Performance of Code Division Multiple Access in Non-Directed Diffuse Optical Wireless Channel

Dong Heon Shin, Chanbum Park, and Jae Hong Lee
Department of Electronics Engineering, Seoul National University,
Shillim-dong, Gwanak-gu, Seoul 151-742, Korea
phone) 82-2-880-8430, fax) 82-2-880-8224
e-mail) scorpios@dosa1.snu.ac.kr

Abstract—Optical wireless channel has abundant available bandwidth and is suitable for high data rate, indoor communications. In this paper, the performance of CDMA as a multiple access technique for optical wireless communication is examined. As the signature sequence, a (43,3,1,1) and a (63,3,1,1) optical orthogonal code (OOC) is used. Information data is modulated through a simple on-off keying (OOK) modulation scheme. Data rate of 2Mbps is used and the bit error rate (BER) performance is simulated with respect to signal-to-noise ratio (SNR), number of users, and threshold values. It is possible to find the optimum number of users, the optimum threshold value from the results. It is seen that interference from other users actually helps to improve the BER performance, upto a certain number of users.

I. INTRODUCTION

In high rate indoor wireless communication, radio channels suffer from multipath fading and have low security. Due to increasing demand for wireless services, wireless communication is seeking for new frequency spectrum. As a solution to these problems, an optical wireless channel is considered for indoor wireless communications [1]. Since the channel has practically unlimited resource of bandwidth, it can accommodate wireless multimedia communication. The nature of infrared light makes optical wireless communication strong against eavesdropping, and the short wavelength of the infrared light causes spatial diversity at the receiver prevents multipath fading. Modulation techniques, channel simulation and baseband transmission have been studied for an optical wireless channel [2-4]. Performance of multiple access and multiplexing has not been studied for an optical wireless channel with high data rate.

Code division multiple access (CDMA) has been used in mobile radio and optical fiber communications, as it has high frequency utilization and robustness against multipath fading and interferences. These advantages can be extended to optical wireless communication. Unlike the mobile radio communication, optical wireless communication employs modulation and direct detection (IM/DD) which do not require phase acquisition. This simplifies receiver structure significantly. Moreover, a CDMA system does not require a stable and tunable laser for accurate wavelength control and symbol synchronization, as in TDMA or FDMA.

In this paper, performance of a CDMA system in an optical wireless channel is examined. Simulation is performed for various values of parameters such as the number of users, OOC period $n$, and threshold $T_h$. Section II describes the channel model used for the simulation. In Section III, the definition and the fundamental properties of optical orthogonal code (OOC) used as a signature sequence for the optical wireless CDMA system is explained. The optical wireless CDMA system model is shown in Section IV. Section V presents the simulation results.

II. CHANNEL MODEL

Optical wireless channel employs IM/DD to achieve high SNR. In intensity modulation, data signal modulates the intensity of the infrared light, and the transmitted signal $x(t)$ is instantaneous optical power. Photodetector at the receiver transforms the received optical signal to current signal $y(t)$ which is the integral of the received optical power over the detector surface. As the wavelength of infrared light is much shorter than the antenna size, spatial diversity at the receiver prevents multipath fading. However, multipath dispersion due to reflections from walls, ceilings and other reflectors exists and causes intersymbol interference (ISI) at high data rates. This channel can be modeled by a linear, time-invariant (LTI) impulse response $h(t)$ which is fixed for a given configuration. The path loss $H(0)$ is given by,

$$H(0) = \int_{-\infty}^{\infty} h(t) dt$$

In many applications, non-directed optical communications occur in the presence of intense infrared and background light. Fluorescent lightings cause low frequency noise which can effect the transmission of baseband optical signal. This can be removed by optical highpass filtering but, ambient background light still remain. Together with quantum noise, these strong ambient light causes intense shot noise at the receiver photodetector which can be modeled as white Gaussian noise $n(t)$. The channel can be summarized as a linear baseband model shown below [3].

$$y(t) = h(t) \ast x(t) + n(t)$$

In particular, as the transmitted signal represents power, it
cannot be negative, and the average power is proportional to a time integral of \( x(t) \), rather than the usual \( \| x(t) \| ^2 \).

Transmitted signal has average power constraint \( P \) such that,

\[
P_{\text{avg}} = \lim_{T \to \infty} \frac{1}{T} \int_0^T x(t) dt \leq P
\]  

(3)

where \( T \) is the symbol duration.

Various simulation and experiments to examine the channel impulse response is found in literatures. In this paper the experiment results for non-directed diffuse channel is used [3].

**III. OPTICAL ORTHOGONAL CODE (OOC)**

For CDMA in any environment, it is important to choose the high rate sequences, namely signature sequences, on which the data bits of different users is mapped. In CDMA, many users occupy the same channel simultaneously, and a desired user’s receiver must be able to extract its signature sequences in the presence of other user’s signature sequences. Therefore, a sequence with good auto- and cross-correlation properties are needed.

Optical wireless system is modeled as a positive system, in which the signals are always positive and cannot be manipulated to add to zero. Therefore, codes or sequences which are based on \{+1, -1\} could not be suitable for positive systems, because these sequences take advantage of the ability to add the signals to zero.

Optical orthogonal code is a family of 0,1 sequences with good auto- and cross-correlation properties that are suitable for CDMA in positive systems [5]. An \((n, k, \lambda_a, \lambda_c)\) OOC code is sequences of length \( n \), weight \( k \) with auto-correlation constraint of \( \lambda_a \) and cross-correlation constraint of \( \lambda_c \). The maximum number of user \( N \) is constrained as below.

\[
N = \left\lfloor \frac{n - 1}{k(k - 1)} \right\rfloor
\]  

(4)

There are a few methods for designing the OOC and in this paper, projective geometry construction method is used [6].

**IV. CDMA SYSTEM MODEL**

Fig. 1 shows a block diagram of the optical wireless CDMA system used for simulation. The system employs IM/DD and \((43,3,1,1), (63,3,1,1)\) OOC’s are used as the signature sequences. Non-return to zero (NRZ) on-off keying (OOK) is used to modulate the information data. Modulated signal of each user is transmitted over a non-directed diffuse optical wireless channel, which is modeled by a LTI impulse response \( h(t) \). Ambient light noise modeled as white Gaussian noise \( n(t) \) is added to the modulated signal. At the receiver of each user, the correlation between the received signal and the delay synchronized OOC of the desired user is computed and sampled at \( kT \). The receiver compares this with the threshold \( T_h \) so as to extract the transmitted data.

![Fig. 1. Block diagram of optical wireless CDMA system.](image)

It is assumed that all users have the same effective average power at any receiver so that one user could not overwhelm others, and all users have identical bit rate and signal format. Also, we assume that low frequency noise by fluorescent light has been prevented by highpass filtering and only white Gaussian noise is present. Perfect synchronization of the OOC sequence is assumed. The simulation is performed in the presence of white Gaussian noise by the ambient background light, interference from other users and multipath dispersion by the channel.

**V. SIMULATION RESULTS**

Bit error rate (BER) performance is simulated with respect to signal-to-noise ratio (SNR), number of users \( N \), OOC length \( n \), and threshold level \( T_h \). Each user transmits data at rate of 2Mbps with OOK modulated transmission average power of 0.5W. The optical path loss \( H(0) \) is assumed to be 1. SNR used in the figures is defined as

\[
SNR = 10 \log \frac{P_t}{P_N}
\]  

(5)

where \( P_t = k/n \cdot P_{OOK} \). \( P_{OOK} \) is the average power of OOK modulated signal, \( n \) is the length of OOC, and \( k \) is the weight of OOC. Threshold value shown in the figures is \( T_h \), given by,

\[
Threshold = T_h \cdot \frac{k}{2 \cdot \frac{n}{n}}
\]  

(6)

In all the figures shown, SNR is defined as (5), with \( k = 3 \), \( n = 63 \) and \( P_{OOK} = 0.5 \) W, for comparison.

Fig. 2 shows the BER vs SNR performance of optical CDMA system with \((43,3,1,1)\) OOC sequence for various number of users, with threshold \( T_h \) fixed at 3. BER vs SNR
Fig. 2. BER performance of optical wireless CDMA system as a function of SNR with various number of users. Data rate = 2 Mbps, (43,3,1,1) OOC, $T_0$ = 3.

Fig. 3. BER performance of optical wireless CDMA system as a function of SNR with various number of users. Data rate = 2 Mbps, (63,3,1,1) OOC, $T_0$ = 3.

Fig. 4. BER performance of optical wireless CDMA system as a function of SNR. Data rate = 2 Mbps, (43,3,1,1) OOC, SNR = 2 dB, $N = 4$.

Fig. 5. BER performance of optical wireless CDMA system as a function of $T_0$. Data rate = 2 Mbps, (63,3,1,1) OOC, SNR = 6 dB, $N = 5$ and 7.
performance for (63,3,1,1) OOC sequence, with the number of users as parameters and threshold $T_\text{th}$ fixed at 3, is shown in Fig. 3. In both cases, it is shown that as the number of users increase, BER performance improves at high SNR. For (43,3,1,1), it is shown that around $10^{-3}$, performance of 7 user CDMA has 1dB gain over 2 user case. The results mean that in optical wireless channel, interference from other users and ISI from the dispersive characteristics of the channel, actually compensates the loss made by the Gaussian noise giving performance improvement. The explanation for this phenomena can be found from the nature of the optical communication where interference from other users always add to the desired signal in a positive way, as the transmitted optical power signal can never be negative. In optical wireless CDMA, the desired signal is recovered from the received signal by multiplying the desired user’s OOC, which is assumed to be properly synchronized. The interference adds to the optical power thus increasing the amplitude of the recovered current signal in each chip. This helps the detection in the threshold decision. It can be intuited that if the number of users increases to a certain level, there will always be an accumulating power due to the interference and gradually error rate will increase. Finally, if the accumulated power exceeds the threshold, the detection will always output a 1, and the performance will be poor. But, the maximum number of users upper limited by (4), prevents this from happening.

From the figures, it can also be predicted that the optimum number of users for (43,3,1,1) is 7, and that for (63,3,1,1) is 7. In the case of (63,3,1,1), as the number of users increase beyond 7, degradation of performance occurs. It is likely to be due to the accumulation of interference effects.

Fig. 4 shows the effect of threshold values on the performance of optical wireless CDMA system with (43,3,1,1) OOC. SNR is fixed at 2 dB, and $N = 4$. Results for (63,3,1,1), is shown in Fig. 5, with SNR = 0, and $N = 5, 7$. In the case of both (43,3,1,1) and (63,3,1,1) OOC, the optimum threshold is found to be 3. It can be easily expected, as the weight of the code $k$ is 3.

From these results, we can predict the optimum number of users, the optimum threshold value for the optical wireless CDMA system, for a particular OOC. These results can help in the selection of OOC for specific applications.

VI. CONCLUSIONS

In this paper, performance of CDMA for optical wireless communication has been examined. It is found that BER performance improves as the number of users increase up to a certain point where interference from other users starts to degrade the performance again. Interference in positive systems like the optical wireless system, is seen to compensate the loss by the Gaussian noise. Optimum number of users exist for each OOC, where it is not necessarily the maximum value in (4). At the receiver, optimum threshold value is found to be equal to the OOC weight $k$.

REFERENCES