Light Wave Modulation Schemes for Visible Light Communication

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Abstract- *Visible Light Communication, a class of wireless communication, uses light waves, in contrast of, radio waves for data transmission. It provides higher capacity, greater efficiency and better security as compared to traditional radio wave communication. Light Emitting diode (LED) is a revolutionary product as it is replacing all incandescent and fluorescent bulbs at every place. In addition to luminance device, it can be used as a high speed switching device to different light intensity. Therefore LED along with photo detector, became an important element of visible light communication. However there is a need of proper modulation scheme which can use light as a medium for data transmission. Furthermore, the selection of modulation scheme largely depends on its response to the particular networks and its own performance under noise and interference environment. By keeping this into account this paper presents an overview of visible light communication and various modulation schemes, their challenges and prospective solution to combat the challenges.*

Keywords- VLC, LED, Photo diode, OOK, OFDM, CSK.

I. INTRODUCTION

Solid state lighting is going to become a widespread solution for indoor lighting. The traditional incandescent and fluorescent bulbs have extremely low energy efficiency. However, recent advancements in solid-state lighting through Light Emitting Diodes (LEDs) have proved not only energy efficient source of lighting but also found useful in data communication. Average luminous efficacy of best-in-class LEDs is as high as 113 lumens watt in 2015 [1], and is projected to be around 200 lumens/watt by the year 2020 and the lifespan of these bulbs more than fluorescent bulbs (10,000 hours). Apart from the energy efficiency and durability, the LEDs are compact, very less harmful materials in design and lower heat generation. Due to these benefits, LED adoption is on a consistent rise and it is expected that nearly 75% of all illumination will be provided by LEDs by the year 2030 [2]. One supplementary feature of LEDs is that they are capable of switching to different light intensity at a very fast rate. This feature can be used for communication where the data is encoded in the emitting light in numerous means. A photodetector can receive the modulated signals and decode the data. This means that the LEDs can be utilized for illumination as well as communication. The ground work of using LEDs for dual purpose is found in year 2000 in [3] where Japan proposed the use of white LED in homes for building an access network. This was further developed to build high-speed communication through visible light. The communication using LEDs (or Li-Fi) possesses special characteristics as compared to existing wireless communications or Wi-Fi. First, the “demand and supply” curve of mobile data and spectrum is not adequate. Even with efficient frequency and spatial reuse, the current RF spectrum is not able to meet the exponential increasing traffic demand. Compared to this, the visible light spectrum which includes hundreds of terahertz of license free bandwidth, as shown in Fig. 1 is completely unexploited for communication.

Visible Light Communication (VLC), therefore, can replace radio based wireless communication [4]. Second, due to its high frequency, visible light works on line of sight phenomenon which forces designer to make micro cell of LED transmitter with no co-channel or adjacent channel interference. Thereby it is increasing the capacity of wireless channel with high security [5]. Third, VLC can be mounted with existing indoor lighting which reduces the effort of building infrastructure; hence VLC can be deployed with relatively lesser efforts and at a lower cost [6]. Due to all these features and benefits of VLC over radio based communication attracted researchers towards VLC and the interest in VLC research is growing. The increasing interest in VLC has published many articles and surveys in past couple of years. This paper differs from previous study of VLC. In this review, the overview architecture of VLC with transmitter and receiver characteristics and various modulation schemes suitable for VLC are provided.

II. VLC ARCHITECTURE

This section provides an overview of VLC architecture which comprises Transmitter, receiver and mode of communication. A Block diagram of VLC system is illustrated in Fig. 2.

A. VLC Transmitter

An LED luminance system is the transmitter in a VLC system which consists of an LED lamp, stabilizer, cabinet and other components. The LED lamp can include one or more LEDs (Fig. 3). The lamp is provided with a driver circuit which is modified in order to modulate the data through the use of emitted light. For example, in a simple On-Off Keying modulation, the data bit "0" and "1" can be transmitted by selecting two independent levels of light intensity.

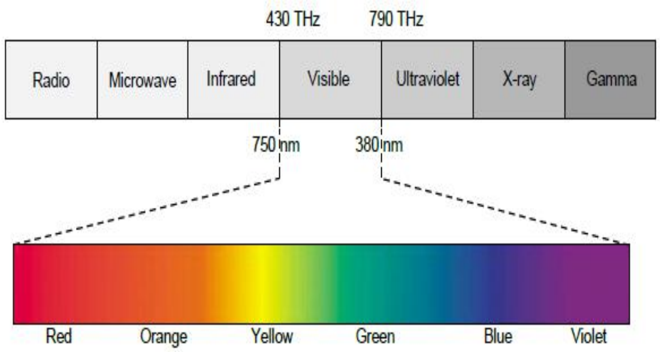

Figure 1. Visible Light Spectrum

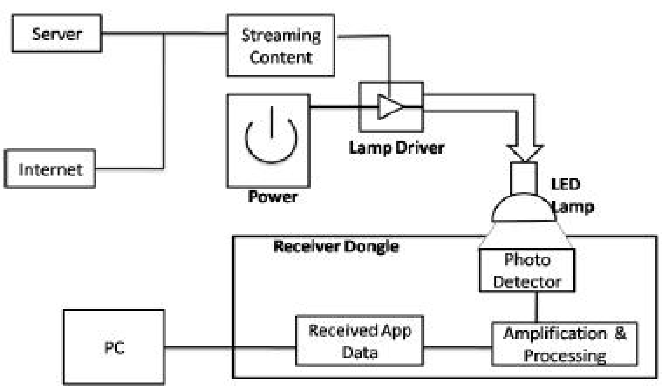

Figure 2. VLC Block Diagram

Also the driver circuit is used for controlling the brightness of the LED light. As per color is concerned, white light is the most widely used form of lighting in both indoor as well as outdoor applications for the close resemblance of the objects. In LED, the white light is produced in following two ways –

- Blue LED with Phosphor Coating:

In this method, the white light is produced by using a blue LED with yellow phosphor coating. When the blue light traverses through the yellow coating, the combination produces a white light.

- RGB Mixture:

White light can also be produce by the proper combination of red, green and blue light. In this method, three distinct LEDs are used which increases the cost of LED luminaire compared to using the Blue LED with Phosphor.

Figure 3. LED Lamp

B. VLC Receiver

Two types of photo devices namely photodetector and image sensor are used as a receiver for VLC.

- Photodetector:

The photodetector is a semiconductor device that converts the received optical signal into current. The present photodetectors in market can sample the received light at rates of 10MHz. (Fig. 4)

Figure 4. Photo-diode

- Imaging Sensor:

An imaging sensor or a camera sensor can also detect visible light signals. Moreover camera sensors are readily available on mobile phones to capture videos and images, hence it can be converted into VLC receivers. An imaging sensor consists of many photodiodes organized in a matrix on an integrated circuit (Fig. 5). However, the constraint of an imaging sensor is its requirement of more number of photo-diodes for high-resolution photography and it provides low data rates. To enhance the data rate the "rolling shutter" property of camera sensor can be used to receive the data at a faster rate [7].

Figure 5. Image Sensor.

C. VLC Modes of Communication

Visible light communication can be classified into two modes: (1) Infrastructure-to-device communication and (2) Device-to-device communication. An indoor scenario where LED luminaires are used to illuminate the room is shown in Fig. 2. In this case, the luminaires can transmit data to various devices inside the room. The LEDs can also coordinate between themselves to reduce the interference and even enable coordinated multi-point transmission to receiving devices. The uplink transmission from the devices are difficult to achieve because using LEDs on end-user devices can cause noticeable disturbance to users. In such case, RF or infrared communication can be used for the uplink transmissions. Similar to the indoor case, the LEDs used in street lamps as well as traffic lights can be used to provide internet access to users in cars and pedestrians.

Due to omni-present camera sensor for mobile devices, the visible light communication can also be used for near-field device-to-device communication. Here, the LED pixels on the display of one smartphone can be used to transmit data to the camera sensor of another smartphone. With recent advances in design of efficient codes, such screen-to-camera streaming has been shown to achieve very high throughput. In another form of device-to-device communication, cars and other vehicles on the road can communicate with each other to form an ad-hoc network using VLC.

III. MODULATION CHALLENGES

With the understanding of path-loss, noise and SNR, we now discuss various modulation methods used in VLC. The most striking difference between VLC and RF is that in VLC, the data can not be encoded in phase or amplitude of the light signal [8]. This means that phase and amplitude modulation techniques can not be applied in VLC and the information has to be encoded in the varying intensity of the emitting light wave. The demodulation depends on direct detection at the receiver. These set of modulation techniques are referred as IM/DD (Intensity Modulated/Direct Detection) modulations. In this section, we will discuss the IM/DD modulation techniques used for visible light communication.

Different from other types of communications, any modulation scheme for VLC should not only achieve higher data rate but should also meet the requirements of perceived light to humans. These requirements about perceived light can be characterized by following two properties –

A. Dimming

It was suggested that different levels of illuminance is required when performing different types of activities. As an example, an illuminance in the range of 30-100 lux is often enough for simple visual tasks performed in most public places. On the other hand, office or residential applications require higher level of illuminance in the range of 300-1000 lux. With the advancements in LED driver circuits, it has become possible to dim an LED to an arbitrary level depending on the application requirement to save energy.

If an LED can be dimmed to an arbitrary level, it is also necessary to understand its impact on the human perceived light.

B. Flicker mitigation

An additional requirement for any VLC modulation scheme is that it should not result in human-perceivable fluctuations in the brightness of the light.

IV. MODULATION SCHEMES

This section presents the various modulation schemes used in VLC to combat the above challenges.

A. On-Off Keying (OOK)

In OOK, the data bits 1 and 0 are transmitted by turning the LED on and off respectively. In the OFF state, the LED is not completely turned off but rather the light intensity is reduced. The advantages of OOK include its simplicity and ease of implementation. OOK-like modulation is widely used in wireline communication.

Most of the early work on using OOK modulation for VLC utilize white LED by combining the blue emitter with yellow phosphor. The major limitation of the white LED is its limited bandwidth due to slow time response of the yellow phosphor. It was first proposed by [9] to use NRZ OOK with the white LED and a data rate of 10 Mbps was demonstrated over a VLC link. To further improve the performance, [10] used a blue filter to remove the slow-responding yellow component, resulting in a datarate of 40 Mbps. On-off keying requires less bandwidth than FSK. On-off keying consumes 50 % less power when compared to FSK/FM transmitters. The advantage of On-off keying is simple and easy to implement.

B. Pulse Modulation Methods

Although OOK provides various advantages such as simplicity and ease of implementation, a major limitation is its lower data rates especially when supporting different dimming levels. This has motivated the design of alternative modulation schemes based on pulse width and position which are described next.

C. Pulse Width Modulation (PWM):

An efficient way to achieving modulation and dimming is through the use PWM. In PWM, the widths of the pulses are adjusted based on the desired level of dimming while the pulses themselves carry the modulated signal in the form of a square wave. The modulated signal is transmitted during the pulse, and the LED operates at the full brightness during the pulse. The data rate of the modulated signal should be adjusted based on the dimming requirement.

D. Pulse Position Modulation (PPM):

Another pulse modulation method in visible light communication is based on the pulse position. In PPM, the symbol duration is divided into t slots of equal duration, and a pulse is transmitted in one of the t slots. The position of the pulse identifies the transmitted symbol. Due to its simplicity, many early designs of optical wireless systems adapted PPM for modulation [11]. However PPM has disadvantage of low spectral efficiency and low data rate.

E. Orthogonal Frequency Division Multiplexing (OFDM)

One limitation of previously discussed single-carrier modulation schemes is that they suffer from high inter-symbol interference due to non-linear frequency response of visible light communication channels. OFDM has been widely adopted in the RF communication due to its ability to effectively combat the inter-symbol interference and multipath fading. In OFDM, the channel is divided into multiple orthogonal subcarriers and the data is sent in parallel sub-streams modulated over the subcarriers. OFDM for VLC can reduce the inter-symbol interference and does not require complex equalizer, however, there are multiple challenges in realizing its implementation [12]. First, the OFDM technique for RF needs to be adapted for application in IM/DD systems such as VLC. This is because

OFDM generates complex-valued bipolar signals which need to converted to real-valued signals. This can be achieved by enforcing Hermitian symmetry constraint on the sub-carriers and then converting the time-domain signals to unipolar signals. Depending on how the bipolar signals are converted to unipolar, there are two types of OFDM techniques:

- Asymmetrically Clipped Optical OFDM (ACO-OFDM):

The odd subcarriers are only modulated in ACO-OFDM, which tends to symmetric time domain signal.

- Direct Current-biased Optical OFDM (DCO-OFDM):

All subcarriers are modulated but to produce unipolar signal a positive direct electron flow is added

F. Color Shift Keying (CSK)

To overcome the lower data rate and limited dimming support issues of other modulation schemes, IEEE 802.15.7 standard [13] proposed CSK modulation which is specifically designed for visible light communication. Modulation by colour shift key depends on the color space chromaticity figure. Colors perceivable by the human vision are mapped to chromaticity image to two chromaticity variables —x and y. The complete homosapiens observable length of waves is separated into seven bands. Based on the color space chromaticity image, the CSK modulation is performed by RGB constellation triangle determination and plotting data bits to chromaticity values.

V. CONCLUSION

Visible light communication has the potential to provide high speed data network with enhanced energy efficiency and security. With impending crisis of RF spectrum shortage, VLC can become analternative mean communication for the existing RFnetworks. Increasing interest from research community and industries as well the standardization efforts such as VLCA and IEEE 802.15.7 show that VLC can be successfully commercialized in coming years. In this survey, an overview of literature covering visible light communication, VLC transmitter, VLC receiver, Mode of communication and various types of modulations used in VLC is provided. In this review it is discussed how different modulation techniques should be able to provide dimming support and minimize flickering effect while maintaining higher spectral efficiency. This included a discussion of four major modulation techniques (OOK, PPM, OFDM and CSK). It was shown that due to their higher data rate capacity, OFDM and CSK are likely to be play an important role in future VLC broadband access networks.

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