Short Distance Optical Wireless Communication

Alvin Abraham, Jintu k joseph
1^{st} semester student of M.tech in Communication Systems,
RVCE, Bangalore.
2^{st} semester student of M.tech in VLSI and Embedded systems,
PESIT, Bangalore.

Abstract— **In recent years, interest in optical wireless(OW) as a promising complementary technology for RF technology has gained new momentum fueled by significant deployments in solid state lighting technology. This article aims at reviewing and summarizing recent advancements in Short Range Optical Wireless communication, with the main focus on indoor deployment scenarios. This includes a discussion of challenges, potential applications,state of the art, and prospects. We discuss exclusively about the deployment of OWC technique using the existing infrastructure such as LED lighting fixtures, mobile phone cameras and flashes, and headlamps of vehicles, with little or no add-ons, which in turn will enable Internet of Things (IoT). This paper also discusses the challenges and potential of Optical Wireless Communication.**

I. INTRODUCTION

An optical wireless (OW) communication system relies on optical radiations to convey information in free space, with wavelengths ranging from infrared (IR) to ultraviolet (UV) including the visible light spectrum. The transmitter/source converts the electrical signal to an optical signal, and the receiver/detector converts the optical power into electrical current. Light emitting diodes (LEDs) or laser diodes (LDs) can be used as optical sources and photodiodes (PDs)as detectors.The key design challenges to achieving highspeed OW transmission indoors stem from the free space loss (FSL), ambient light noise, and/or interference, and multipath dispersion causing intersymbol interference (ISI). The induced signal degradation is greatly influenced by the link configuration.

Recently, Visible Light Communication(VLC) technology using white LEDs is gaining attention in academia and industry, driven by progress in white LED (WLED) technology for solid state lighting and the potential of simultaneously using such LEDs for wireless data transmission. Generally, WLEDs used are classified into two types, trichromatic and blue-chip LEDs. Simulation results for data rates up to 400 Mb/s are reported. The maximum measured data rate for a VLC system using blue-chip LEDs is reported in, where a modified version of the classical orthogonal frequency division multiplexing (OFDM) modulation technique is considered to achieve data rates higher than 500 Mb/s[1].

VLC technology, pioneered by the Visible Light Communication Consortium (VLCC) in Japan, is receiving increasing interest worldwide. The VLCC contributes to research, development, and standardization of VLC. In June 2007, the Japan Electronics and Information Technology Industries Association (JEITA) issued two visible light standards, JEITA CP-1221 and JEITA CP-1222, based on VLCC proposals. In October 2008, the VLCC started cooperation with the Infrared Data Association (IrDA) and the Infrared Communication Systems Association (ICSA). In March 2009, a VLCC specification standard adopting and expanding the IrDA physical layer was announced. A standard for VLC local area network (LAN) based on full duplex by the aid of wavelength-division multiplexing (WDM) (IR and visible) is being pursued by the ICSA. In early 2009, the task group IEEE 802.15.7 was working on a VLC standard encompassing both new physical and medium access control (MAC) layers based on a clean slate approach. In November 2010 the P802.15.7 IEEE draft standard was published.

Wireless optical radiation offers attractive features, distinct from those of radio. First, there is huge, unregulated and available bandwidth, without electromagnetic interference (EMI) to existing radio systems. Further on, OW signals do not penetrate through walls. Such signal confinement naturally makes each room a cell, without any inter-cell interference. Thus, one can reuse the same operating frequencies in adjacent cells and hence, have uniform equipment in a cellular architecture. This enables a simple design of high capacity wireless local area networks since transmissions in adjacent rooms need not be coordinated. As a high degree of privacy and security against eavesdropping is inherently offered, such systems are of interest e.g., for military use or financial messaging. Moreover, they are highly attractive for operating environments such as hospitals and airplanes, where radio systems are not desired. Thus, both radio and optical media might jointly provide a broad spectrum of capabilities that radio alone would find difficult to do.

II. INDOOR OW POTENTIAL

A block diagram of a typical indoor OW system is illustrated in Fig. 1 . A basic OW system consists of a light source, free space as the propagation medium, and a light detector. Information, in the form of digital or analog signals, is input to electronic circuitry that modulates the light source. The source output passes through an optical system (to control the emitted radiation, e.g., to ensure that the transmitter is eye safe)into the free space. The received signal comes through an optical system (e.g., an optical filter that rejects optical noise, a lens system or concentrator that focuses light on the detector), passes along

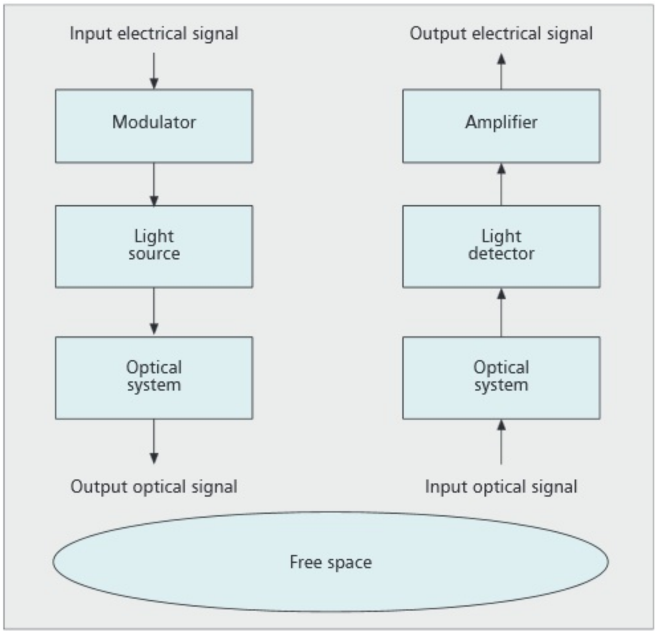

Fig. 1. Typical OWC system

the detector, and the resulting photocurrent is amplified before the signal processing electronics.For most indoor applications, LEDs are the favored light sources due to the relaxed safety regulations, low cost, and high reliability compared to LDs. PIN PDs are commonly used due to their lower cost, tolerance to wide temperature fluctuations, and operation with an inexpensive low-bias voltage compared to avalanche photodiodes (APDs). Simple and low-cost optical carrier modulation and demodulation are usually achieved through intensity modulation with direct detection (IM/DD). The desired waveform is modulated onto the instantaneous power of the optical carrier, and the detector generates a current proportional to the received instantaneous power; that is, only the intensity of the optical wave is detected, and there is no frequency or phase information.

In this paper we will discuss only about the potential of short range optical wireless communication in which we can utilize the existing infrastructure (lighting fixtures) to provide a better data speed for current and future needs.

A. *Indoor Communication*

Li-Fi, as coined by Prof. Harald Haas during his TED Global talk,is bidirectional, high speed and fully networked wireless communications, like Wi-Fi, using visible light. Li-Fi is a subset of visible light communications (VLC) and can be a complement to RF communication (Wi-Fi or Cellular network), or a replacement in contexts of data broadcasting.

It is wireless and uses visible light communication (instead of radio frequency waves), part of Optical wireless communications technology, which carries much more information, and has been proposed as a solution to the RF bandwidth limitations. A complete solution includes an industry led standardization process.

It is a visible light communication system that uses light from light-emitting diodes (LEDs) as a medium to deliver networked, mobile, high-speed communication in a similar manner as Wi-Fi[1]. Li-Fi could lead to the Internet of Things, which is everything electronic being connected to the internet, with the LED lights on the electronics being used as Li-Fi internet access points. Visible light communications (VLC) works by switching bulbs on and off within nanoseconds, which is too quickly to be noticed by the human eye. Although Li-Fi bulbs would have to be kept on to transmit data, the bulbs could be dimmed to the point that they were not visible to humans and yet still functional. The light waves cannot penetrate walls which makes a much shorter range, though more secure from hacking, relative to Wi-Fi. Direct line of sight isn't necessary for Li-Fi to transmit a signal; light reflected off the walls can achieve 70 Mbit/s.

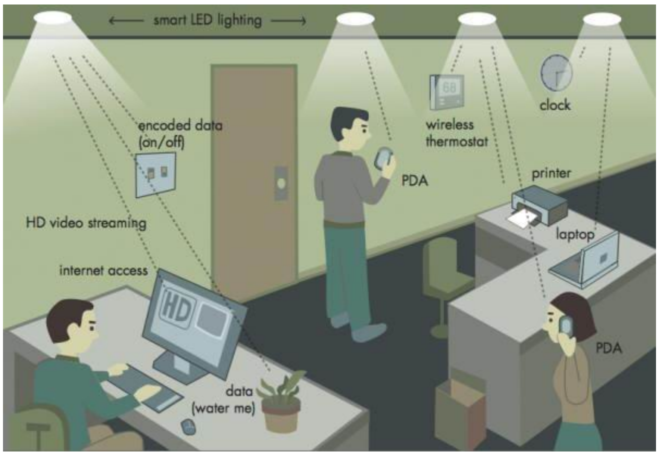

Fig. 2. Li-Fi in office environment

Li-Fi has the advantage of being useful in electromagnetic sensitive areas such as in aircraft cabins, hospitals and nuclear power plants without causing electromagnetic interference. Both Wi-Fi and Li-Fi transmit data over the electromagnetic spectrum, but whereas Wi-Fi utilises radio waves, Li-Fi uses visible light. While the US Federal Communications Commission has warned of a potential spectrum crisis because Wi-Fi is close to full capacity, Li-Fi has almost no limitations on capacity.The visible light spectrum is 10,000 times larger than the entire radio frequency spectrum.[14] Researchers have reached data rates of over 10 Gbit/s, which is more than 250 times faster than superfast broadband.Li-Fi is expected to be ten times cheaper than Wi-Fi. A typical Li-Fi application in office environment is depicted in Fig.2.

PureLiFi demonstrated the first commercially available Li-Fi system, the Li-1st, at the 2014 Mobile World Congress in Barcelona. Various research groups are working towards making optical wireless communication a reality.

B. *Mobile Data Transfer*

Over the last decade, mobile phones with embedded cameras have become common. The majority of new gen-

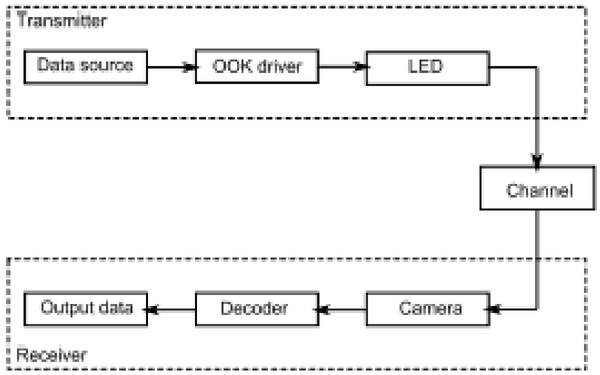

Fig. 3. System block diagram: The upper part shows the transmitter (which consists of an On-Off Keying driver, and an LED) and the lower part shows the receiver (mobile phone).

eration smartphones have built-in Complementary Metal-Oxide-Semiconductor (CMOS) cameras providing the ability to capture photos and videos. Each sensor array of pixels is triggered row-sequentially a process known as rolling shutter. This effect allows us to transmit with data rates that far exceed the frame rate of the camera.

In this paper we develop a model for the transmission of data from an LED to a smartphone using the built-in camera as a receiver. The model (Fig. 2) involves the transmitter protocol and an Android application for the signal reception and decoding at the smartphone. Using this model, data can be transferred reliably to a mobile device. A generalized block diagram is presented in fig.3.

The rolling shutter mechanism is a method of image acquisition used by CMOS sensor cameras. A CMOS pixel converts incident photons into electrons which are then converted to a voltage, from which the pixel value is obtained. The level of signal generated by the image sensor depends on the amount of light incident on the imager, in terms of both intensity and duration. Most CMOS sensors contain pixel that are arranged in sequentially activated rows (scanlines) and therefore do not capture the entire image at once. On activation, each scanline of the sensor array is exposed, sampled and stored sequentially. When this procedure is completed the scanlines are merged together in order to form a single image. Rolling shutter is the term used to describe this process[2].

Various effects can be observed due to the rolling shutter operation such as skew seen in images of a moving object. While this may seem undesirable, this property of the CMOS cameras can actually be utilized in optical wireless communication in order to transmit data from an LED to a mobile phone. When the flashing frequency of the LED is lower than the rolling shutters scanning frequency but higher than the frequency of the preview display of the camera (frames per second or fps), bands of different light intensity appear in the image. When the LED is on, the camera sees a bright frame and the CMOS sensor exposes one array of this image as the first white line in the image.The transmitter then changes to the off state and the second scanline is enabled, which results in the first black line in the image. This procedure continues until all the scanlines are exposed and the image is completed.The width of these bands is proportional to the symbol rate of the transmitter and the rate the camera captures preview images (fps). By adjusting these values, an array of images containing bands with different width and intensity can be obtained. Using simple image processing techniques these bands can be converted to a binary array from which useful information can be extracted.While the camera is limited to a capture rate of approximately 20 to 30 frames per second, the rolling shutter effectallows the capture of multiple information bits (LED states)inside every frame, which leads to speeds significantly higher than the frame rate of the camera.

The light from the transmitter is used to illuminate a surface and the reflection is received by the camera of the smartphone[5]. The preview mode of the camera is used to capture a continuous array of frames and then, a decoder based on Java is applied frame by frame.As previously mentioned, the application takes advantage of the rolling shutter effect of CMOS cameras in combination with the ability of the mobile phone to store temporarily the continuous preview images in a buffer. In order to achieve maximum performance, a buffer queue of three is used. Every time a preview frame is captured, it is stored in a buffer in order to be processed by the decoder. After processing, the buffer is released and returns to the queue. This process continues until the data sent from the LED is received.

This capture data is then analyzed by the software and the transmitted data is decoded. For this purpose special signal processing application for mobile phones can be developed. Which is good for the penetration of optical wireless communication techniques into the field of Near Field Communication(NFC). Like this way , the use of magnetic cards(ATM Cards, shopping cards etc.) and NFC enabled devices can also be avoided using the smartphone apps.

C. *Intelligent Transportation Systems*

In current days, the introduction of intelligent communication devices on board of vehicles and alongside the road, has not reduced traffic-related fatality rates. Road crashes are a leading cause of death, especially among young people. Annually over 1.2 million people are killed due to road accidents. Recent studies forecast that road accidents will increase and become the sixth cause of death in the world by 2020.

To minimize road accidents and fatalities,various modes of vehicular communications, such as vehicle to infrastructure (V2I), vehicle-to-vehicle (V2V) and infrastructure-to-vehicle (I2V), are being investigated (Fig.4). ITS, which interrelates humans,roads,and vehicles through state-of-art information technology, brings a new systematic approach aiming for the solution of road transportation problems, efficient traffic flow and reduction of the environmental load. Recently, ITS have drawn a lot of attention to solve various traffic problems[4].

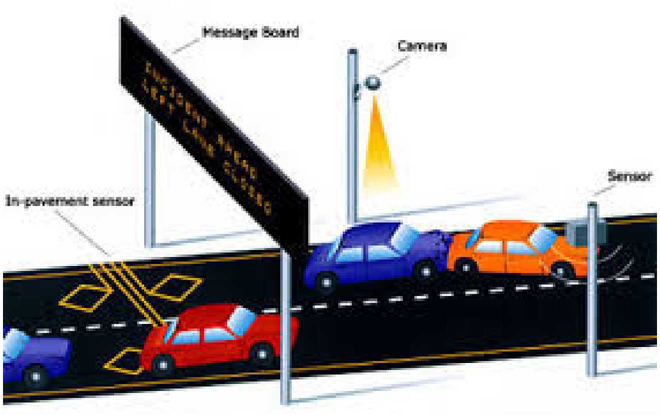

Fig. 4. Intelligent Transportation System

VLC systems can play a key role in ITS as means to broadcast important traffic information. Several configurations are possible: car-to-car (C2C) using LED base rear panel lights; and infrastructure-to-car (I2C) in both directions. A basic study on a traffic information system using LED-based traffic lights was investigated by authors in. They analyzed the performance and defined a service area,in which communications using a specified data rate together with intensity modulation on-off keying (OOK) can be maintained. VLC is not only suitable for a broadcast system in I2C communication systems but it can be equally effective in C2C[]c4. In a C2C scenario example, a vehicle infront of a traffic light receives the information and relays it using the brake lights to the vehicle running behind. Given the merits of VLC systems, it is expected that VLC can play key role in road safety applications.

D. Location Based Services

By leveraging existing LED lighting infrastructure, we can providesa low-cost way for pushing hyper-targeted digital content to shoppers and associates within a retail store.And the ability to reach the broadest number of connected shoppers,we can redefine mobile marketing and workflow management.Innovative indoor location solution enables retailers to engage in-store connected shoppers with location-based services using LED lighting. Using this we can deliver personalized content based on a shoppers identity, location and purchase history.We can make indoor location software for LED lighting. By leveraging existing LED lighting infrastructure, this mobile phone application or software provides a low-cost way for pushing targeted digital content to shoppers and associates within a retail store. With sub-meter accuracy and sub-second latency and the ability to reach the broadest number of connected shoppers. This innovative indoor location solution enables retailers to engage in-store connected shoppers with location-based services using LED lighting. Since papers are being published on indoor location tracking, we can determine the precise location and direction of shoppers in the aisle.

We can give shoppers the same wealth of information available online while they are in-store. Retailers can push a offer coupon for products displayed at the lexact location to a customer in the shop aisle. Shop management and inventory control will become easy. Retailers can deliver detailed planogram instructions and a checklist for an employee stocking a shelf. Software, integrated into a retailers app, drives revenue, customer loyalty, and employee efficiency.

We can also apply the same principles to museums and art galleries to give visitors a very personalised content delivery. In this case also, the LED fixtures are used to transmit the relevant data to the visitor. Since every artifact is illuminates, it can deliver the right content to the intended user. This technology can enhance visitor experience and make museums and art gallary visits more interactive and engaging.

E. Indoor Navigation

Indoor positioning systems are becoming increasingly significant for pervasive and context-aware computing with location awareness, autonomous robot movement, sensor applications etc. During the last two decades, researchers have been trying to develop positioning techniques to provide precise location information using GPS, IR, RFID, Blutetooth, WLAN, Ultrasound,and so on . GPS has been extensively used for positioning in outdoor environment such as in car navigation, mobile phones, ships, planes, surveying of public works etc.However, since GPS positioning depends on radio wave propagation, multipath fading and disturbances from other radio sources lead to large positioning error in indoor environment. The conventional indoor positioning systems such as WLAN, RFID, Bluetooth and Ultrasound system have problems due to system instability, long response time, low accuracy and low precision. Recently, visible light communication (VLC) is emerging as an attractive technology for indoor positioning system . Together with illumination, lighting equipments serve the purpose of data communication in VLC system. This system is regarded as one of the most promising alternativesto band limited radio wave communication since it does not cause or suffer from radio or electromagnetic interference. VLC can be used in buildings, underground and even in hospitals where radio frequency is prohibited.Compared to conventional lighting devices such as incandescentand fluorescent lamps, LED is more advantageous in terms of long life expectancy, high tolerance to environmental hazards, low operating voltage, low power consumption and nominal heat dissipation lighting. Hence, high power white LEDs are considered to be a strong candidate for the future illumination technology. Therefore, we focus on developing VLC based positioning system.The proposed system uses received light intensity and accelerometer measurements to compute distances between the transmitters and the receiver.Accelerometer measurements are used to eliminate the need for commonly-used assumptions in the literature.receiver. Lastly, position errors within a few centimeters is achievable, provided the receiver is under three LEDs and pointing towards them[6].

III. Open Issues and Continuing Research

Unlike broadcasting applications, serving users requests and performing adaptive modulation relying on channel information require a realization of an uplink channel which is a challenging design task. A proposal is foreseen through wavelength-division duplexing (WDD) using different IR wavelengths. However, this approach may require alignment or tracking.It is also possible to use the time-division duplexing (TDD) technique to separate the downlink and the uplink signals.

For VLC systems, the performance is limited by the modulation bandwidth of the blue-chip LEDs. Mitigating the poor performance of suchLEDs is the most important step towards achieving high-speed data transmission. It is shown by Grubor et al. in 2007 that the long response time of the phosphor limits the available modulation bandwidth to several megahertz. By using a simple color filter to detect only the blue peak of the emission spectrum, the resulting modulation bandwidth is approximately an order of magnitude larger. The maximum reported bandwidth achieved through this approach is around 20MHz.In optical systems, the LED is a major source of nonlinearity.In order to control the LED nonlinearity induced distortion, searching for an optimum DC operating point and optimal OFDM signal power to modulate the LED intensity is required.

IV. COnclusion

This article reviews OW communication technology, overviews research activities, and states the design challenges that still need to be overcome before being able to realize an entire OW system that can be commercially deployed. It is anticipated that further experimental and theoretical studies will provide enhanced foundations for important new developments in this very rapidly growing area.

References

[1] Harald Haas, "Topics in Optical Communications",*IEEE Communications Magazine, 2011*, pp.56-62.

[2] Christos Danakis, Mostafa Afgani, Gordon Povey, Ian Underwood and Harald Haas,"Using a CMOS Camera Sensor for Visible Light Communication" *3rd IEEE Workshop on Optical Wireless Communications (OWC'12)*, pp. 1244-1248.

[3] J Pesonen and E. Horster Near field communication technology in Tourism *Tourism management perspectives 2012*. pp.11-18

[4]] Xuan Tang et al. Fundamental analysis of a car to car visible light communication system,*9th International symposium on communication systems, networks & digital design 2014*, pp.1011-1016

[5] Mariam M. Galal, Ahmed Abd El Aziz, Heba A. Fayed and Moustafa H. Aly . High Speed Data Transmission over a Visible Light Link Employing Smartphones Xenon Flashlight as a Replacement of Magnetic Cards *IEEE 2013*, pp.157-160

[6] Muhammad Yasir, Badri N Vellambi Indoor positioning system using visible and accelerometer *Journal of Lightwave technology vol. 32, no.19*, October 1, 2014.