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Various Modulation Techniques for LiFi

Prateek Gawande[1], Aditya Sharma[2], Prashant Kushwaha[3]

Research Scholar, Dept of Electronics and Communication, Gyan Ganga College of Technology, Jabalpur, India[1, 3]

Asst. Professor, Department of Electronics and Communication, Gyan Ganga College of Technology, Jabalpur, India[2]

Abstract: This paper set about to elucidate the various modulation techniques for Light-Fidelity (LiFi). Digital modulation techniques generally used for LiFi are summarised, and some special issues and requirements are discussed. In principle, LiFi also relies on electromagnetic radiation for information transmission. Therefore, typically used modulation techniques in RF communication can also be applied to LiFi with necessary modifications. Moreover, due to the use of visible light for wireless communication, LiFi also provides a number of unique and specific modulation formats.

Keywords: Li-Fi, VLC, LED, OOK, PPM, OFDM, CSK.

I. INTRODUCTION

Due to the increasing demand for wireless data communication, the available radio spectrum below 10 GHz (cm-wave communication) has become insufficient. The wireless communication industry has responded to this challenge by considering the radio spectrum above 10 GHz (mm-wave communication). Light-Fidelity (LiFi) [1] is a continuation of the trend to move to higher frequencies in the electromagnetic spectrum. Specifically, LiFi could be classified as nm-wave communication. Li-Fi is a visible light communication technology, having a various range of frequencies and wavelengths from the infrared through visible light as a medium of transmission rather than the traditional radio waves. In VLC if the LED is ON, you are transmitting the data means you transmit a digital 1; and if the LED is OFF, you transmit a digital 0,or null or no data transfer happens. The LEDs can be switched on and off very quickly, which gives nice opportunities for transmitting data[2]. The idea of Li-Fi was introduced by a German physicist, Harald Hass, which he also referred to as "data through illumination". This paper discusses the implementation of the most basic Li-Fi based system to transmit data from one device to another through visible light. The purpose is to demonstrate only the working of the simplest model of Li-Fi with no major consideration about the data transfer speed.

II. GENERAL SYSTEM MODEL OF VLC

VLC is a data communication medium, which uses visible light between 400 THz (780 nm) and 800 THz (375 nm) as optical carrier for data transmission and illumination. This system consists of a light source which emits light and data simultaneously. Data is sent between two or more terminals; in each terminal there is a receiver and an emitter. It uses fast pulses of light to transmit information wirelessly. The emitter transmits data into free space, to be received by a receiver from a different terminal. At first, we modulate information into the luminance and then transmit the information by blinking LED. For optical wireless links, the most viable modulation is intensity modulation (IM), in which the desired waveform is modulated onto the instantaneous power of the carrier. [3]

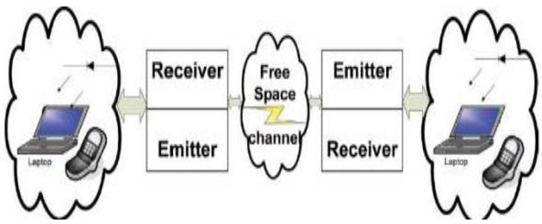

Fig.1 Model of VLC

III. IMPLEMENTATION OF LI-FI

The Li-Fi system consists of mainly two parts, the transmitter and the receiver. The transmitter part modulates the input signal with the required time period and transmits the data in the form of 1"s and 0"s using a LED bulb. These 1"s and 0"s are nothing but the flashes of the bulb. The receiver part catches these flashes using a photodiode and amplifies the signal and presents the output. Transmitter: As per the given diagram, the transmitter section consists of the input, a timer circuit, and High brightness LED which acts as the communication source. The input can be any type of data that you wish to transmit, for example voice, text etc. The timer circuit is used to provide the required time intervals between each bit. These bits i.e. 1"s and 0"s are transmitted in the form of flashes of the LED. Receiver: Silicon photodiode which serves as the receiving element. The flashes of the bulb are received by the photodiode.

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The photodiode then converts the light energy into electrical signals. Next these electrical signals are amplified and the output is presented.

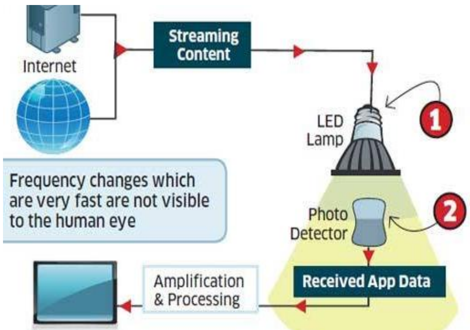

Fig.2 Data transmission using light

Data from the sender is converted into an intermediate data representation i.e. byte format and then converted into light signals which are emitted by the transmitter. The light signal is received by the photodiode at the receiver side. The reverse process takes place at the destination computer to retrieve the data back from the received light. The different components serve the following functions:[4]

Data Conversion Module – Converts data into 1‟s and 0‟s, so that it can be represented as a digital signal. It can also encrypt the data before conversion.

Transmitter Module – Generates the corresponding on-off pattern for the LEDs.

Receiver Module –It has a photo diode to detect the on and off states of the LEDs. It captures this sequence and generates the binary sequence of the received signal.

Data Interpretation Module –converts data into the original format. If encryption was done, it also performs decryption.

IV. CAMPARISION BETWEEN WIFI AND LIFI TECHNOLOGY

There are basic difference between WiFi and LiFi communication system[5],WiFi uses the Radio wave bandwidth of the electromagnetic spectrum and it's transmits data with the help of WiFi router using radio waves where as LiFi uses the visible wave bandwidth of the electromagnetic spectrum to transfer data and it's transmits data with the help of LED bulbs using light.

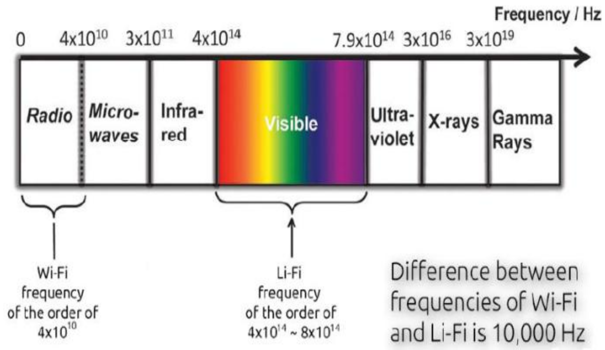

Fig.3 Electromagnetic spectrum

Table-1 COMPARISON BETWEEN LI-FI AND WI-FI

S.no	PARAMETER	LI-FI	WI-FI
1.	Speed for data transfer	About 1 Gbps	54-250 Mbps
2.	Bandwidth	High due to broad spectrum	Low
3.	Range	10 meters (based on light intensity)	20-100 meters
4.	Data density	High	Low
5.	Security	High security due to non-penetration of light through walls	Less secure due to transparency
6.	Reliability	Medium	Medium
7.	Technology	Present IrDA compliant devices	WLAN802.11a/b/g/n/ac/ad standard compliant devices
8.	Device-to-device connectivity	High	High
9.	Transmit/receive power	High	Medium
10.	Ecological Impact	Low	Medium
11.	Spectrum Range	Visible Spectrum Range	Radio spectrum range
12.	Obstacle interference	High	Low
13	Operating Frequency	Hundreds of Tera Hz	2.4 GHz, 4.9GHz and 5GHz
14.	Latency	In the order of microseconds	In the order of milliseconds
15.	Network topology	Point-to-point	Point-to-multipoint

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V. MODULATION TECHNIQUES FOR LIFI

In this section, digital modulation techniques generally used for LiFi are summarised, and some special issues and requirements are discussed. In principle, LiFi also relies on electromagnetic radiation for information transmission. Therefore, typically used modulation techniques in RF communication can also be applied to LiFi with necessary modifications.[1]

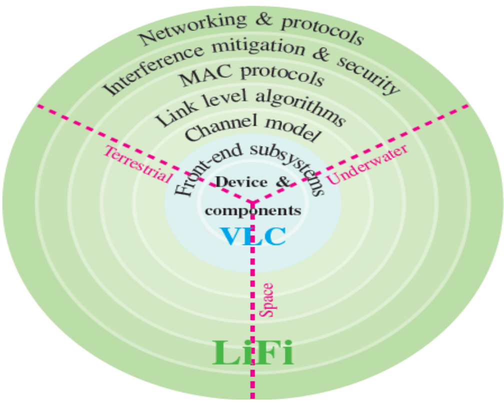

Fig.4 The principal building blocks of LiFi and its application areas.

Moreover, due to the use of visible light for wireless communication, LiFi also provides a number of unique and specific modulation formats.

1. SINGLE-CARRIER MODULATION

Widely used single-carrier modulation (SCM) schemes for LiFi include on-off keying (OOK), pulse position modulation (PPM) and pulse amplitude modulation (PAM), which have been studied in wireless infrared (IR) communication systems [6].

OOK: OOK is one of the well known and simple modulation schemes, and it provides a good trade-off between system performance and implementation complexity. The 802.15.7 standard uses Manchester Coding to ensure the period of positive pulses is the same as the negative ones but this also doubles the bandwidth required for OOK transmission. Alternatively, for higher bit rates run length limited (RLL) coding is used which is more spectrally efficient. OOK dimming can be achieved by:[3]

i) Refining the ON/OFF levels: Dimming through refining the ON/OFF levels of the LED can maintain the same data rate, however, the reliable communication range would decrease at low dimming levels.

ii) Applying symbol compensation: dimming by symbol compensation can be achieved by inserting additional ON/OFF pulses, whose duration is determined by the desired dimming level.

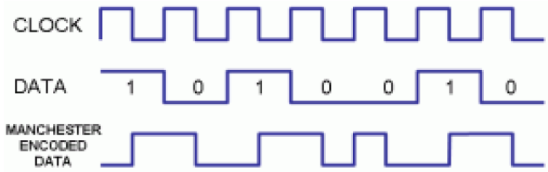

Fig.5 OOK modulation scheme using Manchester Coding

On-off keying (OOK) means the simplest form of amplitude-shift keying (ASK) modulation that represents digital data as the presence or absence of a carrier wave. The data is conveyed by turning the LED off and on (shown in Fig. 5). In its simplest form a digital '1' is represented by the light 'on' state and a digital '0' is represented by the light 'off' state. The beauty of this method is that it is really simple to generate and decode. As the maximum data rate is achieved with a 50% dimming level assuming equal number of 1s and 0s, increasing or decreasing the brightness of the LED would cause the data rate to decrease.

PPM & VPPM: pulse-position modulation(PPM) is a form of signal modulation in which M message bits are encoded by transmitting a signal pulse in one of possible required time-shifts. VPPM is similar to PPM but it allows the pulse width to be controlled to support light dimming, according to a specified brightness level. Therefore, VPPM can be viewed as a combination of PPM and pulse width modulation (PWM).

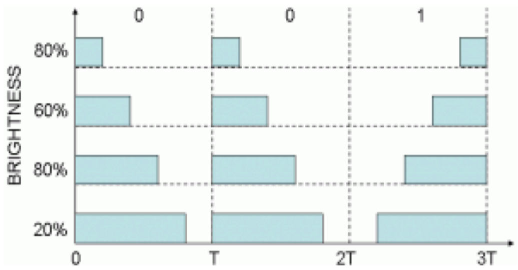

Fig.6 Variable Pulse Position Modulation to support dimming

The duration of the period containing the pulse must be long enough to allow different positions to be identified, e.g. a '0' is represented by a positive pulse at the beginning of the period followed by a negative pulse, and a '1' is represented by a negative pulse at the beginning of the period followed by a positive pulse. When there is no requirement for lighting or indicating, SCPPM (Sub-Carrier PPM) is used in order to save energy.[7]

Compared with OOK, PPM is more power-efficient but has a lower spectral efficiency. A novel SCM scheme, termed optical spatial modulation (OSM), which relies on the principle of spatial modulation, proves to be both power- and bandwidth-efficient for indoor optical wireless communication. As a vibration scheme of quadrature amplitude modulation (QAM) for single carrier systems,

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carrier-less amplitude and phase modulation (CAP) uses two orthogonal signals, in place of the real and imaginary parts of the QAM signalling format, for spectrum-efficient signal transmission in LiFi networks.

2. MULTI-CARRIER MODULATION

For high-speed optical wireless communication, efforts are drawn to multi-carrier modulation (MCM). Compared with SCM, MCM is more bandwidth-efficient but less energy-efficient. One and perhaps the most common realisation of MCM in LiFi networks is orthogonal frequency division multiplexing (OFDM), where parallel data streams are transmitted simultaneously through a collection of orthogonal subcarriers and complex equaliser circuitry can be omitted. Each sub-channel can be considered as a flat fading channel.

OFDM: Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. This is a new approach to transmission in which an additional dimension is added to conventional 2D amplitude/phase modulation (APM) techniques such as quadrature amplitude modulation (QAM) and amplitude shift keying (ASK). Unlike the traditional OFDM technique, the Sub-carrier Index Modulation Orthogonal frequency-division multiplexing technique splits the serial bit stream into two bit sub-streams of the same length. The key idea is to use the sub-carrier index to convey information to the receiver.[8]

As a result, the OFDM-generated signal is complex and bipolar by nature. In order to fit the IM/DD requirement imposed by commercially available LEDs, necessary modifications to the conventional OFDM techniques are required for LiFi. Asymmetrically clipped optical OFDM (ACO-OFDM) is another type of optical OFDM scheme where, as well as imposing Hermitian symmetry, only the odd subcarriers are used for data transmission and the even subcarriers are set to zero. Therefore, the spectral efficiency of ACO-OFDM is further halved. Since only a small DC bias is required in ACO-OFDM, it is more energy-efficient than DCO-OFDM. To incorporate dimming support into optical OFDM, reverse polarity optical OFDM (RPO-OFDM) [9] was proposed to combine the high rate OFDM signal with the slow rate PWM signal, both of which contribute to the overall illumination of the LED.

As an alternative to ACO-OFDM, flip-OFDM and unipolar OFDM (U-OFDM) can achieve comparable bit error ratio (BER) performance and spectral efficiency. A novel modulation scheme, named enhanced unipolar OFDM (eU-OFDM), allows a unipolar signal generation with-out additional spectral efficiency loss as in ACO-OFDM, PAM-DMT, flip-OFDM and U-OFDM. Recently, an alter-native to OFDM has been proposed, which uses the Hadamard matrix instead of the Fourier matrix as an orthog-onal matrix to multiplex multiple data streams.

3. LIFI SPECIFIC MODULATION

LiFi transmitters are generally designed not only for wire-less communication but also for illumination, which can be realised either by using blue LEDs with yellow phosphorus or by colour mixing through coloured LEDs. Luminaries equipped with multicoloured LEDs can provide further possibilities for signal modulation and detection in LiFi systems [4].

CSK: Color shift keying (CSK) is an IM scheme outlined in IEEE 802:15:7 [3], where signals are encoded into colour intensities emitted by red, green and blue (RGB) LEDs. In CSK, incoming bits are mapped on to the instantaneous chromaticities of the coloured LEDs while maintaining a constant average perceived colour.

By combining different colours of light, the output data can be carried by the colour itself and hence the intensity of the output can be near constant. Mixing of RGB primary sources produces different colours which are coded as information bits. The x-y chromaticity diagram shows the colour space and associated wavelengths in blue text (units are nm).

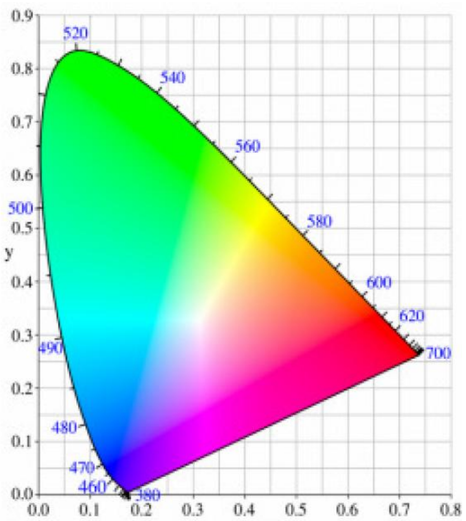

Fig.7 RGB LEDs that combines different wavelengths for CSK

The advantages of CSK over conventional IM schemes are twofold. Firstly, since a constant luminous flux is guaranteed, there would be no flicker effect over all frequencies. Secondly, the constant luminous flux implies a nearly constant LED driving current, which reduces the possible inrush current at signal modulation, and thus improves LED reliability. Based on CSK, metameric modulation (MM) was developed and it can achieve higher energy efficiency and provide further control of the colour quality, however, with the the disadvantage of this system is the complexity of both the transmitter and the receiver. It requiring an additional and independently controlled green LED.

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TABLE-2: COMPARISON OF DIFFERENT MODULATION TECHNIQUES USED IN LI-FI

PARAMETERS	OOK	PPM	OFDM	CSK
Bit rate, Rb	$1x10^6$	$1x10^6$	-	20mbps
Power Efficiency(Ep)	Low	High	Moderate	Low
No. of bits or bit resolution n(M)	10^3	M=3	256(Number of subcarriers)	-
Spectral Efficiency(Es)	High	Low	High	Moderate
Samples per symbols	10	250	128(Number of symbols)	number of samples (up to 25)
Bit duration, Tb	10^{-6}	10^{-6}	-	-
System Complexity	Low	Moderate	High	High
Eb/No	1:10	-10:5	[0:1:15]	-
Sampling time,Ts	10-^{7}	$0.375x10^{-6}$	-	oversampling rate of 25 samples per symbol

VI. CONCLUSIONS

We have presented an overview of Li-Fi based indoor communication system. Li-Fi based indoor communication network can provide us more efficient and genuine substitute of RF based indoor wireless network and this technology has the ability to turn every light Bulb in to a Wireless Hotspot. Li-Fi based Indoor communication system has high Initial Installation cost but when it is implemented at large scale area it can accommodate us by its less operating cost like electricity bills, less operational staff and limited maintenance charges as compare to RF system. In this paper we discuss about various modulation technique OOK, PPM, OFDM and CSK. These techniques should satisfy illumination and communication requirements. The colour dimension offers unique modulation formats for LiFi and adds to the degrees of freedom of LiFi systems. Time, frequency, space, colour dimensions, and the combinations of them can be used for LiFi modulation. LiFi modulation techniques should offer a high speed communication.

Single carrier modulation techniques offer a simple solution for frequency flat Li-Fi channels. Low to medium data rates can be achieved using single carrier modulation techniques. Multicarrier modulation techniques offer high data rates solution that can adapt the system performance to the channel frequency response. Many variants of optical OFDM modulation techniques have been proposed in published research to satisfy certain illumination and communication requirements.

Li-Fi communication user always need line of sight connectivity with its light source therefore some advance research work is required to overcome this limitation to implement this technology in practical use. Service Providers while providing Li-Fi Indoor services has to consider major issues like reliability and availability of system and companies also need to consider how to maintain network for better performance.

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