal, 2003).

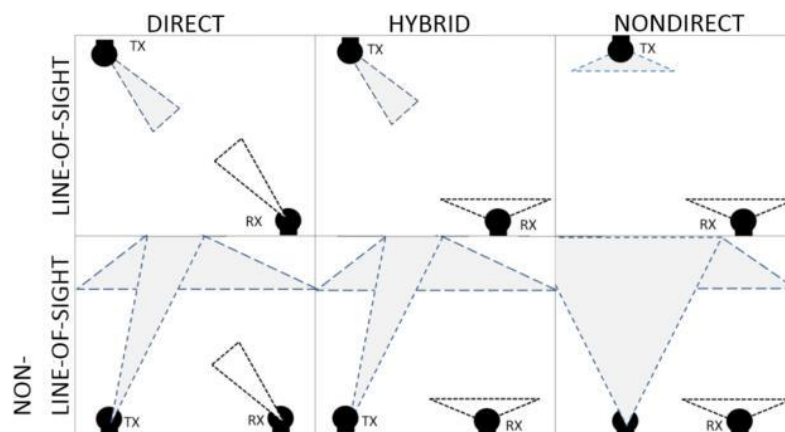
In a general lighting system, two types of LED are used: Phosphorescent White LED and RGB LED. Phosphorescent White LED is the most used technology in the lighting system (Ntogari *et al.*, 2011). The White LED uses a phosphor material to convert blue light to a broad-spectrum white light, like how a fluorescent lamp works. These white phosphor LEDs have benefits concerning long life expectancy, efficacy, minimal heat generation, and color quality performance (Dimitrov & Haas, 2015). On the other hand, RGB-LEDs are used in specific applications such as decorative indoor and outdoor lighting, lighting for agriculture, and traffic signal lighting, among others. However, RGB-LED is not used for indoor lighting because this technology does not have a good color quality performance.

A luminaire is composed of elements that allow for the distribution, filtering, or transformation of light coming from light sources. Thus, a luminaire contains all the items needed for fixing, protecting, and connecting the lamps to a power supply. The LED Driver is the electronic circuit that controls luminous flux through two common methods: analog control or Pulse Width Modulation (PWM). According to the operational principle of LED, the luminous flux has an approximately linear relationship with the forward current. Therefore, the forward current determines the lumen output.

4.4. VLC Links Design

There are six types of VLC links that are shown in Figure 3. These designs are classified under two criteria. The first one is the degree of directionality of the transmitter and receiver. The second criterion is related to whether the link relies upon the existence of a line-of-sight (LOS) uninterrupted or directed between the transmitter and receiver. The performance of data transmission depends on the type of link established. Directed and LOS link design maximizes power efficiency since it minimizes path loss and reception of ambient light noise (Kahn & Barry, 1997). The link used for data communication defines system performance and the error sources.

Figure 3. VLC links design



Source. Author's own.

4.5. Light Detector

A light detector is a solid-state photodiode that converts optical signals into electrical signals. An output current proportional to the incident flux is delivered using the photoelectric effect (Agrawal, 2003). The effectiveness of converting the light power into the electric current is called responsivity; this is defined as the ratio of the photocurrent and the incident light power at a specific wavelength. The semiconductor photodetectors are made from different semiconductor materials such as silicon, germanium, indium gallium arsenide, and indium antimonide. Each material has a characteristic bandgap energy (E_g) which determines its light-absorbing capabilities (Graeme, 1995).

5. Some VLC Developments

Between 2008 and 2011, the OMEGA project “Home Gigabit Access” was developed in Europe (Le Minh *et al.*, 2010). In February 2011, this project presented the results of its work; it was concluded after exposing two systems using VLC and IR that the data rate reached up to 100 Mbits/s and 280 Mbits/s, respectively, for transmitting high-quality video chains of Ethernet bits. In November 2013, Japan created the Visible Light Communication Consortium (VLCC), established for researching, developing, planning, and standardizing the optical communication system. Some companies involved in this consortium are Panasonic Corporation, Toshiba Corporation, Casio Computer Co. LTD, Nak-agawa Laboratories, Inc, and Tamura Corporation (VLCC, 2007).

Regarding modulation developments (Liu *et al.*, 2012), OOK was used via white LED lighting based on phosphor-based white LEDs; transmission reached speeds between 0.1 and 10 Mbps, achieving a link distance of 0.5 m and low bit error rates with a carrier frequency of 200 MHz. In (Zhang *et al.*, 2013a), the implementation of a VLC parallel transmission system using the multi-phase OOK modulation (MP-OOK) was performed, and its results were compared to DC-biased optical OFDM (DCO-OFDM). MP-OOK was improved by N times the bandwidth efficiency regarding conventional OOK modulation, where N is the number of LED lines that transmit to the same phase. However, it could not reach the DCO-OFDM

transmission speeds. According to Tuo *et al.* (2012), a VLC system with a bandwidth of 85 MHz and data rate of 250 Mbps using white LED with a commercially available phosphor layer was developed. Furthermore, a polarization-T circuit was implemented in the transmitter to control the current over the LED and a post equalizer in the receiver to decrease the bit error rate.

Khalid *et al.* (2012) developed a communication system with visible light using discrete multitone modulation, and considering the effects of the linearity of the LED and the power circuit of a LED, speeds of 1 Gbps were attained. Moreover, transmission rates were shown as 680Mbps with low illuminance levels of 10 luxes. The design and implementation of a CSK were presented in Monteiro & Hranilovic (2014), where the author designed of the constellation of points on the CIE-1931 color space. Some other considerations were considered besides the ones defined in IEEE 802.15.7. The constellation exploration utilized a three-dimensional color space, studying and modeling the transmission channel and optimizing of data transmitted symbols considering the light source's color temperature, electric current supply, and the total luminous flux by symbol. In Chen and Chow's study (2014), the decoding of CSK is performed for multiple user access using a code division multiple access techniques.

Further works have been studied in developing detection devices; the traditional photodetectors for OWC and VLC links are designed using-solid state detectors type P-N, P-I-N, or avalanche, usually built with silicon, germanium, and Indian arsenide gallium alloys (Agrawal, 2003). These detectors have responsivity throughout the visible spectrum, with bandwidths between tens of MHz and tens of GHz. They have been widely studied in the implementation of fiber optic communication systems. A new type of VLC receiver based on an image sensor has been explored. Recent works report implementation of cameras on mobile phones as VLC receivers (Nguyen *et al.*, 2019; Rahman *et al.*, 2021; Teli *et al.*, 2021; Chavez-Burbano *et al.*, 2021). This technology is known as Optical Camera Communications (OCC) (Saeed *et al.*, 2019). In (Boubezari *et al.*, 2016), phone-to-phone communication is

implemented using the screen of one device as a transmitter and the camera on the other device as a detector, achieving transmission speeds close to 300 kbps.

6. Challenges

6.1. LED Bandwidth

The modulation response of LEDs depends on carrier dynamics and is limited by the carrier lifetime. Typically, carrier lifetime is in the range of 2.5 ns for InGaAsP~LEDs. The corresponding LED modulation bandwidth is in the frequency range of 50-140 MHz (Agrawal, 2003; Lee, 2015). By using a heavily doped active region, the carrier radiative lifetime can be augmented up to 100 ps, corresponding to a 1.7 GHz modulation bandwidth (Fattal et al., 2008). The process of absorption and re-emission of light in the phosphor layer limits the response of the modulation bandwidth of the commercial phosphor white LED to 2 MHz. A challenge is to increase the modulation bandwidth of commercial phosphorescent white LED. To increase the bandwidth limitation, a blue filter can help remove the slow phosphor response, increasing the bandwidth up to 20 MHz (Grubor et al., 2008). Other possible ways to increase the bandwidth of the optical link are equalizing the transmitter/receiver response (as is shown in Lu et al., 2019) and using bandwidth-efficient modulation schemes.

6.2. LED-Driver Linearity

The Driver allows to control the current in the LED using a voltage signal as an input of this device. Furthermore, when a forward voltage is applied to the LED, a current pass through the diode. This means that the voltage signal at the driver input carries information; because of this, the relationship between this signal and the LED current has to be linear (Lee, 2016). Otherwise, intermodulation will occur, distorting the signal and generating intermodulation-related noise. In optical systems, the LED is a significant source of non-linearity and essential when an analog OFDM modulating signal is used (Elgala *et al.*, 2011). In a commercial luminaire, a nonlinear relationship between control voltage LED Driver and output current will also generate intermodulation, distorting the signal and generating intermodulation noise.

5.3. Up-link

5.4. General Lighting Infrastructure to Internet

Data communication with visible light is mainly implemented in broadcasting applications since VLC channels are naturally broadcast (down-link) channels. There are some ways for generating duplex communication, and all of them involve isolating something: uplink and downlink via wavelength time code or spacial and optical isolation (Bhalerao *et al.*, 2013). Isolation by wavelength uses an uplink with IR spectrum, thus making that data flow simultaneously in both directions. However, this approach may require alignment or tracking (Alsulami *et al.*, 2019). Wavelength multiplexing techniques and time are used to separate the uplink and downlink.

5.5. Dimming and General Lighting Performance

A principal requirement for VLC is that the light source has to be on. During the day, the consumer turns off the lighting system, and the VLC link disappears (El Gamal et al., 2021). Dimming support is another important consideration for VLC. Dimming support is defined as controlling the brightness of the lighting source according to the user's requirements. It has been used to provide moods, energy savings, and ecological benefits. In VLC, the dimming allows maintenance of the VLC communication when the light source is off (Guo, 2020).

The evaluation of a lighting system applied to a specific space is performed to determine whether the conditions that give the luminaires are appropriate within the space and application. This performance can be characterized in terms of the delivered light output, the illuminance on the surface of interest, the quality, and color perception of the incident light, and the efficiency and energy consumption that the system requires (Ministerio de Minas y Energía, 2010). A VLC system should comply with the requirements of general lighting and wireless communication systems. Specifically, the implementation of the CSK in indoor spaces faces a challenge in color quality because the use of the monochromatic LED presents a low color rendering index, which limits the use of this modulation in indoor VLC systems (Gutierrez, 2018).

6. Conclusion

Visible Light Communication VLC is a complementary technology to actual RF communications. Recent research in smart lighting systems has enabled its development in indoor and outdoor applications, specifically in domestic fields where the luminaire performs both lighting and data transmission. Furthermore, the existing international regulation has helped to improve this technology substantially. The incursion of this technology into the already extended spectrum of wireless communications systems will complement and make it less harmful to our environment.

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