International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 21 (2017) pp. 11029-11034
© Research India Publications. http://www.ripublication.com

Rate Adaptive ACO-OFDM on Multipath Channels for Enhancing Spectral Efficency

Zelalem Hailu [1], Philip Kibet Langat[2] and Ciira Wa Maina[3]

[1] *Pan African University Institute of Science, Technology and Innovation, Nairobi, Kenya.*
[2] *Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.*
[3] *Dedan Kimathi University of Technology, Nyeri, Kenya.*

Orcid[1] : 0000-0001-6096-3333, Orcid[2] : 0000-0003-0412-4804, Orcid[3] : 0000-0003-4203-3129

Abstract

In spite of its spectral efficiency problem, asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM) is one of widely accepted transmission scheme for intensity modulation/direct detection (IM/DD) based optical wireless communications. In this paper, we analyze the potential of rate adaptive based ACO-OFDM scheme to enhance spectral efficiency of indoor optical wireless communication. Frequency selective based bit loading strategy is used to transmit variable number of bits on different sub carriers having different channel gains. The result of our evaluations confirms that rate adaptive ACO-OFDM offers better spectral efficiency compared to fixed modulation formats on all sub carriers.

Keywords: rate adaption; ACO-OFDM; IM/DD; optical wireless communications; diffiused optical channel

INTRODUCTION

The booming of different multimedia applications from time to time increases the demand of wireless communication more than ever. According to Cisco global mobile data traffic forecast [1]; overall mobile data traffic is forecasted to be around 49 exabytes per month by the year 2021. The communication based on radio frequency (RF) spectrum is not able to accommodate this huge wireless data traffic alone. Therefore, optical wireless communication (OWC) which uses the visible and non-visible optical domain is becoming a promising complement of RF communication [2-4]. The benefit of having huge unregulated bandwidth in optical domain, its dual purpose (communication and lighting) at the same time, and its excellent security features makes OWC best solution for tackling the RF spectrum crunch.

Due to its excellent feature of combating inter symbol interference (ISI), orthogonal frequency division multiplexing (OFDM) is accepted being the best transmission scheme in high speed OWC [5, 6]. OWC uses light emitting diode (LED) in its front end and photo detector (PD) at the receiver side. In IM/DD system, the input signal for the LED required to be real and positive unipolar [7-10]. Therefore, the conventional complex bi-polar time domain OFDM signal should be manipulated accordingly to fulfill the requirement of IM/DD system. Asymmetrically clipped optical OFDM (ACO-OFDM) and direct current biased optical OFDM (DCO-OFDM) are the most acceptable real unipolar OFDM schemes proposed for OWC [9-11]. ACO-OFDM scheme is confirmed to be energy efficient scheme even if it has drawbacks in offering attractive spectral efficiency [9, 11].

Multipath fading is known for its big challenge in high speed wireless communication. Optical wireless channel in indoor OWC is characterized with frequency selective channel dynamics due to the availability of multipath fading and dispersion. The multipath channel effects on different subcarriers are different in magnitude during multicarrier communication such as ACO-OFDM based OWC. Subcarrier based rate adaptive optical OFDM modulation is a promised solution to enhance the performance of indoor OWC in diffused optical wireless channel environment. Therefore, this paper is dedicated to investigate the potential of adaptive ACO-OFDM to enhance the spectral efficiency of indoor OWC in multipath channel environment. In this paper, it is assumed that the channel information state is completely known by the transmitter and the receiver. The bit loading is done based on the current state of the channel gain of sub carriers.

SYSTEM MODELS

A. ACO-OFDM

In ACO-OFDM, only odd sub carriers are used for carrying information while even indexed subcarriers are left empty. Among the odd sub carriers, the second half of the odd indexed sub carriers are used to impose Hermitian symmetry to obtain real time domain OFDM signal. Let X_k is the frequency domain QAM symbol loaded on the k^{th} sub carrier, the total transmitted symbols using ACO-OFDM scheme having N total sub carriers are as follows:

$$0, X_1, 0, X_3, \ldots, X_{\frac{N}{2}-1}, 0, X^*_{\frac{N}{2}-1}, 0, \ldots, X_3^*, 0, X_1^* \qquad (1)$$

Let x_n is the output time domain signal after IFFT operation is performed on the loaded QAM symbols, x_n and X_k can be related by unitary IFFT/FFT as follows [12,13]:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi kn}{N}}, 0 \le n \le N-1 \qquad (2)$$

$$X_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n e^{\frac{-j2\pi kn}{N}}, 0 \le k \le N-1 \qquad (3)$$

The output time domain OFDM signal x_n is real and bi-polar. Therefore, clipping of negative samples to zero is performed to obtain positive unipolar signal. The clipped signal x_n^c can be written as:

$$x_n^c = \begin{cases} 0, \; for \; x_n \le 0 \\ x_n, \; for \; x_n > 0 \end{cases} \qquad (4)$$

Then after adding cyclic prefix based on the channel length and converting the discrete signal in to analog, the transmitted signal $x(t)$ is given as input to the LED. Assuming a unity conversion factor from electrical to optical and vice versa, the time domain signal $y(t)$ received at the receiver is given by [13,14]:

$$y(t) = x(t) * h(t) + z(t) \qquad (5)$$

Where $h(t)$ and $z(t)$ are the optical channel impulse response and the additive white Gaussian noise with power spectral density of N_o respectively. The channel configuration assumed on this paper is pure diffuse optical channel and Cell bouncing model [7, 15-16] is used to characterize the channel impulse response (CIR). Therefore $h(t)$ is given by:

$$h(t) = H(0) \frac{6a^6}{(t+a)^7} u(t) \qquad (6)$$

Where $a = 12\sqrt{\frac{11}{13}} D_{rms}$ and $u(t)$ is unit step function.

The received symbol Y_k at k^{th} sub carrier can be written as:

$$Y_k = \frac{1}{2} H_k X_k + Z_k \qquad (7)$$

B. *Adaptive ACO-OFDM*

The block diagram of system model of adaptive ACO-OFDM is presented on Fig. 1. Since the channel state information is known by the transmitter and the receiver, it is possible to calculate the amount of the SNR to be achieved at each subcarrier for the current channel condition.

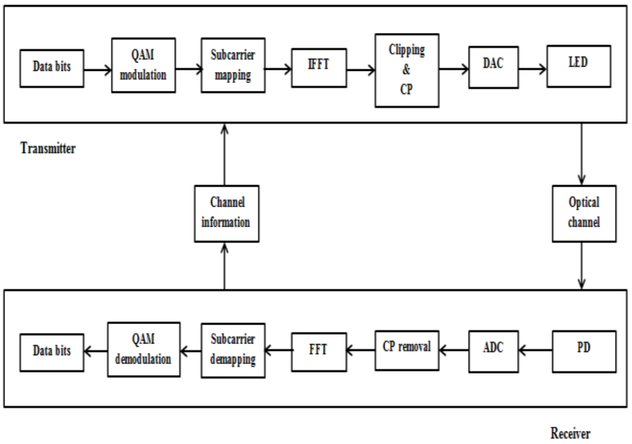

Figure 1: Block diagram of adaptive ACO-OFDM.

Let E_b is the bit energy allocated for each transmitted bit at any sub carrier, the received signal electrical SNR γ_k^{ACO} of ACO-OFDM scheme in terms of bit energy can be given by:

$$\gamma_k^{ACO} = \frac{|H_k|^2 E_b}{2N_o} \qquad (8)$$

In equation (8) H_k is the channel gain of the k^{th} subcarrier whereas N_o is the AWGN noise spectral density. The factor $\frac{1}{2}$ is accounted for the loss of signal power due to clipping of negative samples. During rate adaption, target BER is set to avoid outage of the system. On this work, the target BER is set to be 10^{-3}. It is possible to calculate the SNR required by M-QAM modulation to achieve the target BER from the BER formula of M-QAM modulation given by [17]:

$$BER = \frac{4}{\log_2 M} \left(1 - \frac{1}{\sqrt{M}}\right) \sum_{i=1}^{\frac{\sqrt{M}}{2}} Q\left((2i-1)\sqrt{\frac{3\log_2 M \; \gamma}{(M-1)}}\right) \qquad (9)$$

Where γ is the electrical SNR in terms of bit energy required to achieve the target BER of 10^{-3} for M-QAM modulation. In this paper, five different M-QAM modulations are considered for rate adaption. Those modulation formats are represented by $M_i - QAM$ as:

$$M_i = \begin{cases} 0, \; for \; i = 0 \\ 2^{i+1}, 1 \le i \le 4 \end{cases} \qquad (10)$$

Therefore, the available modulation formats for rate adaption become 0-QAM (no transmission), 4-QAM, 8-QAM, 16-QAM, and 32-QAM. The SNR values $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ are the required SNR to achieve the target BER with 4-QAM, 8-

QAM, 16-QAM, and 32-QAM schemes respectively. The required SNR for the given M-QAM modulation are calculated from equation (9) and given on table 1.

Table 1: Required SNR in dB to achieve the target BER

γ_0 (no transmission)	γ_1	γ_2	γ_3	γ_4
<6.79	6.79	9.63	10.48	13.61

Since higher level modulations are not energy efficient, as shown on table-1:

$$\gamma_1 < \gamma_2 < \gamma_3 < \gamma_4 \qquad (11)$$

Then for each k^{th} sub carrier, the calculated SNR γ_k^{ACO} based on the current channel condition is compared with $\gamma_1, \gamma_2, \gamma_3, \gamma_4$. For certain $M_i\big|_{i\neq 0}$ to be chosen for adaption, the condition $\gamma_i \le \gamma_k^{ACO} < \gamma_{i+1}$ should be fulfilled. If γ_k^{ACO} is less than the required SNR for 4-QAM (γ_1), then no information is transmitted in that particular sub carrier. The rate adaption is done by the following algorithm-1 using mat lab:

Algorithm-1

```
$M = [0\ 4\ 8\ 16\ 32]$ %level of QAM MODULATION for rate adaption
$\gamma_i = [\gamma_1\ \gamma_2\ \gamma_3\ \gamma_4]$ % required SNR for target BER for those QAM mods
$\gamma_k^{ACO} = [\gamma_1^{ACO}\ \gamma_3^{ACO}\ \gamma_5^{ACO} \dots \gamma_{\frac{N}{2}-1}^{ACO}]$ % achieved SNR on subcarriers using CIS
$for\ i = 1 : length(\gamma_k^{ACO})$
    $\text{snr\_subc} = \gamma_k^{ACO}(i)$
    $A = \gamma_i(\gamma_i \ge \text{snr\_subc})$
        $B = length(\gamma_i) - length(A)$
        $D = M(B+1)$
      $M_k(i) = D$ % chosen level of QAM on sub carrier
  $end$
```

Based on the chosen M_k on each information carrying odd sub carriers, different M_k-QAM symbols are loaded to those sub carriers.

SPECTRAL EFIICENCY OF ADAPTIVE ACO-OFDM

Based on the obtained M_k for each sub carriers, it is possible to find the number of subcarriers N_{info} on which the information signal is transmitted, hence, N_{info} is the number of sub carriers having $M_k > 0$ after level of modulations are chosen for rate adaption at each odd sub carrier. The spectral efficiency Se_{ACO}^{ADP} offered by the rate adaptive ACO-OFDM can be calculated as:

$$Se_{ACO}^{ADP} = \frac{1}{N + N_{CP}} \sum_{k=1,3,\dots}^{N_{\text{info}}} \log_2 M_k$$

Where N_{CP} is the length of the cyclic prefix used in the system.

SIMULATION RESULT AND DESCUSSIONS

The spectral efficiency of adaptive ACO-OFDM is simulated and the results are compared with the performance of fixed modulation schemes. For fixed modulation schemes, sub carriers which are not god enough to achieve the target BER with that particular fixed modulation are loaded with zero QAM with no information transmission. The following simulation parameters listed on table 2 are used during simulations.

Table 2: Simulation parameters

Number of subcarriers (N)	2048
Cyclic prefix (CP)	32
Sampling frequency (f_s)	100 MHz
Channel delay spread (D_{rms})	10 ns
Modulations	4,8,16,32-QAM
Target BER	10^{-3}

The samples of channel impulse response are generated by using celling bounce model with consideration of no blocking object between transmitter and receiver. The result of discrete time simulation of the channel impulse response is presented on Fig. 2. The simulation result on Fig.2 confirms that 32 samples length CP is enough since the magnitude of the channel is almost negligible beyond the 8th sample. Fig.3 shows the frequency domain simulation of the channel for D_{rms} of 10 ns. The optical wireless channel has low pass nature and the sub carriers near to zero frequency are in good conditions.

On Fig. 4, the BER performance of adaptive ACO-OFDM with a target BER of 10^{-3} is presented for different magnitudes of electrical SNR in terms of bit energy. The simulation results show that the target BER (10^{-3}) is achieved and no outage of system can happen.

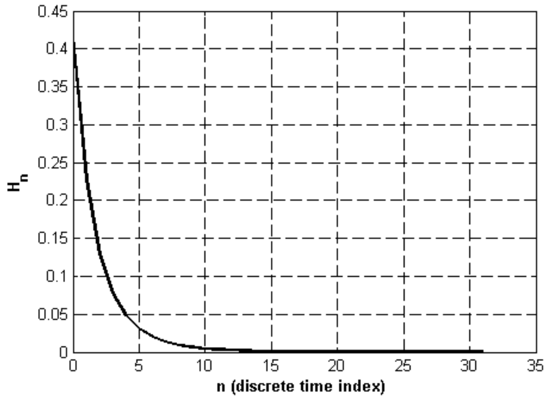

Figure 2: Channel impulse response in time domain

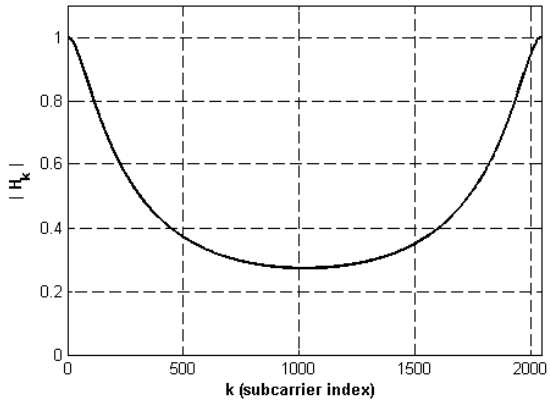

Figure 3: Channel impulse response in frequency domain

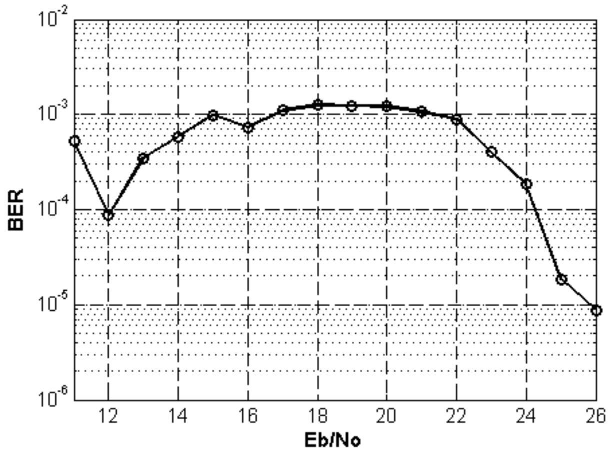

Figure 4: BER performance of adaptive ACO-OFDM for target BER of 10^{-3}.

The comparisons of adaptive M-QAM-ACO-OFDM with fixed modulation formats in terms of spectral efficiency is presented on Fig. 5.

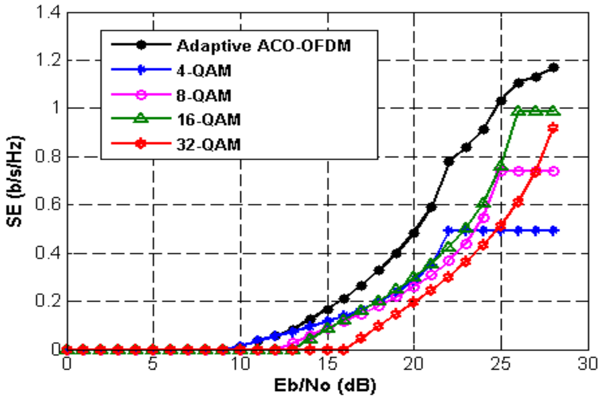

Figure 5: Spectral efficiencies of adaptive ACO-OFDM and fixed modulation schemes for target BER of 10^{-3}.

The simulation results presented on Fig. 5 confirmed that the rate adaptive ACO-OFDM can offer better spectral efficiencies compared to those fixed modulation schemes (4,8,16,32-QAMs). For electrical E_b/N_o of 25 dB, the rate adaptive ACO-OFDM offers a spectral efficiency of around 1 b/s/Hz while 8-QAM and 16-QAM fixed modulation formats offer a spectral efficiency of around 0.75 b/s/Hz. Moreover, 4-QAM and 32-QAM modulations offer a spectral efficiency of 0.5 b/s/Hz for the same amount of SNR (25 dB). The 32 –QAM offers less spectral efficiency because the achieved SNR γ_k^{ACO} at many sub carriers are not enough to achieve the target BER. Therefore, many sub carriers are left empty without data transmission. The bit allocation on sub carriers for adaptive ACO-OFDM is depending on the magnitude of the channel gain at sub carriers. Fig. 6, Fig. 7, and Fig. 8 show the bit allocations on sub carriers for adaptive ACO-OFDM, 16-QAM, and 32-QAM fixed schemes respectively with E_b/N_o of 25 dB.

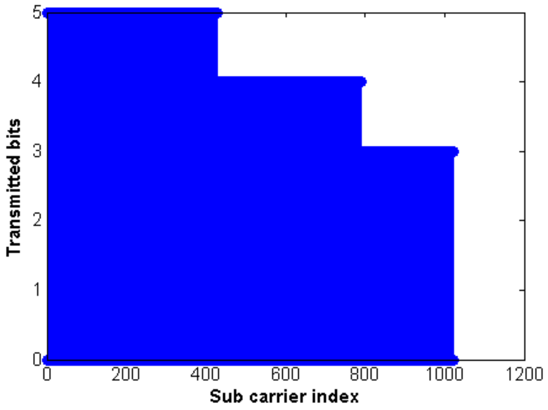

Figure 6: Adaptive ACO-OFDM sub carriers' bits allocation for E_b/N_o of 25 dB.

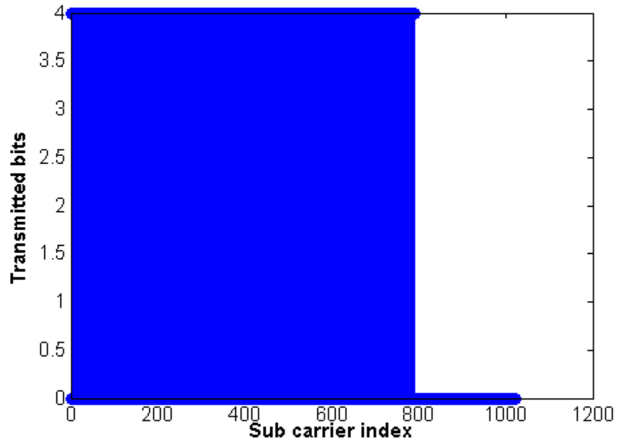

Figure 7: 16-QAM based ACO-OFDM sub carriers' bits allocation for E_b/N_o of 25 dB.

As shown on Fig. 6 the bit allocation for adaptive ACO-OFDM is; the odd indexed sub carriers ranging from 1st to 427th sub carrier are loaded with 5 bits, 429th to 791th are loaded with 4 bits, and 793th to 1023th are loaded with 3 bits. Since the channel has low pass nature as presented on Fig. 3, higher indexed sub carriers are loaded with fewer bits since they are more affected by multipath fading. For 16-QAM based fixed modulation ACO-OFDM, odd subcarriers ranging from 1-791 are loaded with 4 bits while odd subcarriers from index 793-1023 are loaded with zero bits as shown on Fig. 7. The sub carriers from index 793-1023 are significantly affected by the channel and it is not possible to achieve the target BER if they are loaded with 4 bits.

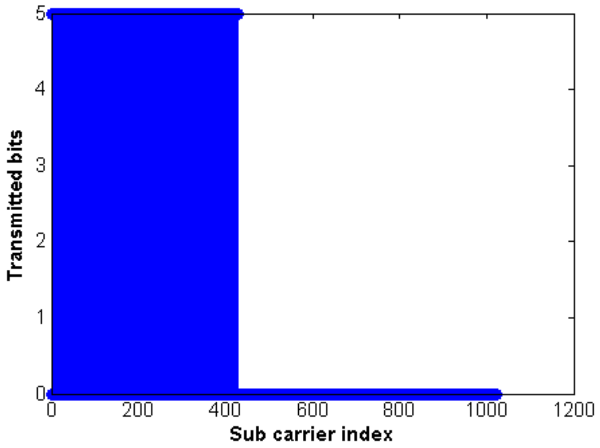

Figure 8: 32-QAM based ACO-OFDM sub carriers' bits allocation for E_b/N_o of 25 dB.

Similarly, only odd subcarriers ranging from index 1-427 are loaded with 5 bits for fixed modulation based ACO-OFDM with 32-QAM scheme as presented on Fig. 8. No transmission is done on sub carriers beyond 427th sub carrier since their condition is too worse to achieve the target BER for the given E_b/N_o (25 dB). For 32-QAM based non adaptive system, most of the odd subcarriers are left empty; hence, the achieved spectral efficiency is lower for E_b/N_o of 25 dB.

CONCLUSIONS

On this paper, the potential of rate adaptive ACO-OFDM on multipath channel to enhance spectral efficiency of optical wireless communication is evaluated. Compared to fixed modulation format based ACO-OFDM, rate adaptive ACO-OFDM has shown better spectral efficiency performance for optical wireless communication over multipath channels.

REFERENCES

[1] Cisco Visual Networking Index, "Global Mobile Data Traffic Forecast Update, 2016-2021," CISCO, White Paper, March 2017.

[2] J. Grubor , S. Randel , K. D. Langer , J.W. Walewski, "Bandwidth-efficient indoor optical wireless communications with white light-emitting diodes," IEEE International Symposium on Communication Systems, Networks and Digital Signal Processing (CNSDSP), Graz, Austria, July 2008.

[3] L. Minh , Z. Ghassemlooy , D. O'Brien, G. Faulkner, " Indoor Gigabit optical wireless communications: Challenges and possibilities,"IEEE International Conference on transparent Optical Networks (ICTON), Munich, Germany, July 2010.

[4] H. Elgala, R. Mesleh, H. Haas, "Indoor optical wireless communication: potential and state-of-the-art," IEEE Commun. Mag., vol. 49, no. 9, September 2011.

[5] T. Ohtsuki, "Multiple-subcarrier modulation in optical wireless communications," IEEE Commun. Mag., vol. 41, pp. 74–79, 2003.

[6] R. V. Nee and R. Prasad, OFDM for Wireless Multimedia Communications. Artech House, 2000.

[7] N. Fernando, H. Yi, and E. Viterbo, "Flip-OFDM for unipolar communication systems," IEEE Trans. Commun., vol. 60, no. 12, pp. 3726-3733, December 2012.

[8] Z. Hailu, K. Langat, C. Maina, "Stratified ACO-OFDM Modulation for Simultaneous Transmission of Multiple Frames Both on Even and Odd Subcarriers," Journal of Communications, vol. 12, no. 5, pp. 261-270, 2017.

[9] J. Armstrong, "OFDM for optical communications," Journal of Light Wave Technology, vol. 27, no. 3, pp. 189-204, February 2009.

[10] O. Gonzalez, R. Perez-Jimenez, S. Rodriguez, J. Rabadan, and A. Ayala, “OFDM over indoor wireless optical channel,” Proc. Inst. Electr. Eng.-Optoelectron., vol. 152, pp. 199–204, Aug. 2005.

[11] J. Armstrong and B. J. C. Schmidt, “Comparison of Asymmetrically Clipped Optical OFDM and DC-Biased Optical OFDM in AWGN”, IEEE Commun. Lett., Vol.12, no.5, pp.343-345, May 2008.

[12] [14] X. Li, J. Vucic, “On the Capacity of Intensity-Modulated Direct-Detection Systems and the Information Rate of ACO-OFDM for Indoor Optical Wireless Applications,” IEEE transactions on communications, vol. 60, no. 3, March 2012.

[13] P. Saengudomlert, “On the Benefits of Pre-Equalization for ACO-OFDM and Flip-OFDM Indoor Wireless Optical Transmissions Over Dispersive Channels,” journal of lightwave technology, vol. 32, no. 1, January 2014.

[14] J. Panta, P. Saengudomlert, K. Sripimanwat, “Performance Improvement of ACO-OFDM Indoor Optical Wireless Transmissions Using Partial Pre-Equalization,” ECTI transactions on electrical eng., electronics, and communications, vol.14, no.1, February 2015.

[15] Kahn, J.M., Barry, J.R., “Wireless infrared communications,” Proc. of IEEE, Feb. 1997, 85, (2), pp. 265−298.

[16] S. K. Wilson,, J. Armstrong, “Transmitter and receiver methods for improving asymmetricallyclipped optical OFDM,” IEEE Trans. on Wireless Comm., vol. 8, no. 9, pp.4561−4567, September 2009.

[17] F. Xiong, Digital Modulation Techniques, 2nd ed. Norwood, USA: Artech House, 2006, ch. 9.