RESEARCH ARTICLE

A Study on Developments in Wireless Visible Light Communication

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Abstract- This paper is gives an in depth survey on Wireless Visible Light Communication. It provides an analytical view on the iterative development of wireless technology in Visible Light Communication (VLC). VLC is an emerging technology in the field of Networks and Tele-communication. VLC is a data communication medium using visible light between 780nm-375nm. The technology uses fluorescent lamps to transmit signals at 10kbit/s or Light Emitting Diodes (LED's) for upto 500Mbit/s coupled with photo diodes at the receiving end. As an alternative to the widely used radio waves, visible light is easier to produce and less harmful to the users and the environment, therefore VLC can be used in all commercials applications.

Keywords- "Visible light communication'', "Li-Fi'', "Optical Wireless Communication", "LED", "Photo Diode"

I. INTRODUCTION

Over the past decade, significant research efforts have been directed towards exploring alternative parts of the electromagnetic spectrum that could potentially offload a large portion of the network traffic from the overcrowded RF domain. One of these alternatives being visible light. The use of the visible light spectrum for high speed data communication is enabled by the emergence of the light emitting diode (LED) which at the same time is at the heart of the next wave of energy-efficient illumination. In that sense, the concept of combining the functions of illumination and communication offers the potential for tremendous cost savings and carbon footprint reductions. VLC is a data communication medium using visible light between 780nm-375nm. The visible light spectrum includes 100s of THz of license free bandwidth, 10,000 times more than the entire RF spectrum up to 30 GHz, including the mmWave spectrum. Also optical radiation, in general, does not interfere with other radio waves or with the operation of sensitive electronic equipment. Therefore, it is ideal for providing wireless coverage in areas which are sensitive to electromagnetic radiation – some examples include: hospitals, airplanes, petrochemical and nuclear power plants, etc.

There are numerous universities and institutions that are developing VLC systems that can be used for multiple applications. This has proven to be challenging as traditional methods used for radio frequency communication cannot be implemented in VLC. Therefore various techniques and methods to efficiently transmit data via light are being researched and tested. One of the popular VLC system developed in recent years is nicknamed "Li-Fi", as in Wi-Fi, for Light Fidelity is developed in the University of Edinburgh by a team led by Professor Harald Haas. This system can be used as a generic model for all VLC systems that are to be developed, it uses LEDs for transmission and photo diodes are the receiver. It uses a string of techniques to represent the data through light.

II. SURVEY

2.1 IEEE 802.15.7 Standard

The IEEE 802.15.7 compliant networks consist of two types of nodes, namely, a coordinator which initializes and manages the network and a remote device which communicate with each other via the coordinator. The IEEE 802.15.7 standard defines three types of topologies, namely, peer-to-peer, star, and broadcast as shown in Fig. 1. The IEEE 802.15.7 defines the first two layers of ISO/OSI stack protocol that includes Physical and Medium Access Control (MAC) layers. IEEE 802.15.7 MAC is a Carrier Sense Medium Access/Collision Avoidance (CSMA/CA) based protocol. The IEEE 802.15.7 describes two mechanisms for MAC channel access: contention based and contention free. Contention-based access allows devices to access the channel in contention access period (CAP) using a random access back off algorithm. Contention-free access is managed by the coordinator through the use of guaranteed time slot (GTS) mechanism in contention free period (CFP).[8]

Most of the IEEE 802.15.7 applications work under a one hop star topology. There are fixed number M remote devices within the star topology, with a common coordinator where all nodes are within carrier sensing range of each other. This is to ensure the transmission is not to be interrupted by other nodes (no hidden terminal). Since the analysis is only concerned about the MAC performance in the CAP, it is assumed that super frame does not have a CFP and an inactive period. Therefore, the entire super frame duration is active; that means SO = BO. In the acknowledged CAP analysis, the assumption is that there are no packet losses; the only cause of transmission failures is due to collisions. MAC level ACKs will always be sent after each successful data transmission and will always arrive to the destination node and no data packet retransmissions after a collision. In this scheme the coordinator notifies the remote node after a packet reception with an ACK. If the node does not receive an ACK, it assumes collisions have occurred; however, no retransmissions will be sent. Data packets are assumed to be a fixed N-backoff slots duration and arrive at the nodes for transmission according to a Poisson arrival rate of λ packets per packet duration. The probability p that a node will get a packet to transmit at the next slot is $p = \lambda/N$. In addition, no buffering is examined at the nodes. New packets are not accepted for transmission when the node is currently transmitting, or, is attempting a transmission.[8]

2.2 Light Emitting Diode

LED is a two lead semiconductor light source. It is a pn-junction diode, which emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. Recently introduced high power LEDs offer a smart solution for flash applications in small form factor portable equipment. Since the diodes are built in tiny packages and not requiring a high voltage, the complete flash solutions can be more cost and space effective. Just as well the same LED can be used for a torch function or a movie light, by just keeping them on continuously at less current.[1] Most blue and white LEDs use Indium Gallium Nitrite (InGaN) as active material. The wavelength of the generated light of these LEDs shows a strong dependency on the driving current. This special property of InGaN-based LEDs must be considered well in advance for new application solutions. To obtain white light, blue light-emitting die (wavelength 450 nm to 470 nm) is covered with a phosphorous based material that is stimulated by blue light and emits a yellow light. The human eye detects the mixture of blue and yellow light as white. This mixture cannot be described by a simple dominant wavelength but as spectrum. The LED characteristics between diodes vary in manufacturing. The ratio of emitted light and LED forward current is one of the major parameters which change during production. Therefore, LEDs are generally preselected in different groups of similar current to light conversion ratio. However, even among these preselected groups of LEDs, the forward voltage still varies about ±0.8V of the nominal value.

A CMOS LED driver for low-cost optical wireless links is presented. The architecture is cellular, with direct optical mapping of arrayed transmitter and receiver elements. The devices are InP-based resonant cavity LEDs and detectors, the driver may be implemented either as a voltage-source or as a current-source. A current-source congregation is preferred for applications in optical systems because: (i) the LED source is a current mode device; (ii) voltage-source drivers are difficult to integrate due to the large speedup capacitors that are required; and (iii) switching between two well-specified voltage levels is also hard to realize in CMOS when driving a large capacitance. For these reasons, the LED driver has been designed to convert a digital (voltage) input signal to a train of current pulses. [2] Table 1 shows the LED configuration of VLC. [4]

VLC SYSTEM PARAMETERS

Parameters	Values
Luxeon LED part number	LXHL-MW1B
LED drive current	200 mA
Optical modulation depth	40%
LED beam angle (Full width half maximum)	45°
Receiver concentration lens diameter	30 mm
Blue filter central wavelength and width	450 nm, 40nm (60% through)
Photodetector (OSD-15T) detection area	15 mm^2
Preamplifier (Max3664) TIA gain	6KΩ
Preamplifier input-referred noise	55 nA$_{RMS}$
Receiver input dynamic range	28 dB
Optoelectronic receiver bandwidth	77 MHz
Equalizer capacitor	15 pF
Equalizer resistor	750 Ω
Load (oscilloscope-input impedance)	50 Ω
Electrical low pass filter cut-off frequency	0.7×data-rate

Table 1. VLC parameters

2.3 Photo Diode

A photodiode is a type of photodetector capable of converting light into either current or voltage, depending upon the mode of operation. Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fibre connection to allow light to reach the sensitive part of the device. Many diodes designed for use specifically as a photodiode will also use a PIN junction rather than the typical PN junction. When a photon of sufficient energy strikes the diode, it excites an electron, thereby creating a free electron and a (positively charged electron) hole. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced. [9]

Critical performance parameters of a photodiode include:
 i) Responsivity: The Spectral responsivity is a ratio of the generated photocurrent to incident light power, expressed in A/W when used in photoconductive mode. The wavelength-dependence may also be expressed as a Quantum efficiency, or the ratio of the number of photo generated carriers to incident photons, a unitless quantity. [9]
ii) Dark current: The current through the photodiode in the absence of light, when it is operated in photoconductive mode. The dark current includes photocurrent generated by background radiation and the saturation current of the semiconductor junction. [9]
iii) Response time: A photon absorbed by the semiconducting material will generate an electron-hole pair which will in turn start moving in the material under the effect of the electric field and thus generate a current. The finite duration of this current is known as the transit-time spread. [9]
iv) Noise-equivalent power: (NEP) The minimum input optical power to generate photocurrent, equal to the rms noise current in a 1 hertz bandwidth. NEP is essentially the minimum detectable power. [9]
When a photodiode is used in an optical communication system, all these parameters contribute to the sensitivity of the optical receiver, which is the minimum input power required for the receiver to achieve a specified bit error rate.

2.4 Orthogonal frequency division multiplexing

The modulation signal in VLC has to be both real valued and unipolar. This limits the application of the well-researched and developed modulation schemes from the field of RF communications. Techniques such as on-off keying (OOK), pulse-position modulation (PPM), pulse-width modulation (PWM) and unipolar M-ary pulse-amplitude modulation (M-PAM) can be applied in a relatively straightforward fashion. As the modulation speeds are increased, however, these particular modulation schemes begin to suffer from the undesired effects of intersymbol interference (ISI) due to the non-flat frequency response of the OWC channel. Hence, a more resilient technique such as OFDM is required. OFDM allows adaptive bit and energy loading of different frequency sub-bands according to the communication channel properties. This leads to optimal utilization of the available

resources. OFDM achieves the throughput capacity in a non-flat communication channel even in the presence of nonlinear distortion.

Conventional OFDM signals are complex-valued and bipolar in nature. Therefore, the standard RF OFDM technique has to be modified in order to become suitable for IM/DD systems. A straightforward way to obtain a real-valued OFDM signal is to impose a Hermitian symmetry constraint on the sub-carriers in the frequency domain as illustrated in Fig. 2.4a.[3] However, the resulting time-domain signal is still bipolar. One way for obtaining a unipolar signal is to introduce a positive direct current (DC) bias around which the amplitude of the OFDM signal can vary as shown in Fig. 2.4b.[3] The resulting unipolar modulation scheme is known as DC-biased optical OFDM (DCO-OFDM). [3]
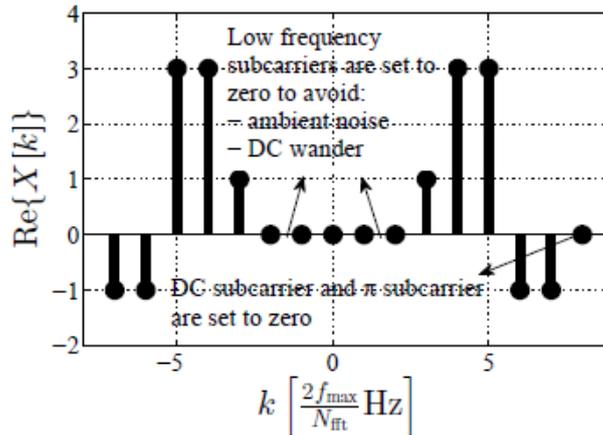

Fig. 2.4a

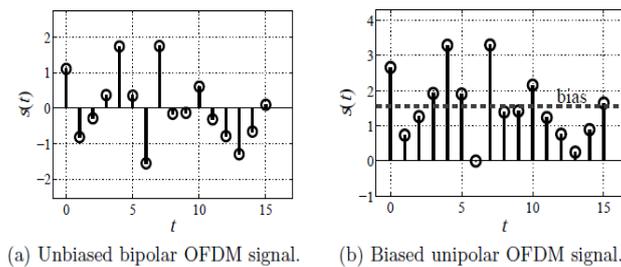(a) Unbiased bipolar OFDM signal.   (b) Biased unipolar OFDM signal.

Fig. 2.4b

From a networking perspective, OFDM offers a straightforward multiple access implementations as subcarriers can be allocated to different users resulting in orthogonal frequency division multiple access (OFDMA). The merits of OFDM have already been recognized, and OFDM is used in IEEE 802.11Wi-Fi systems.[3]

2.5 Working Principle

VLC can only be realized as an IM/DD system. [3] Most practical wireless optical channels use light emitting diodes as transmitters and photodiodes as detectors. These devices modulate and detect solely the intensity of the carrier, not its phase, which implies that all transmitted signal intensities are non-negative. [5] The diagram of an OWC system is presented in Fig. 2.5a. [6] The incoming bits are divided into data chunks and mapped to symbols from a known modulation scheme such as quadrature amplitude modulation (M-QAM) or M-PAM. The MQAM/M-PAM symbols are modulated onto different frequency subcarriers according to one of the following schemes: DCO-OFDM, ACO-OFDM, PAM-DMT, U-OFDM. Then, the resulting time domain signal is subjected to a number of pre-distortion techniques, which condition it for transmission. This block includes oversampling, pulse shaping as well as clipping any values below the allowed minimum or above the allowed maximum. Clipping is performed because a DAC amplifier and an LED can only operate in a limited range, specified by their electrical properties. The conditioned signal is fed to a DAC which outputs an analog signal. This stage of the system consists of a zero-order-hold element or other type of interpolator followed by a low pass filter. The output signal from the zero-order hold is continuous in time. However, because the signal has discrete amplitude levels, corresponding to the samples of the oversampled pulse-shaped and clipped signal s′[t], it is analysed in terms of the discrete time-domain signal s′[t]. It is assumed that the oversampling is sufficient, and the pulse shaping operation is such that the low-pass filter after the zero-order hold outputs a continuous time signal which is equivalent to the signal at its input for all practical considerations. Hence, in the analysis, nonlinear transformations of the signal s′[t] are investigated. The analog output of the DAC is encoded into a current signal by a voltage-to-

current transducer with appropriate bias and supplied to the LED. OFDM-based OWC with incoherent off-the shelf illumination devices can only be realised as a baseband communication technique. Therefore, frequency up conversion is not required and, thus, has not been considered in the presented analysis. Light intensity at the diode varies with the current. At the receiver side, a photo diode transforms the variations in the intensity of the received light into variations of a current signal, which is turned into a voltage signal by a trans impedance amplifier. The resulting signal is discretised at an ADC and passed on to the processing circuitry, which includes a matched filter, an OFDM demodulator with an equaliser, as well as a bit demodulator.[6]
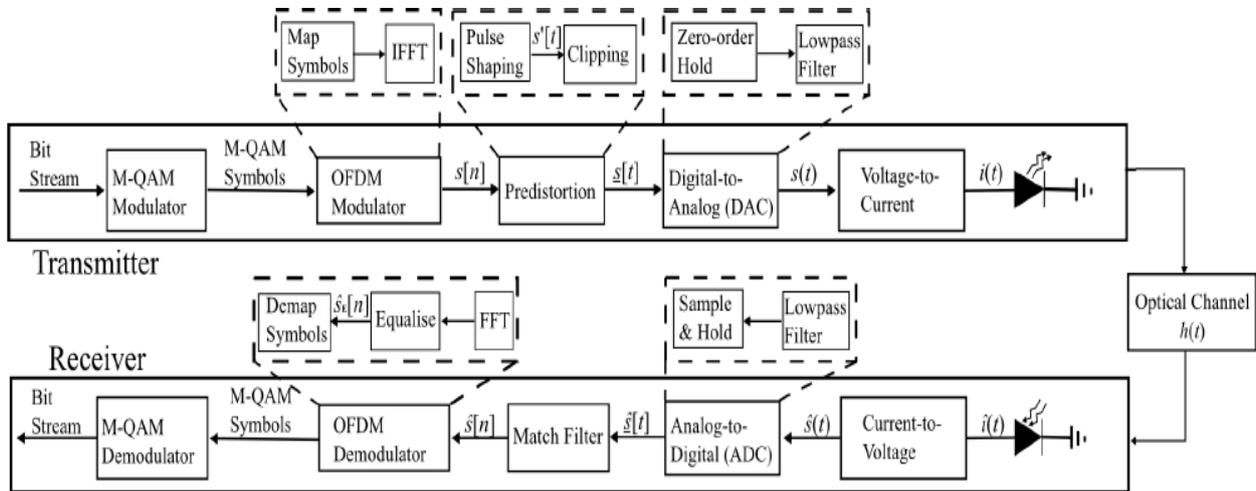

Fig 2.5a

III. APPLICATIONS

The applications of VLC are limitless, some of the top commercial applications are mentioned below.[7]

1. Smart Lighting: Smart lighting with VLC provides the infrastructure for illumination, control and communications which in turn reduces wiring and energy consumption.

2. Mobile Connectivity: By pointing a visible light at another device you can create a very high speed data link with inherent security. This overcomes the problems of connect and pair, provides much higher data rate than Bluetooth and Wi-Fi.

3. Hazardous Environments: Communicating within high risk zones, such as mines and chemical plants, VLC provides both safe illumination and communication.

4. Transportation: Many vehicles already use LED lamps. Traffic and street lights, are also adapting LED technology so there are massive opportunities.

5. Defence and security: The fact that the visible light cannot be detected on the other side of a wall has great security advantages, especially in the Defence sector.

6. Healthcare: Using VLC in hospitals eliminates the use of RF devices which cause disturbance around equipment like MRI scanners.

7. Aviation: Radio is undesirable in passenger compartments of aircraft. LEDs are already used for illumination and can also be used to provide media services to passengers.

8. Underwater Communication: RF does not work underwater but VLC can provide high speed data transmission over short distances. This could enable divers and underwater vehicles to talk to each other.

9. Location Based Services: Each visible light information source can be uniquely identified, so the location of any VLC device can be located quickly and accurately. This can be implemented in Indoor Location Tracking Systems.

10. Wi-Fi Spectrum relief: Congestion in the RF spectrum creates a need for an alternative. VLC can provide data rates equal to or faster than that of Wi-Fi and this can be done at a low cost since the RF components and the antenna system have been eliminated.

IV. CHALLENGES

Visible light communication has properties that are both advantageous and disadvantageous compared to radio-wave wireless communication. Its disadvantages are communication distance and data rate. The communication distance using visible light communication is typically 0.5 to 1 foot. This distance is short compared to radio-wave communication, due to the fact that visible light communication is basically line-of-sight communication, which means that communication is interrupted when there is an object between a transmitter and a receiver. There is another disadvantage of visible light communication, which is data rate. Its data rate is typically between kilobits per second to 10 megabits per second, although there have been active researches going on to reach the speed of gigabits per second. The bottle neck of the data rate is caused by the performance of either white LEDs or receiving photo sensors. The above disadvantageous properties of visible light communication may limit its use for many applications. However, these seemingly disadvantageous properties are indeed useful for some applications by taking advantage of line-of-sight property.

V. CONCLUSION

In this rapidly evolving world of data communication, VLC presents a stable, easy and a faster way of data communication. VLC takes a different approach as compared to other forms of data communications by using light which is available abundantly everywhere and makes use light's two most basic and most effective properties it's speed and reach.

Although the VLC still in its primitive stages of development, it can revolutionise the data communication field, if it's potential is effectively tapped. With dramatic development in LED technology and scarce spectrum resources, there has been a growing interest in VLC, which can be termed as a positive step in this direction. But to progress in this technology certain drawbacks much be acknowledged, such as range, energy efficiency and cost to implement, and to find solutions to overcome these restrictions. Visible light communication is an excellent method of communication and has the potential to be the prime mode of communication in the near future.

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