Visible Light Communication Numerous Applications

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INTRODUCTION

The initial theory of Visible Light Communication (VLC) was founded in the 1880s when Alexander Graham Bell invented the photo-phone which was used to transmit a voice signal using the modulated sunlight. Since the time of Graham Bell, optical communication research has attracted the interest of scholars around the world and has evolved into a new IEEE standard namely the P802.15.7 - Standard for Short-Range Wireless Optical Communication (standard, 802.15.7 (2015)). In 2003 at the Nakagawa Laboratory in Keio University, Japan, they have proposed using the Light Emitting Diodes (LEDs) for data transmission.

A major factor that contributes to the evolution of VLC technology is the existing infrastructure. Hence, previously installed facilities, such as LED traffic lights or LED sign boards are readily used. Since the transmitters for VLC are light sources, they function for lighting purposes and illuminate the surrounding environment, hence the radiation power and signal-to-noise ratio (SNR) is high; paving the way for a stable communication link (T. Yamazato, I. H. (2014)).

With respect to the emergence of green communication, VLC is highly energy efficient as it utilizes LEDs. The United States Department of Energy further corroborated the importance of LED technology, as shown in Table 1. There is superiority in terms of power consumption and operating lifetime in LED technology as compared to traditional lighting technology, such as incandescent and fluorescent lighting. This clearly shows the potential of the LED lighting technology to replace all the conventional illumination tools as well as serve as a reliable transmitter for a VLC link (Chung, Y.-Y. T.-Y. (2014)).

Radio Frequency (RF) wireless connectivity has been used for several decades as it allows for indoor and short distance links to be established without any physical connection. However, these solutions remain relatively expensive and have low to medium data rates. RF wireless links require that spectrum licensing fees are paid to federal regulatory bodies and are required to be contained within strict spectral zones. These frequency allocations are determined by local authorities and may vary from country to country, making a standard interface difficult. Since the visible light spectrum is not in the licensed band (400 to 790 THz), licensing fees can be avoided which effectively reduces system cost. In addition, the broadcast nature of the RF link is beneficial for mobile connectivity but this may result in interference between devices located within close prox-

DOI: 10.4018/978-1-5225-2255-3.ch578

Table 1. Performance of the conventional and LED lighting technology

Lamp Type	Watts	Lumens	Operating Lifetime
Incandescent	60	900	1000
Compact florescent lamp	15	900	8500
LED (2011)	12.5	800	25000
LED – future(2015)	5.8	800	40000

imity. Due to the RF wavelength, it is difficult to contain within boundaries and can impede system performance (Hranilovic, S. (2005)).

Optical radiation in the infrared or visible range is easily contained by opaque boundaries. As a result, interference between adjacent devices can be minimized easily and economically. Additionally, inexpensive LEDs and photodiodes are able to interchangeably work between baseband and transmission frequencies where as high-frequency RF circuit design techniques are required in the RF domain. Free-space optical (FSO) links with an inherent low probability of intercept and anti-jamming characteristics is among the most secure of all wide-area connectivity solutions (Hranilovic, S. (2005)).

Unlike many RF systems that radiate signals in all directions, thus making the signal available to all within the receiving range, FSO transceivers use a highly directional and cone-shaped beam with a dominant line-of-sight (LOS) propagation path. Therefore, interception is extraordinarily difficult and anyone tapping into the systems can easily be detected as the intercept equipment must be placed within the very narrow optical foot print (Ghassemlooy. Z., P. W. (2012)). Although this contributes to the security of wireless optical links and reduces interference it also greatly impacts the high mobility of such devices.

The aim of this book chapter is to introduce the concept of VLC as an emerging technology from a system and hardware design point of view, and shed the light on the rich features and potential of this technology that make it a viable substitution for other wireless technologies. The importance of this technology will be demonstrated by covering various applications and scenarios.

BACKGROUND

VLC is the process of transmitting digital data by using the visible light spectrum. This can be achieved by modulating the data using a light source such as LEDs that can be switched fast enough to avoid observable flickering or light dimming, another possible way is to change the light intensity in a way that is not observable to the human eye but can be detected using an appropriate sensor such as a photo diode (PD). Along with its prime function of lighting, LEDs can also serve to transmit data as long as there are suitable receivers.

Additionally, image sensor pixels can be used as an effective VLC receiver. The ability to spatially separate multiple sources of image sensors provide an attractive feature to VLC. Image sensor pixels can sense LED transmission sources and discards other pixels which detects ambient noise. More specifically, outdoor usage of VLC is possible by discarding pixels associated with noise sources such as the sunlight or streetlights. Hence, image sensor based VLC is an attractive solution for outdoor mobile applications (T. Yamazato, I. H. (2014)). With regards to short-range VLC applications, the SNR of a direct detection receiver is proportional to the square of the received optical power. Therefore, VLC links can tolerate only a comparatively limited amount of signal path loss.

Figure 1 shows a general block diagram for a simple VLC transceiver. As shown in the figure,

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