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Review Article

A REVIEW: MILLER ENCODER FOR OUTDOOR MIMO VLC APPLICATION

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ABSTRACT

Visible Light Communication (VLC) is an emerging field in Optical Wireless Communication (OWC) which utilizes the superior modulation bandwidth of Light Emitting Diodes (LEDs) to transmit data. This paper presents a Visible Light Communication (VLC) system architecture suitable for Multiple Input Multiple Output (MIMO) outdoor applications. VLC usages in outdoor scenarios like traffic system, smart lighting systems and public illumination systems trends to increase the usage of LEDs. The ramping up of LED technology brought new opportunities for energy savings and reduced maintenance cost in illumination systems. This paper also addresses the issues regarding robust communication for short to medium distances using VLC. The presentation is focused on comparative analysis between RF communication, Infrared Communication, visible light communication and also the Manchester code, as a traditional code and the Miller code as a possible candidate for outdoor MIMO applications.

INTRODUCTION

Wireless communication has gone through several paradigm shifts starting from the discovery of Electromagnetic (EM) waves, wireless telegraphy, and the invention of the radio. Fig. 1 shows the EM spectrum along with the wavelength band of various waves which include radio wave, microwave, infrared, ultra violet, X-ray and gamma ray. Along the EM spectrum, as the wavelength decreases, the frequency as well as the energy of the waves increases. The visible light band occupies the frequency range from 430 THz to 790 THz and the radio wave occupies the band from 3 kHz to 300 GHz. Radio Frequency (RF) has been the most widely used portion of the EM spectrum for communication purposes, mainly due to little interference in the frequency band and wide area coverage. Unlike radio waves, electromagnetic waves in the visible light wavelength are not harmful for the human body.

Moreover, the visible light portion of the spectrum is not regulated. This opens up a huge bandwidth for communication, which can be utilized in a wide range of applications.

The demand for wireless access is rapidly growing which resulted in heavily congested spectrum which reduces spectrum efficiency, The available radio-frequency (RF) bandwidth will not be sufficient to meet the increasing demand for wireless access. Visible light communication (VLC) is an alternative method to reduce the burden of RF-based communication. 70% of the communication is indoors, and light emitting diode (LED) arrays are used for illumination purposes because of their low energy and higher lifetime. VLC can be realized as a secondary application in LED arrays that are placed for lighting. To be able to meet this demand, the research community began looking for solutions that target alternative portions of the spectrum.

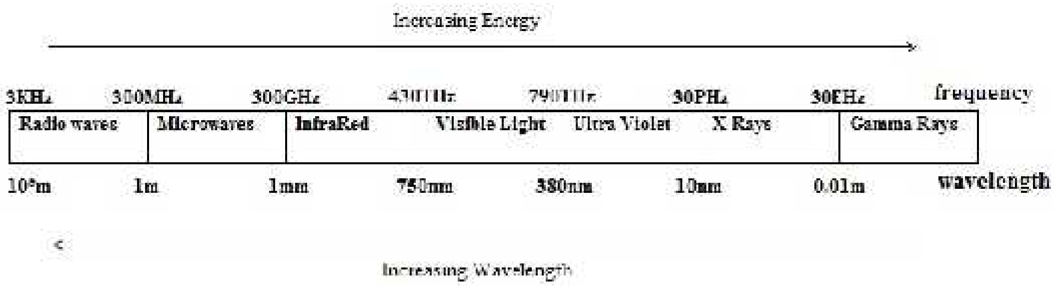

Fig. 1 The Electromagnetic Spectrum

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VLC is one of the promising alternative that aims to provide a communication medium by using the existing illuminating devices. VLC using LEDs comprises OWC links using visible light spectrum, in which LEDs are applied with two functions, illumination and communication, simultaneously [1-2]. For these reasons, VLC attracts significant research interests. With the improvements in LED technologies, it is possible to modulate light in high frequencies such that human eye cannot detect. Due to their lower cost, higher lifetime and lower power consumption, LEDs are expected to replace conventional incandescent and fluorescent lamps in the near future. This enables the use of LEDs for both illumination and communication, making VLC an economic and ubiquitous data transmission solution.

OWC systems can be classified into short and long range systems according to the distance between the transmitter and receiver. Long range systems are used for outdoor applications such as inter-building communications, last mile access networks, high altitude platform (HAP) laser communications, and satellite communications [13]. Short range systems can be applied for VLC, car-to-car communications, unguided optical bus, and inter/intra chip communications [13, 14]. In addition, the emerging area of medical applications and hospital environment using OWC such as transdermal communications will require different and unique set of tools and will be definedas the third category. The three categories provide inherently different propagation environments and pose unique challenges that need careful consideration when designing OWC systems.

The use of visible light as a wireless communication medium is nothing new. In old times humans communicated across great distances using beacon fires, mirror reflections, and light houses. But the first known electronic wireless communication using visible light comes from Alexander Graham Bell, who in 1880 developed a photophone [3] which transmitted modulated voice data over 200 m using beams of sunlight. After that, several incremental improvements on Bell design were done using tungsten lamps with IR filters, and high-pressure vapor and mercury arc lamps [4]. Later, there were other demonstrations featuring fluorescent lights for communication with low data rates [5]. Then, the idea of using visible light as an effective fast communication medium has been retaken with the development of LED lighting systems with lower power consumption and longer life-time compared to other types of lamp systems, in addition to other advantages such as high lighting efficiency, specific spectrum and environmental friendliness. Nowadays, LEDs are becoming the lighting source for almost all illumination applications [2, 6], and such lighting systems provide an infrastructure for VLC with the use of LEDs not only for illumination but for high speed data transmission.

The concept of VLC using fast switching LEDs was conceived in Japan in 1999 by Pang *et al*. [7], who described a VLC system implemented on LED traffic lights to provide open space, wireless broadcasting of audio messages. In 2001, Kulhavy of Twibright Labs developed RONJA (Reasonable Optical Near Joint Access) [8], a free technology project for reliable free-space optical data links using visible light with a range of 1.4 km and communication speed of 10 Mbps full duplex. The use of white-LED for both lighting and communication was driven by Tanaka *et al*. in the early 2000s [9,10], reporting a 400 Mbps data transmission based on numerical analysis and computer simulations. Over the past few years research groups have been able to demonstrate that high data rates up to the gigabit per second range are possible with LED based VLC using the right choice of modulation and line coding schemes, and use of equalizers at transmitter and receiver [8-11].

Comparison of VLC with IR communication

VLC has two major advantages over IR. One is related to safety issues and the other is about ease of deployment. Most of the Infrared emitting diodes use the 800–960 nm wavelength range. A number of problem may arise if radiation within these wavelengths comes into direct contact with the eye, such as a thermal retina hazard and thermal injury risk of the cornea as well as possible delayed effects on the lens of the eye (cataractogenesis). Therefore, transmission power for infrared devices are limited by safety standards such as International Electrotechnical Commissions (IEC) IEC 60825-1 Safety of laser products, and IEC 62471 Photobiological safety of lamps and lamp systems. VLC uses visible light LEDs which are expected to replace the conventional incandescent and fluorescent lamp since they have lower power consumption, high efficiency and longer lifetime. Therefore, the transmitters for VLC will mostly be readily available. Furthermore, technologies such as Power Line Cable (PCL) enable use of existing lighting infrastructure as back-haul in existing installations. PLC enable use of electric cables for communication. PLC also enables the use of power outlets to be used as ports. This alleviates the need to install new communication cables to make VLC work. For new installations, new technologies such as Power over Ethernet (PoE) may be used. Room illumination must meet certain minimum levels according to the standards. For example, the international standard on Lighting of indoor work places, ISO/CIE 8995.1 recommends a minimumilluminance of 200 lux in areas where continuous work is carried out. To meet these illumination levels, distributed ceiling installations are envisioned. Such deployment of LEDs ensure a dominant line-of-sight (LOS) component, resulting in very high signal-to-noise ratio (SNR) (>60 dB through the entire room). This permits simpler receiver structures for VLC compared to IR. For example, due to this large SNR, the receiver does not need to narrow the field-of-view (FOV) [15].

Comparison of VLC with RF communication

Even though both RF and VL communications use electromagnetic waves, they have very different inherent properties. Visible light does not interfere with electronic devices as RF waves do. Therefore, VLC may be more suitable for applications where sensitive electronic devices are used, such as hospitals, chemical plants, and airplanes. Recent studies indicate that more than 70% of wireless traffic originates indoors [16]. Even though RF waves penetrate walls, signal propagation is degraded. On the one hand, this attenuated propagation limits data rates of intended users. On the other hand, since transmission is not strictly confined to the intended area, security of the links may be compromised by eavesdropping malicious users. VLC provides the desired answers to both problems. Since most indoor environments are illuminated, VLC can provide the required coverage. Since visible light cannot penetrate walls, links can be kept confidential.

demodulation, frame processing and error correction can be adequately implemented using an FPGA.

Table I Comparison of VLC with RF and IR

Parameter	RF	IR	VLC
Available Spectrum	~300GHz(Licenced)	~400THz(Unlicenced)	~400THz(Unlicenced)
Safety	Intensity Regulated	Intensity Regulated	Unregulated
Noise	Little	High	High
Security	Limited	High	High
Coverage	Wide	Limited	Limited
Multipath	High	Low	Low
System Complexity	High	Low	Low
Electromagnetic Interference	Yes	No	No
Infrastructure	Access point	Access point	Illumination
Power Consumption for short range links	Medium	Low	Low

VLC system for outdoor application

A VLC transceiver is optical electronic device that converts visible light into an electrical signal and vice- versa. The design of the necessary devices for an outdoor application should take into account the particularities of the application scenario, such as the significant presence of noise components.

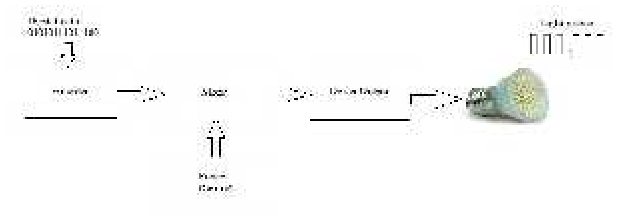

Fig 2 VLC Emitter

Figures 2 and 3 present a top level view of generic emitter and receiver units. On the emitter side (Fig. 2), digital data is processed and converted by an encoder into an electrical output signal that carries the information. These initial operations are implemented on a FPGA that allows for easy system upgrade. The output electrical signal is passed to a mixer module that combines it with the power signal. The outcome is then used to control the output driver module that switches the LED current, thus modulating the input signal from the encoder into the light output of the LED. According to the desired communication range and the type of LEDs applied, an output lens can be applied to shape the output light beam.

Optical MIMO System

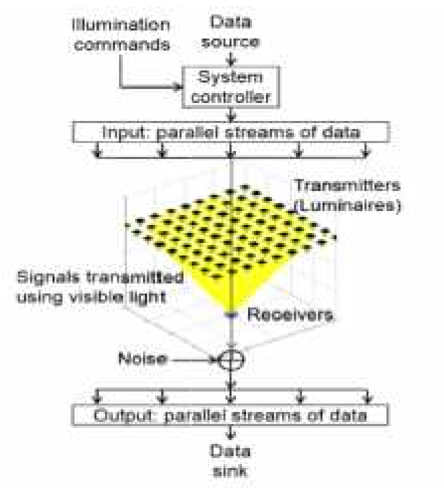

Fig.4 Optical MIMO system

An optical MIMO communication system uses multiple LED-based transmitters and multiple receivers to transfer parallel streams of data. As compared to a single-transmitter single-receiver system using the same amount of signal power, a MIMO system can provide higher data rates with fewer transmission errors and better reliability. An optical MIMO system could greatly enhance the system data transmission capacity compared with a Single-Input Single-Output system

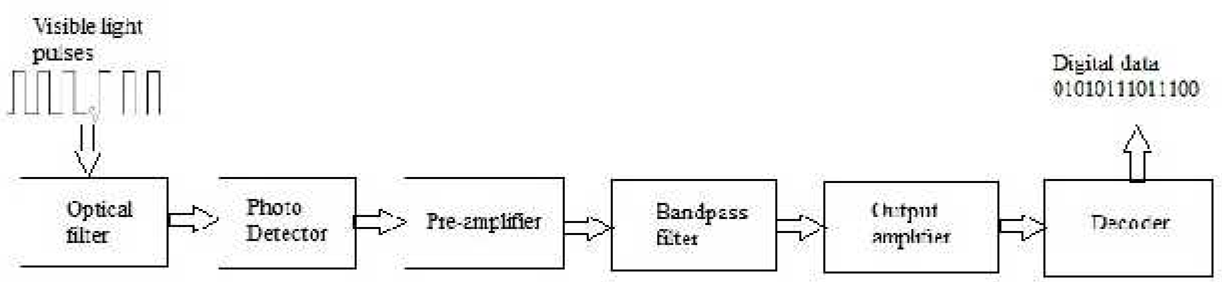

Fig 3 VLC Receiver

On the receiver side (Fig. 3) the visible light pulses pass through an optical filter, before hitting the photo-detector (PD). This results in small amplitude currents which are then amplified and converted into voltages using transimpedance amplifiers. The resulting signal is then filtered, amplified and converted into a digital format using an ADC. Synchronization, (SISO), and thus has drawn much attention recently. MIMO processing can relax the requirement of terminal mobility and precise mechanical alignment [19]. The differences and advantages/ disadvantages of MIMO and SISO system are presented in Table II. From the table, it is clear that MIMO outperforms SISO when considering overall communication aspects of a link.

Table II Difference between SISO and MIMO

Parameter	SISO	MIMO
Number of Transmitter	Single	Multiple
Number of Receiver	Single	Multiple
Number of Channel	Single	Multiple
BER(at 5dB SNR) AWGN Channel / Rayleigh Channel	0.45 / 0.5	0 / 0.25
Optical Crosstalk	Null	High
Aggregate Data Rate	Low	High

There are three different types of optical MIMO systems:

1. **λ-MIMO**: This system is implemented using a single luminaire composed of LEDs that emit different colors of light. Each LED acts as a different transmitter. Thus the parallel data streams can be transmitted over different colors of light. The receiver for this system implements optical filters to recover the signals transmitted over each color.
2. **s-MIMO**: This system is implemented using multiple luminaires that are placed at different locations on the ceiling. Each luminaire is composed of the same type of LED and thus emits the same color of light. In this case, the data streams are separated spatially because they each originate at a different spatial location. A 'camera-like' receiver can then separate the different signal streams and recover data.
3. **h-MIMO**: This system is a hybrid of the above two systems. It uses multiple luminaires, each composed of different colored LEDs to transmit signals that are separated in color and space. A 'camera-like' receiver that can distinguish different colors can then separate the different signal streams and recover data.

The optical MIMO systems focuses on its design, analysis and optimization to achieve high data rates while providing good quality illumination. The framework generated by this work will enable the design of optimal dual-purpose communication and lighting systems.

Encoding Scheme

There are many modulation techniques like Return-to-Zero (NRZ) and Return-to-Zero (RZ) which are used in communication devices. But VLC uses FM0, Manchester and Miller encoding [17] in its architecture. Generally, the waveform of transmitted signal is expected to have zero mean for robustness issue and this is also referred to as dc-balance. The transmitted signal consists of arbitrary binary sequence, which is difficult to obtain dc-balance [18]. FM0, Manchester and Miller codes can provide the transmitted signal with dc-balance. For this reason, VLC prefers FM0, Manchester and Miller encoding techniques.

FM0 Encoding

FM0 encoding is also called as bi-phase space encoding scheme. In FM0 encoding, the signal to be transmitted and done according (Figure 5), to the following rules,

- It inverts the phase of the base band signal at the boundary of each symbol.
- For representing logic '0' level, it inverts the signal at the mid of the symbol.
- For representing logic '1' level, it constant voltage occupying an entire bit window.

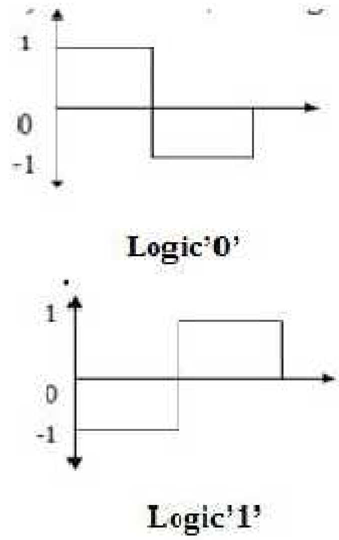

Fig 5 FM0 Basic Function

Manchester Encoding

Manchester code be first developed by G.E.Thomas at 1949. It is also called as phase encoding scheme. In Manchester encoding, the signal to be transmitted and done according (Figure 6) to the following rules,

- A '1' is noted, when low to high transition occurs.
- A '0' is noted, when high to low transition occurs.

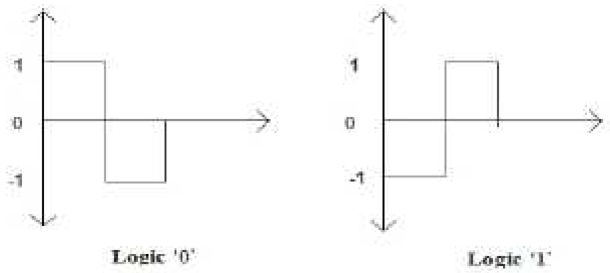

Fig 6 Manchester Basic Functions

Miller Encoding

Miller encoding is also known as delay encoding. It can be used for higher operating frequency and is similar to Manchester encoding except that the transition occurs in the middle of an interval when the bit is 1. While using the Miller delay, noise interference can be reduced. In Manchester encoding, the signal to be transmitted and done according (Figure 7) to the following rules,

- Phase inversion occurs at data '1' symbol.
- Phase changes when the logic '1' data appears after the long continuous logic '0' data.

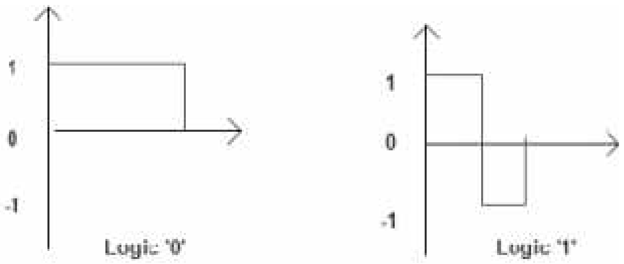

Fig 7 Miller Basic Functions

CONCLUSIONS

In this paper, we provide a comprehensive survey of VLC as an alternative to RF communications. The available studies have shown that VLC can be used in high data rate applications in indoor communications. Therefore, VLC is a promising method to meet ever growing need for wireless access and data rate. Since VLC is a relatively new research area, there are many problems which require significant research attention. However, well-developed techniques for RF communications can be adapted to the characteristics of VL.

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