Optical Wireless Communications: Current and Future Trends

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Abstract
This paper considers the transmission of data over a wireless channel in which the transmitter converts the message into an optical signal. This optical signal is transmitted over a wireless channel which is commonly known as optical wireless channel (OWC). The OWC is still not regulated, i.e., no license is required to transmit over this channel. In addition, this channel can support communications with very high data rates. Further, in its construction, cheap components like light emitting diode (LED) is normally exploited. These factors attractive both the researchers and the industry field to develop a practical transceivers. In this paper, we initially review the basics of this systems, the benefits of using such a system. Then, the current applications are introduced and summarized. Finally, many potential applications are represented.
Keywords: Optical Communications, Wireless Communications, Communication Channel.

1. INTRODUCTION

Nowadays, Communication networks are being received huge amount of research and development in both academia and industry. In particular, communication networks are implemented in a wide range of applications such as wireless sensor networks and local area networks. Due to this huge amount of developments and applications, the spectrum is crowd. These reasons motive the researchers to search for both new techniques of transmission and also the unused spectrum. Cognitive radio is a new transmission technique that can enable unlicensed user to transmit and receive. Further, visible light communications is used to exploit the unused frequency band in wireless communications.

Using visible light in transmission and reception over wireless channel is commonly known as OWC [1,2]. In this transmission technique, the electrical signal is converted into an optical signal at the transmitter. This optical signal is transmitted and received by optoelectronic semiconductor devices over wireless channel [3,4]. By transmitting over the visible spectrum band, a wide spectrum which is between 380 nm and 780 nm may be exploited. This band is still unused and unregulated in wireless communications[6,7]. The signal attenuation over visible light band is high such that this kind of communication may be suitable for outdoor point to point communications or over short range multipath indoor communications. Remember that the transmission over this band has a high attenuation factor. This is due to the fact that as the carrier frequency increases so does the attenuation.

Transmission over the visible light spectrum can be either indoor or outdoor. In indoor propagation [5,6], no line of sight (LOS) is required. However, a higher bandwidth is obtained in the case of LOS. Indoor OWC system is mainly used to connect home or office devices together. In outdoor signal propagation [8,9,10], a LOS connection should be available for reception with high reliability. In the visible light spectrum, the communication is operated at frequency of order 10^{15}. In this frequency range, the attenuation factor is very high such that the received signal is highly attenuated. Remember that as frequency increases so does the attenuation factor.

The rest of this paper is summarized as follows. In Section 2, the principles of OWC, main components, the characteristics, and the advantages of this channel are introduced. Then, in Section 3, the current and future applications of OWC are presented. Finally, the paper is concluded in Section 4.

2. OPTICAL WIRELESS COMMUNICATION: PRELIMINARIES, CHANNEL MODEL AND ADVANTAGES.

In this section, we initially introduce the system model, as shown in Figure 1. The block diagram consists of a transmitter, channel, and a receiver. As will be explained in the next subsections, the transmitter converts the input signal, i.e., the electrical signal into an optical signal that is ready to be transmitted over a wireless channel. The channel is an additive white Gaussian noise (AWGN) in which the transmitted signal, X, is multiplied by channel gain, h, and then a noise term, Z, is added such that the received signal, Y, is expressed by

$$Y = hX + Z \qquad (1)$$

The receiver accepts the signal, amplify it, and then re-converts it into its origin, i.e., the electrical signal.

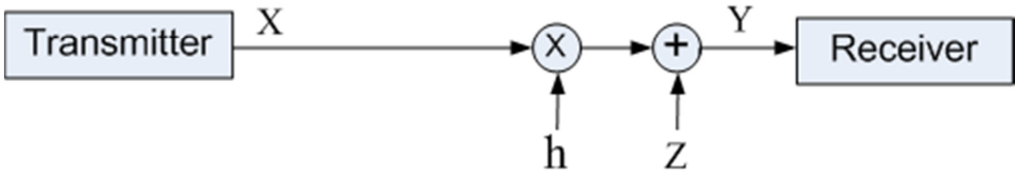

Figure 1: General Model of a Communication System.

2.1. Preliminaries: Optical Components
In this subsection, we describe the process of preparing the signal at the transmitter and also the process of receiving the signal at the receiver. These process are mainly made by using opto-electronic devices at both the transmission ends. We first describe the process at the transmitter. Then, the optoelectronics devices that are used at the receiver are described.

2.1.1 Transmitter Section
As shown in Figure 2, the signal is initially modulated by a modulation scheme such as On-Off Keying (OOK). Basically, OOK was the first practical modulation scheme used to transmit data over OWC. Then, the modulated signal is fed a light source like LED. The intensity of the light source is determined by the OOK, which is basically either positive or zero voltage. Practically, a white based phosphor LEDs may radiate a wide band visible light with bandwidth up to 175 MHz [11]. This white light can be produced by two techniques. In the first one, LEDs which produce red, green, and blue are combined such that a white light is produced. In an another way, a colour converting phosphor is used to generate the white light [12]. Finally, the white light which carries information is transmitted to its destination via wireless channel. In this case, a special antennas that can transmit the optical signal should be employed.

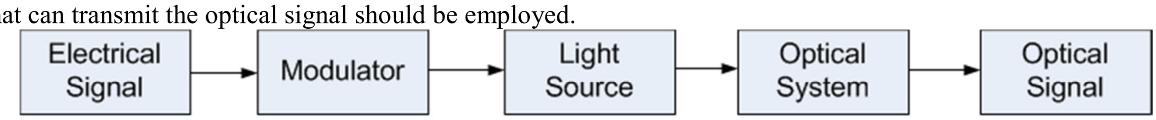

Figure 2: Components of Transmitter in OWC system.

Figure 3 shows a practical OWC scenario in which the ceiling LEDs are used as a light sources as well as access points to forward the data into their receivers. These optoelectronic devices may be used for either transmit or receive data. The receiver components will be discussed in one of the next subsections.

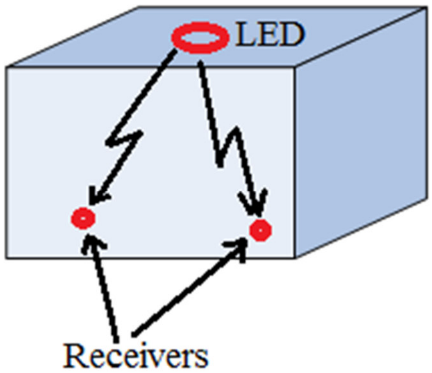

Figure 3: A practical OWC scenario in which the ceiling LEDs can be used for illuminations and data transmission.

2.1.2 The channel model
A wireless channel is used to transmit the data from the source to its destination. The characteristic of this channel can be described based on whether the transmission is in outdoor, or indoor. For outdoor transmission over OWC, a line-of-sight (LOS) connection should be available.

In outdoor propagation, the path loss factor (A) is given by

$$A = G_t G_r \frac{\lambda^2}{(4\pi)^2 d^2} \qquad (2)$$

where G_t is the gain of the transmit antenna, G_r is the gain of the receive antenna, λ is the wavelength of the used signal, and d is the distance between the two transmission ends. Furthermore, $\lambda = \frac{c}{f}$, where c is the speed of light in free space and it is a constant, i.e., $c = 2*10^8\ m/s$, and f is the signal frequency. Now, if we fix the parameters G_t and G_r, then we may have $A = K\frac{\lambda^2}{d^2}$ where $K = \frac{G_t G_r}{(4\pi)^2}$. Clearly, figure 4. shows that as the distance increases so does the path loss. This means that signal strength has an inverse relation with the distance. In addition, increasing the wavelength may marginally reduce the path-loss. Remember that as the wavelength λ increases, the frequency f reduces. In addition, if we substitute the value of λ in (2), then, we may get

$$A = G_t G_r \frac{c^2}{(4\pi)^2 d^2 f^2} \qquad (3)$$

Thus, (3) clearly shows that the path loss is inversely proportional with f^2. In other words, as the frequency increases so does the path loss.

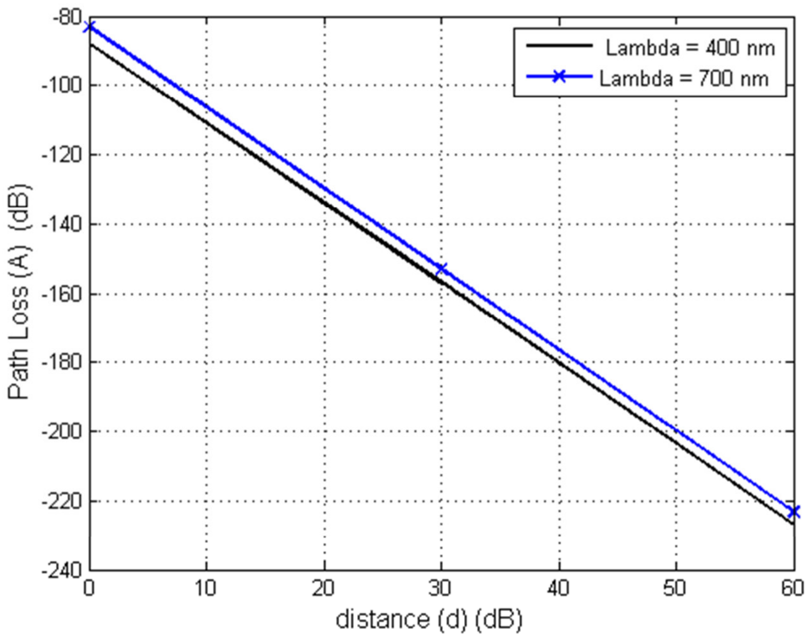

Figure 4: Path loss Vs distance (d) for different values of λ.

In indoor, the channel can be described based on the number of surfaces, type of walls, and the dimensions of the room. In addition, a LOS connection is not required in indoor propagation. In addition, the optical signal in the visible light communication cannot penetrate the surfaces. However, this signal is always reflected from walls and surfaces. Therefore, the received signal is a combination of LOS connection and non LOS paths. Therefore, a multipath propagation channel model between the two transmission ends is obtained. We note that a high transmission data rate is obtained as long as a LOS connection is available.

Furthermore, Figure 5. (left axis) shows the spectral reflectance as a function of wavelength for different walls. It clearly shows that the plaster wall has the highest reflectance power. In addition, the reflectance from the plastic wall may vary based on the wavelength.

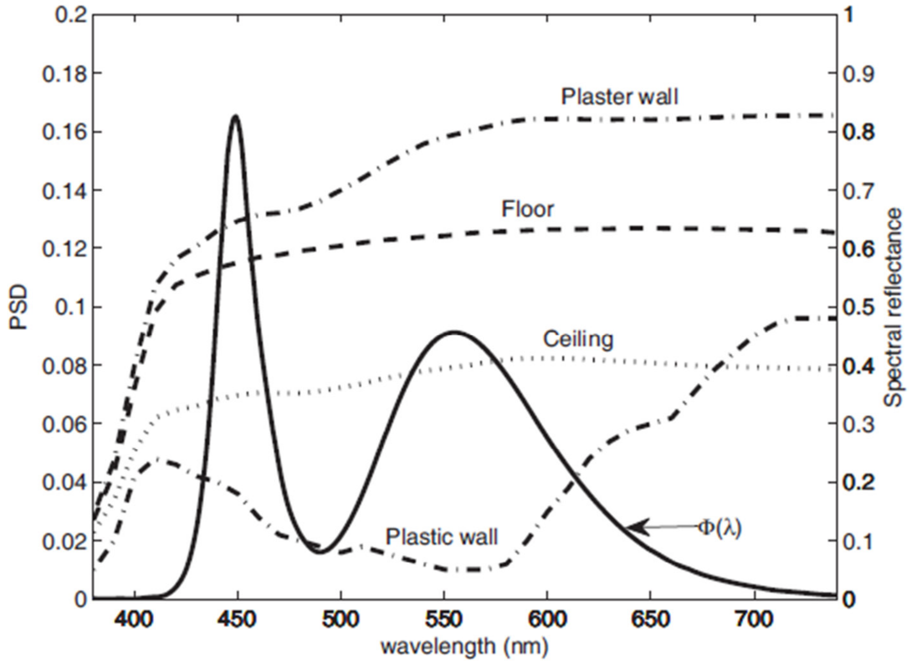

Figure 5 [17]: Power Spectral density Vs wavelength (left axis), and Spectral reflectance Vs wavelength (right axis).

2.1.3 Receiver Section

At the receiver, as shown in Figure 6, the received message is an optical signal. This optical signal should be reversely converted into an electrical signal. In its way, a light detector like PIN photo diodes or avalanche photodiodes (APDs) may be employed. In particular, in the case that photo diodes with a 1 cm effective diameter is employed, a 100 MHz bandwidth is obtained [7]. Further, lens with specific directions are normally used for directive applications.

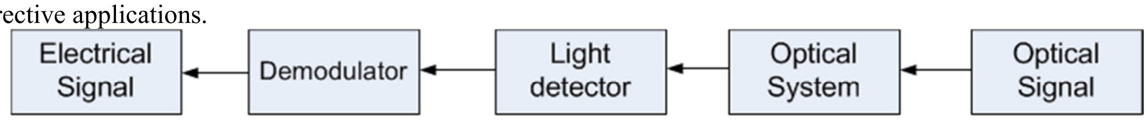

Figure 6: Components of Receiver in OWC system

2.2. Advantages of Optical Wireless Communications

In subsection, the benefits and advantages of employing optics in transmitting data over wireless channel are introduced and summarized.

- Un-licensed Spectrum: The optical spectrum covers the spectrum between 380 nm and 780 nm, or equivalently 3.8×10^{15} Hz up to 8×10^{15} Hz. This wide spectrum is still un-regulated and thus no license is required to use this band.
- Huge Bandwidth and High Data Rate: The optical spectrum extends from 3.8×10^{15} Hz to 8×10^{15} Hz. Thus, the available bandwidth is more than 400 THz. This wide spectrum can be used to send data at very high data rates. Namely, OWC can support transmission up to 1 G bps. Specifically, the authors in [13] developed a system that can support up to 50 Mbps. Later, in 2000, the authors in [14] proposed a model that can achieve a 70 Mbps. Later on, a white LED is used by [15] such that a data rate of 400 Mbps is achieved. Next, the authors in [16] reported that a data rate over 1 Gbps can be obtained by using off the shelf LEDs.
- Security: For indoor propagations, the optical wave cannot penetrated through walls. On the contrary, this kind of waves are reflected by these walls and thus, this signal cannot be heard by others.
- Low cost of transceivers: In transmission and reception, the available cheap optical components such as LEDs are traditionally used. So, no exceptional components are required.
- Illumination: In addition to transmission and reception, these optical components can be used for illumination.

3. Current and Potential Applications

In this section, the current and future applications are discussed. In discussing the applications, OWC may be considered as complementary role in some wireless applications but it will not completely replace the radio communications such as Wi-Fi networks and 4-G communication networks. Note that the optical signal cannot penetrate the walls and services. In addition, OWC can provide high data rate specially in LOS connections and short distance applications. Generally, these applications may be categorized into indoor applications and outdoor applications.

3.1. Indoor Applications

The indoor applications may include a wide range of applications that OWC can support. Namely, these applications may include, but are not limited to,

- Indoor Networks: In this application, OWC may be used to connect devices inside an offices, homes, conference rooms, hospital,..., etc. In these application, we need to remind that OWC may support applications that have short distances between transceivers with fixed or slowly moving devices. For example, OWC may be used to build a LAN inside an office, connect many devices together inside a shopping centre. Further, OWC may be employed to transmit measurements regarding a patient to a storage and processing device. Further, in application required high security like bank offices.

3.2. Outdoor Applications

In outdoor OWC, there are many applications that this transmission technique can support. Namely, these applications may include, but are not limited to,

- Wireless Sensor Networks (WSN): OWC can be used to manage the sensors in WSN. In addition, one main important application is to recharge the battery of the sensors in WSN by using OWC [8]. One solution is use passive optical transmitters in recharging the sensors' batteries. These transmitters has a small size such that it can fit to the size of the sensor. This application may be used to increase the reliability of the WSN by enabling them to increase their transmit power. In addition, the lifetime of this sensor network may be increased.
- Vehicle to Vehicle Communications: OWC may to provide communications between different vehicles. This is can be obtained by using the front and tale lights of cars. In this case, the distance between the communicating cars should be short with LOS connection to provide high quality of communications. In addition, this kind of connections need fast kind of setup and network coordination.
- Satellite Interconnection: Visible light may be used to connect the satellites in space[9]. This is thanks to the high data rate that OWC system can provide. Remember that OWC can support data rate at 400 T bps. In this case, the transmitter may be equipped with semiconductor lasers such that we get a broad bandwidth and high transmitted power.

4. CONCLUSION

In this paper, the principles of the OWC are introduced. In addition, the basic components of OWC are presented. Further, the advantages of using the visible light in wireless communications are summarized. Finally, some current and potential future applications of OWC are provided.

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