

Visible Light Communication LED based Luminaire for General Lighting: State of Art

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Abstract--The use of the LED technology has been increasing in the last years due to the advantages of this technology with respect to the current lighting technologies; one of these advantages is his rapid on-off commutation ability allowing the data transmissions using the light as channel. In this work we will determine the state of art of Visible Light Communication, in order to obtain enough information allowing select and implement some of these visible light communications systems, and evaluate the VLC impact about color quality, comfort and efficacy of the general lighting

Index Terms- Visible Light Communication, Digital Modulation, Light Emitting Diodes, Photodiode, General Lighting System.

Nomenclature

CSK	Color Shift Keying
IR	Infrared
LED	Light Emitting Diode
MAC	Media Access Control
OFDM	Orthogonal Frequency-Division Multiplexing
OOK	On-Off Keying
PHY	Physical Layer
UV	Ultraviolet
VIS	Visible Light Spectrum
VLC	Visible Light Communication
VPPM	Variable Pulse Position Modulation
WPAN	Wireless Personal Area Network

I. INTRODUCTION

Optical Wireless refers to generation of a link using electromagnetic waves in a spectral range from infrared (IR) and ultraviolet (UV) including the visible light spectrum (VIS). This technology has gained attention due to the high demand of mobile data services in urban city center [4]. The other hand, Visible Light Communication (VLC) refers to wireless communications using a spectral range from 380 to 780 nm for the transmission of information [3]. This type of communication has several advantages respect to the RF

wireless communications, such as free use of the visible spectrum, increased security in communication, the bandwidth 300THz [3] and null electromagnetic interference [4]. Table I shows some comparative aspects between RF and VLC.

The development of lighting has allowed the emergence and improvement the technology for light sources in factors such as cost, low power, high light efficiency, high color quality and increased lifetimes [1]. Light sources based on solid state devices, LED (Light Emitting Diode), OLED (Organic Light Emitting Diode) and P LED (Polymer Light Emitting Diode) have shown be high future projection technologies with significant advantages in performance. LED lighting technology is currently most commonly used solid-state and developed and it has also been developed, with applications in industrial and domestic areas, for indoor or outdoor architecture, traffic control and other [2].

TABLE I
COMPARATIVE ASPECTS BETWEEN RF AND VLC

Property	VL Comm.	RF Comm.
Bandwidth	Unlimited, 400nm~700nm	Regulatory, BW Limited
EMI	No	Yes
Line of sight	Yes	No
Standard	Beginning	Matured
Power consumption	Relatively low	Medium
Visibility security	Yes	No
Infrastructure	LED Illumination	Access Point
Mobility	Limited	Yes
Coverage, Distance	Narrow, Short	Wide, Medium

The generation of the IEEE 802.15.7 standard is introduced to defines a PHY and MAC layer for short-range optical. Wireless communication using visible light in optically transparent media [8]. This emerging technology faces challenges in increasing bandwidth limited by the slow response of the commercial phosphor coated LEDs, LED nonlinearities and Driver, uplink, among others. The evaluation of a lighting system applied to a specific space is performed in order to determine whether the conditions that give the luminaires are appropriate with 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 of the system

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requires [16].

II. OVERVIEW

In Europe during three years (January 2008 to March 2011) the project OMEGA "hOME Gigabit Access" was developed, and it implemented a 1 Gigabit/second (Gbps) data rate via interior lighting system [6]. In February 2011, the project presented the results of its work, which included exhibition of the VLC systems and infrared systems, achieved data rate of 100Mbit/s and 280Mbit/s respectively [7].

In January 2009, IEEE called the inaugural meeting of IEEE 802.15 WPAN Task Group 7 (T G7x) Visible Light Communication; IEEE 802.15.7 define the Physical (PHY) and Media Access Control (MAC) layers for short-range optical wireless communications using visible light. The standard will provide (i) access to several hundred THz of unlicensed spectrum; (ii) immunity to electromagnetic interference and noninterference with RF systems; (iii) additional security by allowing the user to see the communication channel; and (iv) communication augmenting and complementing existing services (such as illumination, display, indication, decoration, etc.) from visible light infrastructures and considers the impact of modulation on illumination [8].

The Visible Light Communication technology is currently led by Japan with the creation of the Visible Light Communication Consortium VLCC in November 2013, established for research, develop, plan, standardize the optical communication system. Between the companies that make the consortium are Panasonic Corporation, Toshiba Corporation, Casio Computer Co. LTD, Nakagawa Laboratories, Inc, Tamura Corporation [5].

A. Applications

There are several application where the communications is performed with visible light, among which are tracking vehicle to vehicle communication, location based services, areas where RF is not permitted, indoor and outdoor general lighting system.

1) Indoor Positioning by LED: The typical indoor positioning system based in GPS, IR, RFID, Bluetooth, WLAN, Ultrasound, and so on present problems due to system instability, long response time, low accuracy and low precision, therefore the VLC is emerging as an attractive technology for indoor positioning system using the lighting equipments [15]. Boston Company is marketing indoor-positioning technology called ByteLed. Byte Led is software that controlled leveraging existing LED lighting infrastructure for send a ID number to individual's mobile phone that decodes the light pulses perceived by the phone's camera, in order to identify the phone's location.

2) Personal Area Networks: High demand for mobile data

services has motivated the use of VLC technology in Wireless Personal Area Networks (WPAN). It aims to increase the bandwidth and data rate connection. In this type of computer network, the connection can make among devices such as computer, phone, 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 [23]. The working group IEEE 802.15 develops Personal Area Network standards for short distance wireless networks [23]. In the Omega project, its VLC demonstration consists in the VIDEO HD signal transmission to four video players through Ethernet stream and by the modulation of driver current fed to 6 High Power Led Lamps [7].

3) Vehicle to Vehicle, and Vehicle to Infrastructure: With the introducing of the technology LED to the traffic signal, vehicles lamp, and in general, in transport systems, have developed intelligent vehicle safety applications. The Vehicle Safety Communications Project developed by U.S. Department of Transportation, National Highway Traffic Safety Administration in March 2005 present the report of the result for the Identify Intelligent Vehicle Safety Applications; applications high priority identified 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 traffic signal violation warning, infrastructure transmits the vehicle the state of the road, so assist the driver during a travel. The project defined the requirements to each application, the transmission mode, minimum frequency, allowable latency, data to be transmitted and/or received and maximum required range of communication [11]

4) No Radio Frequency Area: There are areas where the use of radio frequency is forbidden, as the hospitals. Reports describing medical device malfunction related to cellular phones and the phenomena of electromagnetic interference (EIM); the electromagnetic interference is the unwanted reception of electromagnetic (EM) waves in medical devices, the captured EM waves altering the analog or digital signal in the instruments, and with this the corrupted data results [13]. The VLC does not emit EIM. Other areas with forbidden use of radio frequency are aircraft and spaceship.

B. Data Communication

A simple model for a data communication system is shown in the Appendix A. The diagram composed of five blocks helps to understand the principle of the data communication, but it conceals a wealth of technical complexity.

- Source: Device that generates the data to be transmitter. Examples are telephones and personal computer.
- Transmitter: The transmitter transforms and encodes the information to produce electromagnetics signals that can be transmitted across some sort of transmission system.

- **Transmission System:** This can be a single transmission line or complex network connecting source and destination. **Receiver:** The receiver accepts the signal from the transmission system and converts it into a form that can be handled by the destination device.
- **Destination:** Takes the incoming data from the receiver.

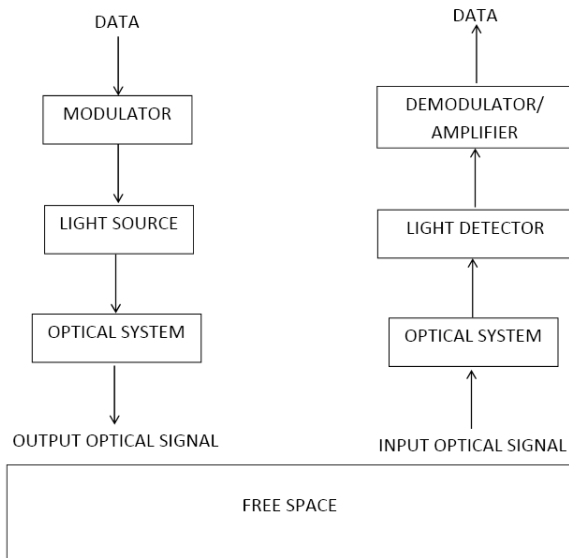


Fig 1. Functional diagram block of VLC system.

In data communication, four terms are used frequently: data, signal, signaling and transmission. Data is an entity that conveys meaning. Signals are electric or electromagnetic encoding of data. Signaling is the act of propagating the signal along a suitable medium. Transmission is the communication of data by the propagation and signal conditioning. The nature of the data and signal can be define as analog and digital; this terms analog and digital correspond, roughly, to continuous and discrete, respectively.

Consider when a user wants to connect the computer to internet, which requires the link communication between PC and Wireless Router, therefore the Source of the data is the PC disk and the destination is the memory of Wireless Router. PC sends the input information (text, music, video, file, and o on) in digital signals to the transmitter, which in this case will be the network card of PC. The network card transforms the digital data to analog signals (electromagnetic waves) that can to be transmitted. The system transmission is the media transmission, air. The router converts the electromagnetic signals captures in digital signal and finally it sends to memory of router.

Now consider a telephone conversation. In this case, the input to the telephone is a message in the form of sound waves. The sound waves are converted by the telephone into electrical signals of the same frequency. These signals are transmitted without modification over the telephone line. Hence, the input signal and the transmitted signal are identical.

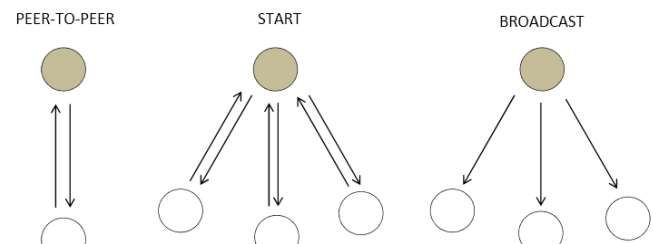


Fig 2. Supported MAC topologies

III. VLC SYSTEM

The Visible Light Communication is type of data communication where the transmitted signal is a Electromagnetic wave in the visible range, which propagates in a specific media. A typical VLC system applied to general lightning is illustrated in the Figure 1. A basic optical wireless system consists of a light source, free space as the propagation medium, and a light detector. In a side for send data, the input information in the form of digital or analog signals is input to electronic circuitry that modulates the light source. The light output passes through an optical system such as filter, lens or reflectors. The light travel free space and is receiver in the side of the light detector through optical system such as color filters, lens concentrator or noise filter. The light signal captured is converted by light detector to the electric signal Depending on the type of modulation, the input electric is amplified or demodulate [10].

A. IEEE 805.5.7

IEEE Standar for Local and Metropolitan Area Networks in the part 15.7 Short-Range Wireless Optical Communication using Visible Light defines a PHY and MAC layer for short range optical wireless communications using visible light in optically transparent media [8]. Aspects as data rates to support multimedia services, mobility of the visible link, compatibility with lightning infrastructure, interference and noise from ambient light, regulations for eye safety are consider in this standard. The standard defines three types of devices for VLC: infrastructure, mobile and vehicle; each of these devices is applied in three topologies: peer-to-peer, star, and broadcast as shown in Figure 2.

The PHY layer supports multiple PHY Types, which as shown in the Table II. The PHY is responsible for the following tasks:

- Activation and deactivation of the VLC transceiver
- WQI for received frames
- Channel selection
- Data transmission and reception
- Error correction
- Synchronization

In data link layer, the MAC sub-layer is responsible for the following tasks:

- Generating network beacons if the device is a coordinator

- Synchronizing to network beacons
- Supporting VPAN association and disassociation
- Supporting color function
- Supporting visibility
- Supporting dimming
- Flicker-mitigation scheme
- Supporting visual indication of device status and channel
- quality
- Supporting device security
- Providing a reliable link between two peer MAC entities
- Supporting mobility

TABLE II
DESCRIPTION PHY LAYER TYPES

	Data Rate	Modulations
PHY I	Low: tens of hundreds kb/s	OKK, VPPM
PHY II	Moderate: tens of Mb/s	OKK, VPPM
PHY III	Moderate: tens of Mb/s	CSK

B. Modulation Techniques

Studies and developments made for VLC have allowed the generation of the IEEE 802.15.7 standard which is introduced to standardize the different communication schemes visible light modulation techniques and applied modulation schemes [12]. This standard includes three modulations: OKK, V PPM, and CSK. Others modulations are compatible with the VLC principle, such as MSM modulations, specifically OF DM modulation. Appendix B presents description of the schemes used in VLC modulations.

C. Light Source

The light source used in V LC actually is a light source based on solid state devices, LED, OLED and P LED. The principal feature of the light sources are solid state switching capacity at high speeds; this feature allows the state of the modular light source for sending data using visible light as a transmission medium while a certain area is illuminated. Radiative recombination of electron-hole pairs in the depletion region allows LED generates light when a p-n junction is biased in the forward direction. This phenomenon is called spontaneous emission. LED spectrum depends the wavelength of the photons emitted in a radiative recombination event is determined by band gap energy given by the equation 1. LEDs are made from different semiconductor materials and each material has characteristic band gap energy (Eg). The principle of coating phosphor layers is based on the absorption and re-emission of light. The

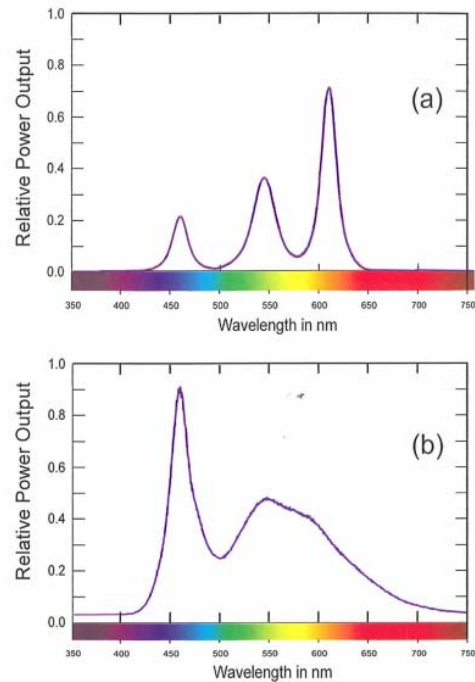


Fig 3. Spectra of white LED: (a)RGB (Trichromatic) (b)White Led [22].

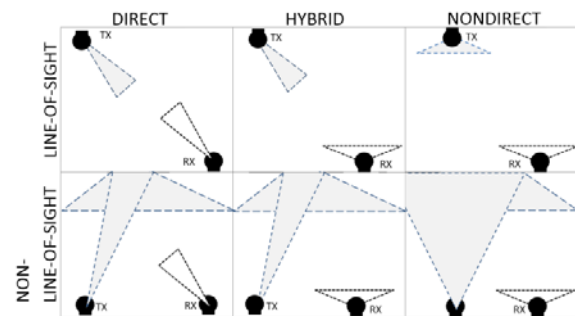


Fig 4. Designs links VLC.

absorption of blue light (excitation) cause that phosphor layers emit a certain color [29].

$$\lambda = \frac{hc}{Eg}$$

In general lightning system, two types of LED are used: Phosphorescent White LED and RGB LED. Phosphorescent White LED is the technology most used in lightning system [17]. The White LED use a phosphor material to covert blue light to a broad-spectrum white light in the same way as a fluorescent lamp cover light. In the figure 3 shown the spectra response of LED. These LEDs are advantageous in terms of long life expectancy, low power consumption, and minimal heat generation [18]. Compared with RGB LED, the white LED has a better color quality performance.

A luminarie is a equipment that distributes, filters or transforms the light given by a lamp or lamps, and which

contains all the necessary items for fixing and protecting the lamps and connecting them to a power supply. The LED Driver is the electronic circuit is responsible for controlled the luminous flux through two common methods, using constant voltage control or constant current control. According to the features LED, the luminous flux has an approximate linear relationship with the forward current, therefore, the forward current determines the lumen output.

D. VLC Links Designs

There are six types for infrared link which shown in Figure 4. These designs are classified under two criteria. The first criterion is the degree of directionality of the transmitter and receiver. The second criterion relates 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 is established, e.g. Directed and LOS link design maximizes power efficiency, since it minimizes path loss and reception of ambient light noise [24]. The link used for data communication defines system performance and the error sources.

E. Light Detector

Light Detector is a solid state photodiode that converts optical signals into electrical signals. Using the principle of photoelectric effect, the photodiode output current is delivered, proportional to the flux incident on the photodiodes surface [1]. The responsivity of a photodiode is a measure of the sensitivity to light, and it is defined as the ratio of the photocurrent and the incident light power to a determined wavelength. It is measure of the effectiveness of the conversion of the light power into electrical current. The semiconductors photodetectors are made from different semiconductor materials such as silicon, germanium, indium gallium arsenide, indium antimonide, inter alia. Each material has characteristic band gap energy (E_g) which determines its light-absorbing capabilities [25].

IV. CHALLENGES

A. LED BANDWIDTH

The modulation response of LEDs depends on carrier dynamics and is limited by the carrier lifetime τ_c . Typically, τ_c is in the range 2–5 ns for InGaAsP LEDs. The corresponding LED modulation bandwidth is in the range 50–140 MHz [26]. Using a heavily doped active region, the carrier radiative lifetime can be 100 ps, corresponding to 1.7 GHz modulation bandwidth [28]. The process of absorption and re-emission of light in phosphor layer limits the response the modulation bandwidth of the commercial LED to 2 MHz. The primary challenge is to increase modulation bandwidth of commercial phosphorescent white LED. In order to increase overcome this bandwidth limitation, a blue filter can be used to remove the phosphor slow response; it increase the bandwidth up to 20 MHz [30]. Two possibles ways to increase the bandwidth

are equalize the transmitter/receiver response and use of bandwidth-efficient modulation schemes.

B. LED No Linearity

The relationship between input voltage and output current is a follows [31]:

$$i_D = i_S(e^{\frac{qv_D}{kT}} - 1)$$

When the forward voltage v_D is applied the current i_D passing through the diode. Since v_D carries the information, it is important that the relationship between these two elements is linear. If not, intermodulation will occur, distorting the signal and generating intermodulation noise. In optical systems, the LED is a major source of nonlinearity and particularly important when analog OF DM modulating signal is used [10], where the bipolar time domain DCO OF DM signal is clipped in lower peaks because the turn-on voltage of the LED, and upper peaks because the saturation voltage. This effect can reduced if the LED operates in a quasi-linear segment around the chosen DC operating point.

In a commercial luminaire, a nonlinear relationship between control voltage LED Driver and output current also will generate intermodulation, distorting the signal and generating intermodulation noise.

C. Up Link

Data communication with visible light is mainly implemented in broadcasting application, because VLC channels are naturally broadcast (down-link) channels. There are some ways for generate duplex communication, isolating the uplink and downlink through wavelength, time, code and also by spatial or optical isolation [32]. Isolation by wavelength uses uplink with IR spectrum can perform that data flows in both directions simultaneously; however, this approach may require alignment or tracking [33]. A retro-reflector [2] is used for return a portion of a incident light and provide a data path. Techniques wavelength multiplexing and time are used to separate the uplink and downlink.

D. Dimming

A principal requirement for VLC is that light source is on. During the day, the consumer turns off the lighting system and the VLC link disappears. Dimming support is another important consideration for VLC. Dimming support is defined as controlling the brightness of the lighting source according to the user requirements. It has been used to provide moods, energy savings, and ecological benefits. In VLC, it is desirable to maintain communication while a user arbitrarily dims the light source. The dimming allows maintain VLC communication when the light source is off. In [8], dimming support is one of the main challenges for VLC. This document presents the dimming support for OKK, VPPM, CSK modulation methods.

V. CONCLUSIONS

Visible Light Communication is a complementary technology at the actual RF communications. Research in smart lighting systems has enabled the development in indoor and domestic field where the luminary performs both task: Lighting and data transmission. The existing legislation has helped improve the technical progress VLC and allowing cooperation in research aspects. The inclusion of this technology will be an increase in the capacity of wireless communication systems; today, VLC communications systems have two important general lighting challenges, improving the bandwidth and link generation LED uplink. This paper presents the general condition of this technology and allows you to start with the technical development of three VLC systems.

VI. ACKNOWLEDGMENT

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VIII. BIOGRAPHIES



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IX. APPENDIX A

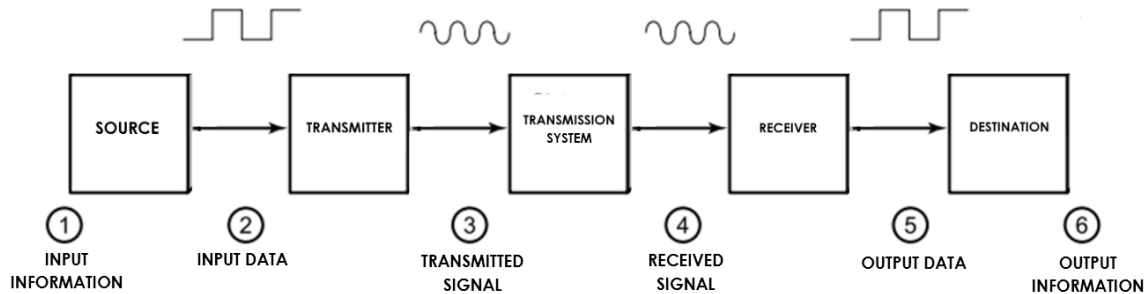


Fig 5. Simple diagram for data communication system.

X. APPENDIX B

TABLE I
MODULATIONS USED FOR VLC.

ABR.	NAME	DESCRIPTION
OKK	ON-OFF KEYING	The configuration of this modulation is the simplest, in this modulation data as the presence or absence of light using two types of codes are sent: NRZ and Manchester. The IEEE standard 802.15.7 Section 2 Manchester recommended codes[3].
VPPM	VARIABLE PULSE POSITION MODULATION	This modulation utilizes the basic principle of the ON-OFF modulation but adding to this variation of the pulse duration, the pulse duration can be used to identify the bit is sending.
MSM	MULTISUBCARRIER MODULATION	The information is modulated into one another orthogonal carriers, the sum signal is then transmitted. There are several schemes for multi carrier modulations proposed <i>VLC</i> , being <i>OFDM</i> more known and studied at present.
OFDM	ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING	The basic idea of <i>OFDM</i> is divide the transmission spectrum into narrower bands, giving these bands for orthogonality between the sub-channels achieving overlay. There are two types of <i>OFDM</i> modulation: <i>DCO - OFDM</i> and <i>ADC - OFDM</i> .
CSK	COLOR SHIFT KEYING	This modulation sent the information by configuring several chromaticity points which define the constellation design that will be used. By controlling the intensity of each RGB component luminaire chromaticity point to be sent is defined.
MM	METAMERIC MODULATION	Unlike CSK modulation metamerism modulation does not change the chromaticity point light source emits but it maintains a constant chromaticity point using different gamuts (LEDs)[4].