



PERFORMANCE ANALYSIS OF INDOOR OPTICAL WIRELESS CDMA SYSTEM USING OPTICAL ZERO CROSS CORRELATION CODE

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ABSTRACT

In this paper, we present an indoor optical wireless model to evaluate the impact of direct and reflected light on the bit error rate (BER) performance of an indoor optical wireless CDMA system. In this model, we divided each wall into small reflecting surfaces and took into account multiple surfaces. Based on this model, the optical received power with and without considering the reflected light were calculated. Moreover, the BER performance based on zero cross correlation code (ZCC) analysed. By using ZCC code, the BER gives better performance due to low effective power used at the photodetector. The results show good performance at the centre of the room compared to the edges. Therefore, the BER performance significantly depends on the position of the transmitter, the size of the room and the number of users. So, these parameters have to be considered whenever an indoor optical wireless CDMA is used.

Keywords: indoor optical wireless, zero cross correlation, optical CDMA.

INTRODUCTION

Optical wireless communication systems (OWCs) have developed in response to a growing need for higher data rates, higher security, and more cost effective. This rapid growing need is the main driving force behind the development of optical wireless communication systems that operate at infrared frequencies which is a free licensed spectrum band (Smitha et al., 2008), (Lucaciu et al., 2010). Moreover, OWCs are free from harmful electromagnetic interference which may cause malfunction to some equipment in some health care areas (Khalid et al., 2013). However, the optical code division multiple access (OCDMA) is the area of interest for the last years since it has the ability for multiple users to access the same bandwidth simultaneously without employing high-speed electronic data processing circuits that are necessary in the optical TDMA networks (Lin et al., 2005). Moreover, it provides high-level security during transmission. The basic idea of OCDMA works based on spread spectrum techniques that have been widely used in wireless communication systems (Dixon, 1994). OCDMA has been recognized as one of the most important technologies for supporting many users in shared media simultaneously by assigning a unique code to each user and to communicate with another node, users imprint their agreed upon code onto the data (Maric et al., 1996). At the receiver end, it decodes the bit stream by locking onto the same code sequence. This is how it preserves the security properties in optical systems, and also has additional support in electrical security.

However, for the growing area of indoor optical wireless communication, energy savings and low-cost solutions are considered. Therefore, LED-based communication has attracted wide interest in constructing the indoor optical wireless system. OWCs can be classified into two main configurations when IR technology is considered in indoor environments. These two configurations are line of sight (LOS) configuration

and diffuse configuration. LOS requires alignment between transmitter and receiver. Therefore, it has better power efficiency and lower multipath dispersion. Besides, it has the drawback due to the moving object across the direct path which causes shadowing. Diffuse configuration does not require any alignment between the transmitter and receiver, and instead, make use of reflections from walls, ceiling, and other reflectors. However, diffuse transmission links are usually affected by multipath dispersion (which causes pulse spread and significant ISI), poor power efficiency and higher collection amount of ambient light noise at receiver part (Green et al., 2008), (Jivkova and Kavehrad, 1999).

In this paper, we consider an empty room with dimensions of 5x5x3 m³ and each wall surface was divided into a number of equalized sizes of reflection elements with an area of dA and reflection coefficient ρ . The reflections from windows, doors and objects are considered to be identical to the wall reflections. We analyze the received power with and without considering the reflected lights. We also analyze the bit error rate (BER) performance by taking major noise sources such as shot noise, thermal noise.

The paper is organized as follows: in part 2, we describe the system structure, in that we present the system in term of optical wireless CDMA (OWCDMA), and channel propagation model. We analyze BER performance in part 3. In part 4, we discuss and analyse the results, before concluding in part 5.

SYSTEM STRUCTURE

In this section, we introduce the indoor system model and the optical channel propagation. As shown in Figure-1, the transmitter which is comprised of LEDs is located on the centre of a ceiling with field of view (FOV) directed downward to the floor while the receiver is at a height of one metre above the floor level.

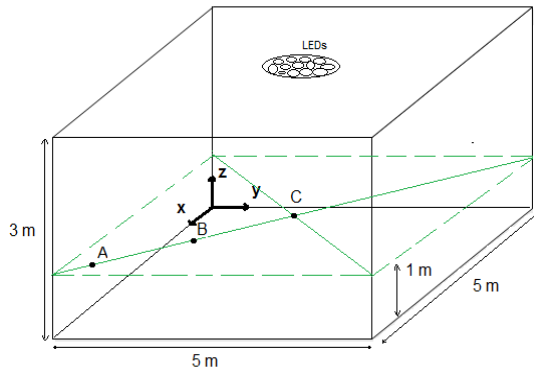


Figure-1. The configuration of the transmitter and receiver for indoor optical wireless system.

Optical wireless CDMA (OWCDMA)

Figure-2 shows the structure of the developed system which consists of N transmitters and N receivers. The information bit is firstly encoded by an optical zero cross correlation code (ZCC) for each user. So, the spectrum of LEDs is shared by many users. Then, all users are combined and sent wirelessly at the same time. At the receiver side, the positive-intrinsic-negative (PIN) diode is used to detect the optical transmitted signal in the system, and then decoded by the corresponding ZCC code (Anuar et al., 2007).

Let's consider the signal of n th user to be $S_n(t)$, then the received signal can be modelled as

$$r(t) = \sum_{n=1}^N S_n(t - \tau_n) \otimes h(t) \quad (1)$$

Where τ_n denotes the associated delay for a given receiver. $h(t)$ is the channel gain of the system.

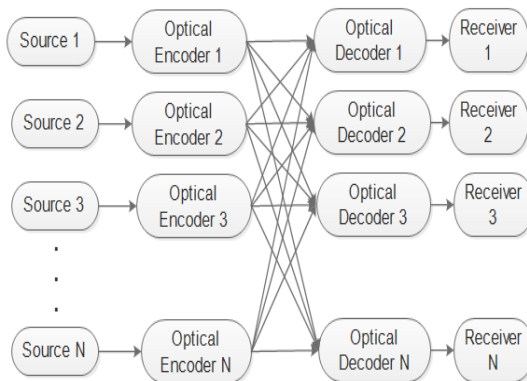


Figure-2. The structure of optical wireless CDMA.

In this paper, we consider one dimensional zero cross correlation code to be applied to the system, in which it designed with no overlapping of bit '1' among users and orthogonal for any number of users and weights. Basically, ZCC relates to the group of spectral amplitude

coding in which shot noise and thermal noise are considered and phase-induced intensity noise (PIIN) is ignored due to the zero correlation between users. In ZCC, we define K to be the basic number of users, L is the code length, and W is the code weight. The relationship between these parameters is shown below:

$$K = W + 1 \quad (2)$$

$$L = K \times W \quad (3)$$

Equation (3) shows that the code weight is proportional to the code length. So, as the code weight increases the code length increases in order for the cross correlation to be maintained at zero.

Channel propagation model

In this model, we consider line of sight (LOS) and first order reflection propagation links, since one reflection has the highest contribution to the overall impulse response after the direct light. Unlike, second and higher order reflections which ignored due to their small contributions. The radiation intensity of the transmitter with a generalized Lambertian radiation can be modelled as:

$$R_0(\phi) = \frac{m+1}{2\pi} P_t \cos^m(\phi), \quad -\frac{\pi}{2} \leq \phi \leq \frac{\pi}{2} \quad (4)$$

where m is the Lambertian order of emission which is related to the half power semi-angle and represented as (Kahn and Barry, 1997):

$$m = \frac{-\ln(2)}{\ln(\cos \phi_{1/2})} \quad (5)$$

The system consists of LOS propagation link which represents the direct path between the transmitter and receiver and its channel DC gain can be mathematically calculated as (Nguyen et al., 2010):

$$h(0)_{los} = \begin{cases} \frac{m+1}{2\pi D_d^2} A_R T_F(\psi) T_c(\psi) \cos^m(\phi) \cos(\psi), & 0 \leq \psi \leq \psi_c \\ 0 & \psi > \psi_c \end{cases} \quad (6)$$

where D_d is the direct distance between the transmitter and receiver. A_R is the physical area of the photo-detector. $T_F(\psi)$ is the gain of the optical filter. $T_c(\psi)$ is the gain of the optical concentrator. ϕ is the angle of incidence and ψ is the reception angle. ψ_c denotes the width of the field of view of the receiver.

The optical concentrator $T_c(\psi)$ can be given as

$$T_c(\psi) = \begin{cases} \frac{n^2}{\sin^2(\psi_c)} & 0 \leq \psi \leq \psi_c \\ 0 & \psi > \psi_c \end{cases} \quad (7)$$



n represents the refractive index.

Moreover, the light reflected by an entire wall surfaces can be calculated numerically by dividing the reflecting surfaces into small reflecting elements dA . Therefore, the channel DC gain for the first order reflection is given as (Kahn and Barry, 1997):

$$h(1)_{ref} = \begin{cases} \frac{(m+1)(m_{element}+1)}{4\pi^2 D_1^2 D_2^2} A_R dA \rho T_F(\psi) T_c(\psi) \cos^m(\phi) \dots \\ x \cos(\gamma) \cos^{m_{element}}(\beta) \cos(\psi), & 0 \leq \psi \leq \psi_c \\ 0 & \psi > \psi_c \end{cases} \quad (8)$$

where D_1 is the distance between the transmitter and a reflective point on the wall, D_2 is the distance between a reflective point and the receiver. γ is the angle of incidence to a reflective point on the wall, β is the angle of irradiance to the receiver. ρ is the reflection coefficients of the wall surface. $m_{element}$ is considered as an ideal Lambertian reflector and equalled to 1.

The total received power resulting from direct and reflected light can be calculated as

$$P_{sr} = (h(0)_{los} \bullet P_t) + \sum_{n=1}^{N_{element}} (h(1)_{ref} \bullet P_t)_n \quad (9)$$

In which $N_{element}$ is the total number of reflecting element. P_t is the average transmitted power.

In these analyses, the listed parameters in Table-1 were used.

Table-1. Simulation parameters.

| Parameters | Values |
|---|--|
| Room dimensions (x, y, z) | 5x5x3 m ³ |
| Reflection coefficient (ρ) | 0.8 |
| Total Transmitted power | 1.0 W |
| Lambert's order | 1 |
| Position of the receiver, $R_x(x, y, z)$ | A(0.5,0.5,1.0) B(1.5,1.5,1.0) C(2.5,2.5,1.0) |
| Physical area of a photodetector (A_R) | 1.0 cm ² |
| Field of view (FOV) | 90 [deg.] |
| Semi-angle at half power | 70 [deg.] |
| Pixel size ($\Delta x, \Delta y$) | 0.11x0.11 m |
| Gain of an optical filter (T_F) | 1.0 |
| Refractive index of a lens at a photodetector (n) | 1.5 |
| Elevation | 90 [deg.] |
| Azimuth | 0.0 [deg.] |

BER PERFORMANCE ANALYSIS

Using ZCC, data bit consists of '0' and '1' will be carried in a different code form for each user. With the assumption of bit synchronism and equal power at the receiver, the power spectral density (PSD) at the

photodiode for direct detection during one bit period can be modelled as (Wei et al., 2001), (Nur et al., 2013):

$$\begin{aligned} G(v) &= \frac{P_{sr}}{\Delta v} \sum_{k=1}^C d_k \sum_{i=1}^N c_m(i) c_n(i) \Pi(i) \\ &= \underbrace{\frac{P_{sr}}{\Delta v} \cdot 1.w. \frac{\Delta v}{L}}_{\text{auto-correlation}} + \underbrace{\frac{P_{sr}}{\Delta v} \cdot 1.0. \frac{\Delta v}{L}}_{\text{cross-correlation}} \\ &= \underbrace{\frac{P_{sr}}{L} w}_{\text{auto-correlation}} + \underbrace{0}_{\text{cross-correlation}} \end{aligned} \quad (10)$$

where P_{sr} is the received power. $G(v)$ is the power of a signal as a function of frequency.

Using the property of ZCC, the value of autocorrelation part will only be considered. Therefore, the total power incident on the photodiode is calculated as:

$$i_{total}^2 power = \Re \int_0^\infty G^2(v) = \underbrace{\frac{\Re^2 P_{sr}^2 w^2}{L^2}}_{\text{auto-correlation}} + \underbrace{0}_{\text{cross-correlation}} \quad (11)$$

where \Re is the responsivity of the photodetector and it is computed as $\Re = \frac{\eta e}{h\nu}$, as η is quantum efficiency, e is the electron charge, $h\nu$ is photon energy.

To analyze system performance, the intensity noise, shot noise and thermal noise are considered. But PIIN can be neglected because of no overlapping of bit '1' between users. So, the total mean square noise current at the receiver can be written as:

$$i_{total}^2 noise = \underbrace{\frac{2e\Re P_{sr} w B}{L}}_{\text{shot noise}} + \underbrace{\frac{4KTB}{R_L}}_{\text{thermal noise}} \quad (12)$$

Since, the signal to noise ratio (SNR) is equal to the average power divided by the average power of total noise sources which is written as:

$$SNR = \frac{\langle i_{total}^2 power \rangle}{\langle i_{total}^2 noise \rangle}$$

By substituting equation (11) and (12) in this equation, we get:

$$\begin{aligned} &\frac{\Re^2 P_{sr}^2 w^2}{L^2} \\ &= \frac{\Re^2 P_{sr}^2 w^2}{L^2} \frac{2e\Re P_{sr} w B}{L} + \frac{4KTB}{R_L} \end{aligned} \quad (13)$$

where T is the absolute temperature in degrees Kelvin, R_L is the receiver load resistance, e denotes the electronic charge, K is Boltzmann's constant, B is the receiver electrical bandwidth.



The system performance is characterized through the bit error rate (BER) which can be computed as:

$$BER = 0.5 * \operatorname{erfc}\left(\sqrt{\frac{SNR}{8}}\right) \quad (14)$$

where

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \quad (15)$$

For this study, the typical parameters used to calculate the BER are shown in Table-2.

Table-2. Typical parameters used for simulation.

| Parameters | Values |
|---|--------------------------------------|
| Operating wavelength (λ_0) | 1550 nm |
| Photodetector quantum efficiency (η) | 0.6 |
| Data bit rate (R_b) | 622 Mbps |
| Electrical bandwidth (B) | 311 MHz |
| Receiver noise temperature (T) | 300 K |
| Receiver load resistor (R_L) | 1030 Ω |
| Electron charge (e) | $1.6 \times 10^{-19} \text{ C}$ |
| Planck's constant (h) | $6.66 \times 10^{-34} \text{ J s}$ |
| Boltzmann's constant (K) | $1.38 \times 10^{-23} \text{ J / K}$ |

RESULT AND DISCUSSION

Figure-3 and 4 show, respectively the received power of the indoor optical wireless with and without considering the reflected light. The expected received power in dBm according to the indoor position can be mathematically obtained. As shown in Figure-1, we considered three positions in the room, position A (at the corner), B (at the centre point between A and C), and C (in the centre of the room). In the case of considering the reflected light, we noticed that when the receiver is in position A, the received power is about -25.6 dBm, and is getting larger as the position is getting closer to the centre of the room. So, at position B and C the received power is -21.2 dBm and -18.2 dBm respectively. On the other hand, when we ignored the reflected light, the received power is about -27, -21.5 and -18.3 dBm at position A, B, and C respectively.

From this analysis, we can summarize that the reflected light can mainly affect the positions at the edges of the room. Unlike, the centre of the room which has very small effect of the reflect light due to the distance.

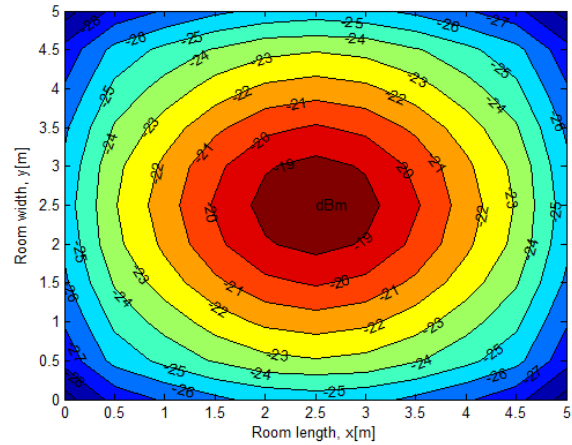


Figure-3. The received power in dBm with consideration of direct and reflected lights.

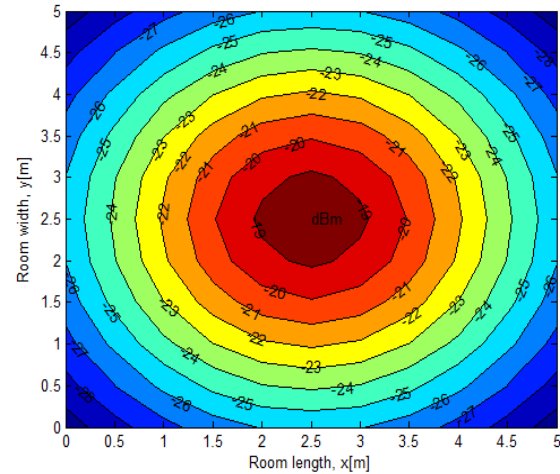


Figure-4. The received power in dBm with consideration of direct light only.

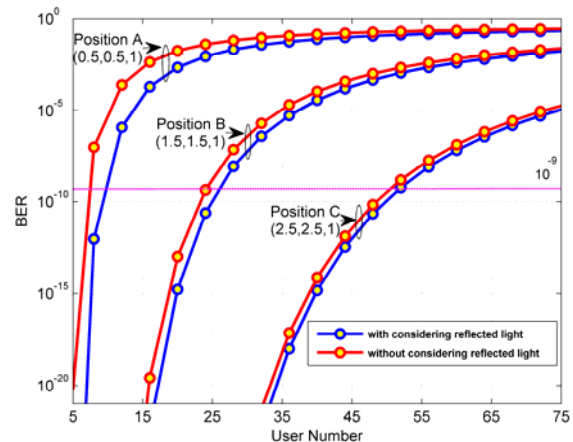


Figure-5. BER versus user number with and without consideration of reflected light.



Figure-5 shows that the smaller the user number is, the lower the bit error rate (BER) can be achieved. By comparing the red lines with the blue lines. It is shown that when the user number is small, the impact of the reflected light is obvious. But that impact is reduced as the user number increase or if the position of the receiver is getting closer to the centre of the room where the reflected light cannot reach.

Most lightwave systems specify a BER of 10^{-9} as the operating requirement. However, different positions in the room can support different number of users. For instance, if the reflected light is not considered, position A can support up to 8 users, position B up to 25 users, and position C up to 52 users. But if the reflected light is considered, position A can support up to 10 users, position B up to 27 users, and position C up to 53 users.

The performance of developed system was simulated using MATLAB, and the used weight in optical ZCC code is $w = 3$.

CONCLUSIONS

In this study, we have studied the impact of direct and reflected light on the bit error rate (BER) performance of an indoor wireless optical CDMA system. The optical received power with and without considering the reflected light were calculated. We also analysed the BER performance based on zero cross correlation code (ZCC).

As the results, the indoor optical wireless system gives better performance with considering the reflected light. As well as, the performance at the centre of the room is better compared to the edges. Additionally, the gap of the signals between with and without considering the reflected light reduced as the receiver is getting close to the centre of the room. Therefore, the BER performance significantly depends on the position of the transmitter, the size of the room and the number of users.

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