A REVIEW PAPER ON VISIBLE LIGHT COMMUNICATION: ARCHITECTURE, STANDARDIZATION, APPLICATION AND RESEARCH ISSUES

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Abstract: ***VLC uses white Light Emitting Diodes (LED), which sends data by flashing light at speeds which are invisible to the human eye. One of the major advantage of VLC is that one can use the infrastructure around them without making any changes to it. The ability of LED is to transfer information signals over light (which is between 430THz to 770THz of frequency and whose wavelength is between 380nm to 750nm) makes it a very good communication medium. The light we use in our daily life can not only be used for providing light but also for communication. Doing more investigations of VLC research, it was found that a lot of research is being done to make this technology available for commercial use in various fields, including Internet access and vehicle-to-road communication using traffic signal lights. From our review of the literature, it is clear that work should be done to design a new model that could be fitted to the present infrastructure for indoor applications.***

Keywords: VLC (Visible Light Communication), LED (light emitting diode), Li-Fi(Light Fidelity), OWC(Optical Wireless Communications, JEITA (Japan Electronics and Information Technology Industries Association) ,RF(Radio Frequency) ,pc-LEDs(Phosphor Converted LEDs)

I. INTRODUCTION

In Visible Light Communication (VLC), data is sent through the modulation of light waves from the visible spectrum whose wavelength ranges from 380 nm to 750 nm .The system in which information is transmitted using light waves which are visible to human eyes called as Visible Light Communication. In VLC, transfer of data is invisible to human eye. Number of nomenclatures have been made for similar Technologies such as OWC (Optical Wireless Communication) and Li-Fi (Light Fidelity).An extensive studies were done on radio waves for various works since the commencement of the nineteenth century [14] Which led to a lot of discoveries about the properties of this wave which brings many new technologies to the daily lives of people around the world, from military resources to medical applications. The efficiency of radio communications has improved more due to many number of researches in this field. The communication using visible light has fascinated the awareness from academic institutions and industry from the past decade [3].It is underexplored till today when it is compared to the radio frequency spectrum of the electromagnetic spectrum.

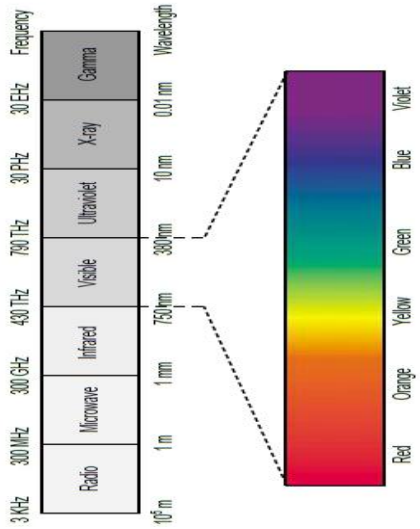

Fig. 1: Electromagnetic Spectrum [1].

Fig. 1 depicts the range of the electromagnetic spectrum from low frequencies to high frequencies (radio waves to gamma radiation). The visible spectrum of light ranges from 380 nm to 750 nm and any information which is transferred by modulating the light waves in this range can be considered as a Visible Light Communication. The radio waves, which includes the Wi-Fi technology covers frequencies ranging from 3 KHz to 300 GHz while visible light frequencies vary from 430 THz to 770 THz, which is 10,000 times larger than the entire radiofrequency spectrum [1].Because of implementation of VLC systems is closely linked to the rapid and increasing adoption of LEDs around the world as well as due to development of the smart lighting paradigm [1] ,Visible Light Communication became a very promising technology. Therefore, LED light bulbs will play two different roles in future such as lighting and communication. Recently, VLC has been studied in major industry and academy, such as NASA [13], [8], Disney [17] and Philips [14].These industries have also products and research in this field.

VLC and other nomenclatures: There are a number of nomenclatures given to the different technologies involving light as a form of communication. Some of the main nomenclatures are as follows:

Optical Wireless Communications (OWC): Optical Wireless Communication involves any type of data transfer in which the medium used is the optical medium [15].

Free-Space Optical Communication: This nomenclature has

been widely used for large-scale transmissions such as communications between satellites and towers on Earth. Applications using such nomenclature is very complex because of dealing with atmospheric turbulences [20], [7]and due to high-cost equipment [16].

Visible Light Communication (VLC): The use of wireless optical communication has become very popular in recent years. Since this area is being studied greatly in academic institutes and commercial companies [5]. Visible Light Communication includes all the frequencies of the visible light spectrum which ranging from 430 THz to 790 THz [14].

Light Fidelity (Li-Fi): The Li-Fi was invented in 2011, when Professor Harald Haas gave a practical demonstration of the potential of the technology. Li-Fi is a type of VLC [4]. However, a paper published in 2015, highlighting the main differences between VLC and Li-Fi [10]. Among the differences between the two technologies such as VLC and Li-Fi, two-way multi-user communication and high speed, aspects present in the concept of Li-Fi.

Invention of LEDs is like a great opportunity for VLC: Lot of factors contributed to the increasing interest in VLC because LED is used mostly for manipulation of light waves.

Semiconductor Material	**Wavelength**	**Color**
GaAs-Gallium Arsenide	850-940nm	Infra-Red
GaAsP-Gallium Arsenic Phosphide	630-660nm	Red
GaAsP-Gallium Arsenic Phosphide	605-620nm	Amber
GaP-Gallium Phosphide	585-595nm	Yellow
InGaAIP-Indium Gallium Aluminum Phosphide	550-570nm	Green
SiC-Silicon Carbide	430-505nm	Blue
GaN-Gallium Nitride	450nm	White

Table I: LEDs and colors

For example, Red LEDs, are made of gallium arsenide phosphide (GaAsP), and their wavelength varies from 630 nm to 660 nm. Table I shows some colors and its respective semiconductor material, as well as the wavelength of the emitted light. Some known advantages of LED light source are energy efficiency, durability, and low-cost. Residential LEDs use at least 75% less energy and can last 25 times longer than a traditional incandescent light bulb. In addition to this, it is possible to focus the light of an LED bulb in a single direction. Due to these advantages, LEDs bulbs are used in various devices, such as smart phones, vehicles, video screens, and Visible Light Communication. This technology has many benefits to the industry, and the future of residential lighting is definitely based on LED lights. Both yellow and blue photons combine which generates white light. However, in terms of Visible Light Communications, the RGB bulb is more useful, because of the controlling over light and the IEEE standard for VLC [15] outlines a modulation method based on the intensity of the RGB LED. There are several types of LEDs, which makes them suitable for VLC applications depending on the material used in the manufacturing of the chip, light is emitted in a specific region of the visible spectrum. As a result, the photon will be emitted with a characteristic wavelength, resulting in a color. Gallium Arsenide (GaAs), Gallium Phosphide (GaP), are examples of compounds used in LEDs. The main types of LEDs, along with their details are as follows:

Phosphor Converted LEDs (pc-LEDs): The pc-LEDs are extensively used because of low complexity and low cost. They consist of a blue LED chip coated with a phosphor layer, whose function is to convert part of the blue light to green, yellow and red, while a fraction of the blue light is emitted, resulting in white light. This type of LED has a limited band due to the slow response of phosphorus. Multi-chip LEDs: This type of LED consists of three or more chips and which emit lights of different colors. Normally, the different chips emit the RGB colors in order to produce white light. The great advantage of this type of LED is the ability to control the colors that are emitted, through the intensity of each chip. It is important to note that modulation was created especially for this type of LED, called Color-Shift Keying. Organic LEDs (OLEDs): This type of LED consists of a series of thin organic films between two conductors. When an electric current is applied, light is emitted. They are widely used in displays of smart phones. The great advantage of this type of technology is the possibility of building transparent and flexible devices. However, in terms of frequency and durability, this type of LED is still inefficient when compared to other types [11].

	Wi-Fi	**NFC**	**Bluetooth**	**VLC**
Spectrum	2.4GHz/ 5GHz	13.56 MHz	2.4 GHz	~400T Hz
Infrastructure	Access Point	Device	Device	Illumination
Ambient interference	Low	Low	Low	High
Security	Limited	Limited	Limited	High
Coverage	High	Low	Low	Limited
System complexity	High	High	High	Low
Electromagnetic interference	Yes	Yes	Yes	No

Table II: Comparison between radio frequency Technologies and VLC [14].

II. VLC ARCHITECTURE

The main components of VLC systems are transmitter and receiver. Researchers discuss mostly physical, data link, and application layers when they describe the architecture of VLC systems [17].Fig.2 gives an overview of the architecture of a VLC system. LEDs transmit data through Intensity Modulation. The receiver must be in the line of sight of the LED so that it receives the light beams containing the information. During light transmission, there will be a loss in light signal quality due to particles diffusion and the inherent interference of ambient light. To reduce interference, filters may be used. At the receiver node, light is incident on the photo sensor directly which adjust the current. The use of amplifiers turns the signals less prone to interference and noise [15]. Finally, the signal is demodulated to retrieve the original information. The details of each component of a VLC system are as follows:

Transmitters: LEDs are used as transmitters in VLC systems. Most commercially available light bulbs**.**

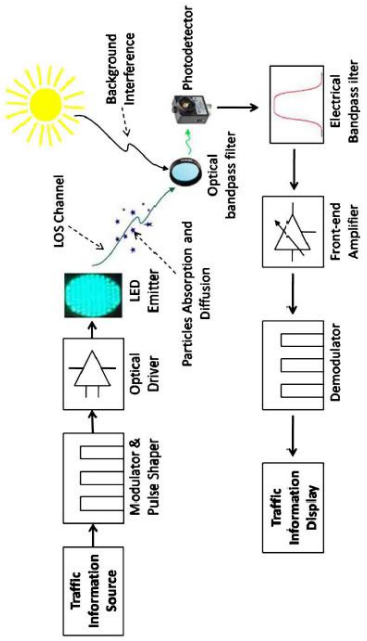

Fig.2: VLC System Architecture [12]

Contain several LEDs. These light bulbs contain a driver responsible for controlling the current passing through **t**he LEDs, directly influencing the intensity of the illumination [3].

Receivers: Receivers are responsible for capturing light and converting it into electrical current. Normally, photodiodes are used as receivers in Visible Light Communication systems [2]. However, photodiodes are extremely sensitive, and capture waves beyond the spectrum of visible light, such as ultraviolet and infrared [18]. They also saturate easily in an external environment and exposed to sunlight, for example, the photodiode would fail to receive data due to high interference. For this reason, other components can be used to capture light. One of them is the smart phone camera itself, which allows any cell phone to receive data sent by a VLC transmitter.

III. VLC STANDARDS

The first effort to standardize Visible Light Communication happened in 2003. In 2007, . In 2007, two standards were included in JEITA (Japan Electronics and Information Technology Industries Association), the JEITA CP-1221, which covers the asics of VLC systems, and JEITA CP-1222, a standard for Visible Light ID Systems [18].

IV. APPLICATION OF VLC

VLC has a wide range of applications, from high-speed Internet access through LED light bulbs to interplanetary communication. VLC applications are very diverse and bring a new perspective which is considered ubiquitous. Applications of Visible Light Communication are as follows: Indoor VLC, Localization systems, under water communication, Vehicular communication etc.

V. RESEARCH ISSUES

The main challenges of VLC communications from light-specific issues are flickering, dimming, line of sight, and interference to wireless communication-related challenges that must be addressed to attain a good performance.

Flickering: It is a major challenge in VLC and it can be defined as the fluctuation in the brightness of the light perceptible by humans. Usually, this problem is addressed in work that implements indoor VLC systems like as an office or supermarket. Depending on the modulation mechanism of the light waves, there may be oscillations perceptible by the human eye, which may cause uneasiness and health risks [19].

Dimming: Using LED light in a VLC system, the communication signal power is directly related to the light intensity. Theoretically, the lower the light intensity, the smaller the communication range and the data communication rate [2]. Dimming is the control of the perceived light source brightness, according to the requirements of the user. In many places, dimming is an essential feature which creates benefits such as comfortable environments and energy saving.VLC systems must support dimming. IEEE 802.15.standard which defines a series of mechanisms to adapt the modulations in order to enable dimming control. To provide dimming control, a compensation time must be place in the frames in order to regulate the average light intensity.

VI. CONCLUSION

VLC is a grand opportunity to provide wireless communication. This growing demand for wireless and ubiquitous communication raises a number of issues related to the current infrastructure of wireless networks. In this sense, we can identify a forthcoming Wi-Fi spectrum crunch, where the demand for resources becomes greater than the capacity offered by the network. Among the alternatives proposed recently to complement the current infrastructure of wireless networks, VLC came into existence due to its many advantages that it provides such as Free spectrum, high frequencies, availability of infrastructure and LED light bulbs has great advantages that draw attention to visible

light communication. However, many obstacles like Flickering, dimming control, uplink, and interference are some of these challenges which are preventing VLC-based technologies and applications from being commercialized. Indoor positioning, underwater and vehicular communication systems are some examples of applications that can utilize visible light.

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