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SUPPRESSED CARRIER FREQUENCY DIVISION MULTIPLEXING FOR INDOOR OPTICAL WIRELESS COMMUNICATION

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Abstract

Asymmetrically clipped orthogonal frequency division multiplexing (ACO-OFDM) is one of the optical modulation techniques for indoor optical wireless communication systems (OWC) to enable intensity (IM) modulation and direct detection (DD). As compared to other techniques, ACO-OFDM is power efficient, bandwidth efficient and has zero impact of clipping noise. However, its high peak to average power ratio (PAPR) may lead to performance deterioration and also introduce nonlinear distortion in optical source. To further enhance its performance by reducing the PAPR, suppressed carrier frequency division multiplexing (SC-FDM) is proposed and the system is titled as interleaved coded ACO (ICACO)-OFDM. To evaluate the performance of the system, simulation has been carried out for 16-QAM, 256 subcarriers, 1000 symbols. By observing the curves generated by Complementary cumulative distribution function (CCDF) at the probability of 10^{-3}, PAPR has been characterized. It is observed that PAPR of ICACO-OFDM is 4.98 dB less as compared to ACO-OFDM system.

Keywords:

Asymmetrically Clipped Orthogonal Frequency Division Multiplexing (ACO-OFDM), Peak to Average Power Ratio (PAPR), Complementary Cumulative Distribution Function CCDF, Subcarrier Multiplexing

1. INTRODUCTION

Based on the high demand for the high data rate applications it is anticipated that available radio frequency (RF) spectrum becomes congested. This has driven to concentrate on an alternative region of spectrum that is visible light spectrum. Its high frequency band satisfies the content consumption applications such as mobile video, video conferencing, multimedia, usage of social networks and so on. Optical communication can be either with free space or optical fiber system [1].

In this paper we refer to optical communication adopting free space as a transmission media known as Optical wireless communication (OWC). In OWC light spectrum is used to transmit information wirelessly. At the transmitter optical sources such as Light emitting diodes (LED's) are preferable than laser by taking in to consideration of eye safety and modulation bandwidth. Transmitted signal is captured by photodiode at the receiver. Favorable features like unlicensed bandwidth and usage of low-cost transmission and reception devices motivated the researchers to explore different areas related to optical wireless communication system [2].

This paper focusses on optical modulation techniques. In contrast to RF communication, in OWC intensity modulation (IM) and direct detection (DD) are the practical means of transmission and reception techniques for indoor and outdoor applications. OWC is an age-old technology used to transmit data by turning on and off the optical sources based on single carrier modulation (SCM) techniques.

SCM is used to transmit data efficiently for low data rate applications. But results in delay spread which in turn results in intersymbol interference (ISI) for high data rate. This gained importance to multicarrier modulation techniques (MCM). Orthogonal frequency division multiplexing a form of MCM technique overcomes the ISI by replacing complex modulators, multiplexers and equalizers that are used in SCM. Though MCM has been well explored in RF communication but it has been recently introduced in optical communication, a backbone for various communication systems.

OWC retained importance for the last few years due to wide bandwidth of optical spectrum that meets the requirement of high carrier frequency applications. In addition to that introducing multicarrier modulation techniques in OWC overcomes the limitations of SC modulation techniques like On-Off Keying (OOk) and Amplitude Shift Keying (ASK). OFDM a multicarrier transmission system is a driving force to meet the requirement of high data in 4G technologies like LTE, WiMAX and beyond [3].

In OFDM data is carried out on different sub bands. Each sub band has a carrier frequency to perform modulation on the QAM symbols. OFDM performs modulation and multiplexing by replacing the complexity in designing the bank of modulators [4]. Its capability as a practical transmission technique attracted researchers to be a part of optical domain in addition to guided and unguided form of communication.

RF- OFDM systems that are designed to send the information signal on electric field is not suited for optical communication. In OWC base band signal is carried on the intensity of light and so we are interested on the parameters the optical power depends. Optical power transmitted is proportional to the amplitude of the signal and the phase is not considered to transmit the information. This is the reason for the need of positive real signal [1], a unipolar communication system.

Amplitude modulated RF wireless, Optical communication either with free space or optical fiber, base band digital modulation can be named as few examples for unipolar communication systems. Various unipolar OFDM forms proposed by various researchers are DC biased, without DC bias and hybrid techniques. DCO-OFDM, ACO-OFDM, Flip-OFDM, unipolar OFDM and ADO-OFDM are some of the techniques [5]-[8]. These are used as a modulation technique in Light fidelity (Li-Fi), a concept of enabling huge amount of data parallelly with illumination. Since ACO-OFDM is widely used, proposed technique is built on ACO-OFDM. Subcarrier mapping and clipping operation in ACO-OFDM results in low value of SNR for a targeted BER but possess high PAPR. PAPR reduction techniques available in literature are mainly focused on uncoded unipolar techniques.

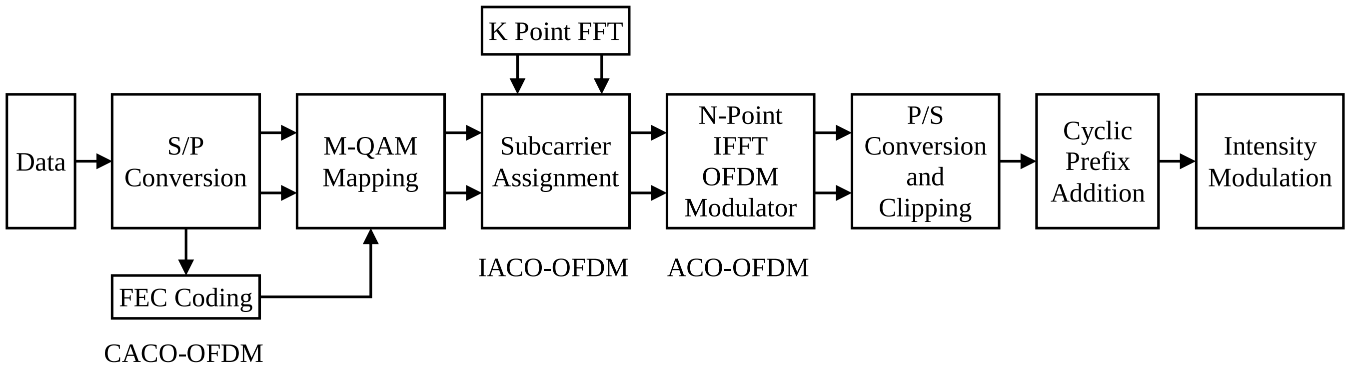


Fig.1. Schematic diagram of Transmitter section of ACO-OFDM, CACO-OFDM and IACO-OFDM

Our work is focused on coded unipolar technique. ACO-OFDM has been modified by introducing error control coding and suppressed carrier (SC)-FDM technique. Coded ACO-OFDM (CACO-OFDM) aims to transmit the signal at low power. Though CACO-OFDM outperforms than ACO-OFDM by attaining better signal to noise ratio for a targeted BER but its PAPR is same as ACO-OFDM. Second modification is done by introducing SC-FDM in CACO-OFDM (ICACO-OFDM). This resulted in reduced value of PAPR as compared to CACO-OFDM. Therefore, proposed method has low transmit power and reduced value of PAPR which is very crucial to overcome the nonlinearity of lasers and LEDs resulted a PAPR value of 7.65dB.

This paper presents related work in section 2, proposed work in 3, results and discussion 4, section 5 concludes the contributions

2. RELATED WORK

Unipolar OFDM communication techniques for indoor optical wireless communication is broadly classified based on interleaving and on various ways to obtain positive real signal. Hermitian symmetry a preliminary condition applied to obtain a real signal for higher order modulation techniques. To acquire this condition, 50% of IFFT is sacrificed in DCO-OFDM, Flip-OFDM and unipolar OFDM. Where as in ACO-OFDM 75% of IFFT is sacrificed due to modulating only on odd subcarriers. This results in anti-symmetry signal in ACO-OFDM. To further obtain positive real signal clipping is performed. Amplitude of the resultant ACO-OFDM signal is half the amplitude of the base band signal. This is the key advantage in ACO-OFDM system to have a reduced value of transmit power. More over significant requirement of low transmit power is for the skin and eye safety. ACO-OFDM, a power efficiency system is the most preferred optical modulation technique. Sequence of operations performed in ACO-OFDM is depicted in Fig.1.

Addition of DC bias and clipping results in positive real signal in DCO-OFDM [6]. In Flip-OFDM, DC bias is not used and it preserves both positive samples and negative samples, by flipping the negative samples and then transmitting them separately one after the other with a delay in between the transmissions. The complexity of Flip-OFDM is 50% less as compared to ACO-OFDM [8]. Where as in U-OFDM positive and negative samples are separated from time domain signal [7].

Table.1. Simulation parameters

Parameter	Value
OFDM symbols	1000
No. of subcarriers	256
Data carrying subcarriers	127 (DCO-OFDM, Flip-OFDM) 64 (ACO-OFDM)
Modulation technique	16QAM

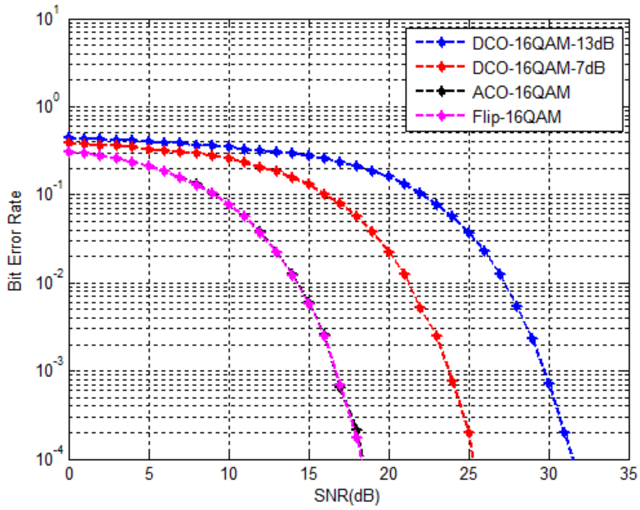
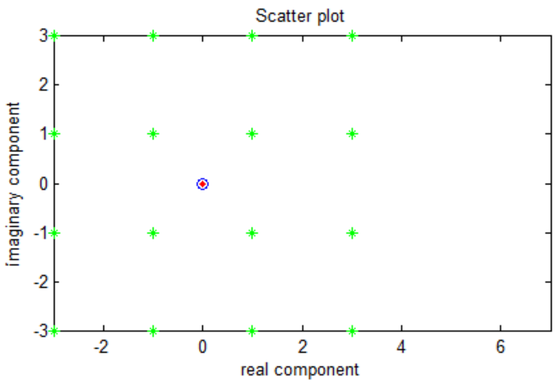


Fig.2 BER performance of DCO-OFDM for 13dB and 7dbias, ACO-OFDM and Flip-OFDM in AWGN for 16-QAM constellation

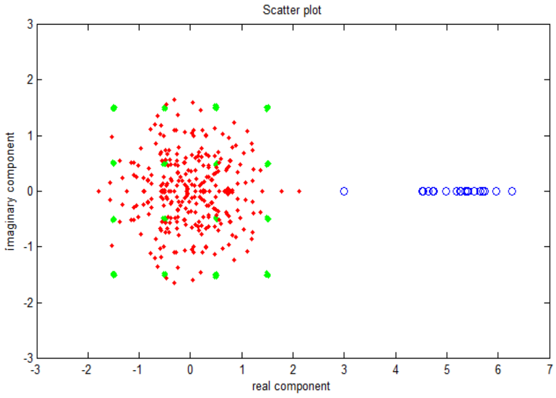
Positive samples are further represented by active and inactive samples, and negative samples by inactive and active samples. Active samples and inactive samples are grouped together and transmitted. Shot noise that can affect the performance of the system can be modelled as AWGN noise [9]. BER performance for different optical modulation techniques in the presence of AWGN is evaluated by the simulation as per the parameters specified in the Table.1 and the results are depicted in Fig.2. Out of four methods investigated DCO-OFDM requires DC bias which increases the optical power thus reducing optical power efficiency by attaining the signal to noise power higher than the other three forms as shown in Fig.2.

The 16-QAM DCO-OFDM with 7dB bias requires approximately more power of 6.85dB and with 13dB bias requires 12.8dB more power than ACO-OFDM and Flip-OFDM for BER of 10^{-4}. Further the performance of ACO-OFDM and Flip-OFDM is exactly the same in terms of BER performance.

In addition to above observations, it is also noticed that Flip-OFDM and ACO-OFDM has the same value of SNR to achieve a target BER of 10^{-4}. As shown in Fig 3(a) in ACO-OFDM the data carrying odd subcarriers are indicated by green constellation points, the even subcarrier and DC subcarrier are indicated by red and blue constellation points respectively. The data carrying odd subcarriers constellation points before clipping have the values {±1, ±3, ±1j, ±3j}.



(a)



(b)

Fig.3. Scatter plot for ACO-OFDM signal for 20 OFDM symbols and *N*=256 subcarriers. (a) Before Clipping (b) After Clipping

On account of clipping the amplitude of odd subcarriers is reduced exactly to half of their original value i.e. {±0.5, ±1.5, ±0.5j, ±1.5j} as seen in Fig.3(b) by green constellation points. Thus, effectively reducing mean optical transmit power which is an advantage in IM/DD optical wireless system. The even subcarriers have noise like distribution indicated by red constellation points. The clipping noise has no effect on overall system performance due to interleaving the even subcarriers with zeros. Lastly the DC subcarrier indicated by blue constellation points is positive for every OFDM symbol but varies symbol to symbol depending on the data. Further to enhance the power efficiency in ACO-OFDM, FEC coding for different generator polynomial is evaluated.

Probability to find error of the received signal is analyzed with the help of Bit error rate (BER). If the BER is not within the acceptable range then SNR has to be increased. However, increase in SNR results in increase in the transmit power. As per the square law relationship between SNR and power, a *N* dB average power is related to 2*N* dB in SNR. Coding techniques improves the performance without increasing the power [10]. Sequence of operations in ACO-OFDM and CACO-OFDM with coding is depicted in Fig.1.

Convolution coding one of the most acceptable and widely used in wireless communication is used to evaluate the performance of CACO-OFDM. Performance of convolutional code depends on the code rate and constraint length. Increase in the constraint length improves the performance but at the same time increases the complexity In CACO-OFDM Trellis structure which is an unfolded version of state diagram is used and decoding using Viterbi decoder [11]. In CACO-OFDM, after the generation of stream of bits forward error coding (FEC) is performed then M-QAM mapping is performed to obtain the frequency samples.

Once the frequency samples are generated the operations are the same as ACO-OFDM. Convolution encoder of rate R=1/2 and maximum likelihood estimation is performed using Viterbi decoder at the receiver using the metric path and hamming distance. Simulation is carried out as per the parameters specified in Table.2 and the graphical results are presented in Fig.5. With the FEC coding $E_b(elec)/N_0$ at BER of 10^{-4} graph shown in Fig.5. It has been observed that ACO-OFDM requires approximately 4.5dB more transmit power that of CACO-OFDM for 16 QAM modulation. Though the performance of CACO-OFDM is better than ACO-OFDM with respect to transmitted power but both the forms possess the equal values of PAPR. PAPR one of the weaknesses of OFDM degrades the performance of the system.

PAPR reduction in DCO-OFDM for underwater applications has been discussed in [12]. PAPR reduction in DCO-OFDM using interleaved subbanding scheme has been discussed in [12]. Vandermonde like matrix (VLM) technique is proposed to reduce the high peak-to-average power ratio in [13]. This technique achieved a PAPR of 9.96dB. In our method to reduce the PAPR an attempt is made by introducing suppressed carrier frequency division multiplexing in CACO-OFDM which is explained in detail in section 3.

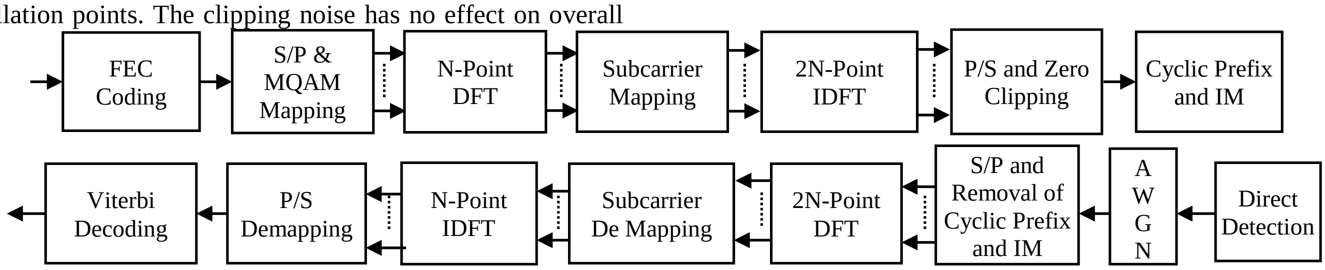


Fig.4. Proposed ICACO-OFDM Transmitter and Receiver System

Table.2. Simulation parameters

Parameter	Value
Number of OFDM symbols	1000
Size of IFFT	256
Data carrying subcarriers	64(ACO-OFDM) 64(CACO-OFDM)
Modulation technique	16QAM

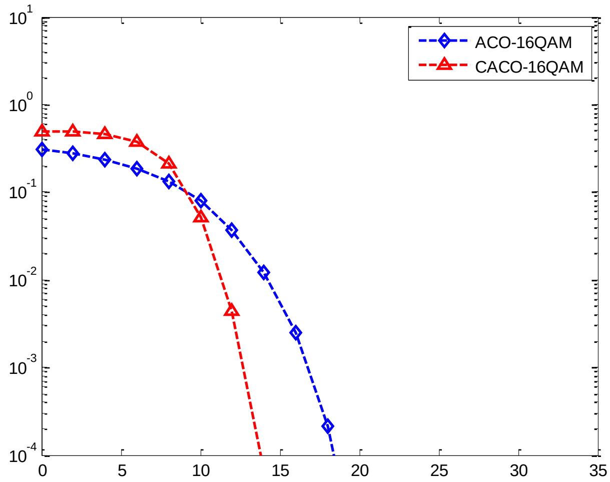


Fig.5. BER performance of 16-QAM ACO-OFDM and rate-“1” / “2” convolution coded CACO-OFDM

3. PROPOSED TECHNIQUE

ICACO-OFDM is depicted in Fig.4. Randomly generated stream of bits {1,0,0,1,0,0….} are encoded by convolution encoder of rate R=1/2 and then mapped in to voltage levels $\{a_1+jb_1,\ a_2+jb_2\ldots\ldots\}$ based on the M-QAM modulation. In our proposed method discrete Fourier transform (DFT) is performed on QAM symbols and the output of DFT is given by eq.1

$$X(n)=\frac{1}{N-1}\sum_{k=0}^{N-1}x(k)e^{-\frac{j2\pi nk}{N}}\quad n=0,1,2\ldots.N\text{-}1 \tag{1}$$

where N denotes the number of subcarriers.

Then DFT frequency domain samples are assigned to 2N-point IDFT modulator as shown in Eq.(2.

$$Y=[0,X(0),0,X(1),0,X(2)\ldots.X(N\text{-}1)] \tag{2}$$

Output of 2N-Point IDFT is given by Eq.(3)

$$y(n)=\frac{1}{N}\sum_{k=0}^{2N-1}Y(k)e^{-\frac{j\pi nk}{N}} \tag{3}$$

$$x_{ICACO}=\begin{cases}y(n) & if\ y(n)\geq 0\\ 0 & otherwise\end{cases} \tag{4}$$

To retain the properties of the OFDM DFT size is chosen to be less than that of IDFT. Output of IDFT is a bipolar and real and this is made suitable to perform IM by clipping the samples with negative amplitude to zero as shown in Eq.(4). Addition of cyclic prefix x_{ICACO} reduces the inter symbol interference. Average transmitted power is proportional to $E\{x_{ICACO}(t)\}$.

Once the signal is generated it is transmitted wirelessly and the shot noise emitted due to background light which is a dominant noise can be modeled as an AWGN noise. This is followed by the cyclic prefix removal, DFT, subcarrier demapping and then followed by N-Point IDFT. Demapping and Viterbi decoding is performed and bits are retrieved and the system performance is characterized by BER response. In this paper our focus is towards the suppression of PAPR in ICACO. Though CACO requires low transmit power as compared to ACO-OFDM as discussed in section 3 and also shown through simulation results its PAPR is equal to that of CACO.

In order to make the system an efficient an attempt is made to analyze the performance of PAPR by modifying the block diagram with the introduction of SC-FDM. Wide research has been done in the reduction of PAPR in RF systems. High peak time domain signal generated by IDFT OFDM modulator is due to superposition of signals generated by parallel independent subbands.

This results in non-linearity’s at the transmitter side that leads to distortion such as in-band and out-of band. Operation of LED in quasi linear region minimizes the distortion as shown in Fig.5. Quasi linear region is indicated in LED nonlinear characteristics is depicted in Fig.6.

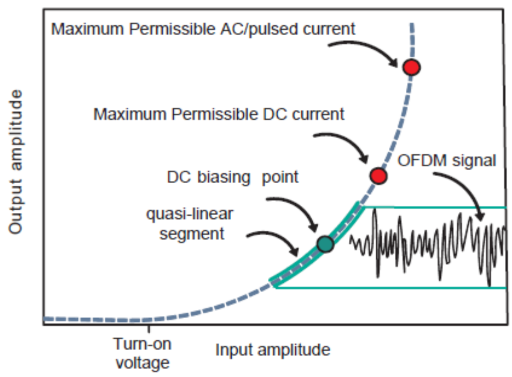


Fig.6. Nonlinear LED Transfer Characteristics

4. RESULTS AND DISCUSSIONS

PAPR a crucial factor to analyze and is defined as a ratio between maximum peak power of the signal to the average power of the signal PAPR is given by the Eq.(5).

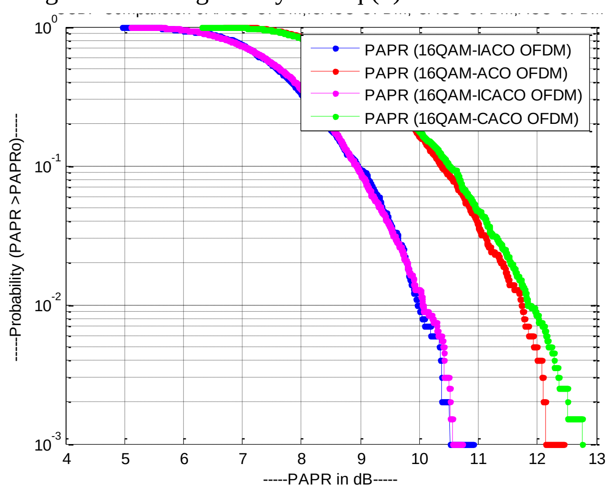


Fig.7 CCDF’s of PAPR for ACO-OFDM, ACO- OFDM, IACO-OFDM and ICACO- OFDM

Higher value of PAPR drives the LED to nonlinear region and loses its feature of orthogonality. PAPR is calculated for ACO-OFDM, IACO-OFDM, CACO-OFDM and ICACO-OFDM. PAPR is investigated as per the various parameters in Table.2 Performance of PAPR is characterized with the help of CCDF plot. In Fig.7, CCDF's of PAPR of ACO-OFDM, CACO-OFDM, IACO-OFDM and ICACO-OFDM is compared. By observing the CCDF plot in Fig.6 it is noted that PAPR of ACO-OFDM and CACO-OFDM at 10^{-2} is 11.8 dB and PAPR of IACO-OFDM and ICACO-OFDM at results in reduced value of PAPR. Average PAPR for all these four forms is shown in Table.3.

$$PAPR\text{ (dB)}=10\log \max\{|x_{ICACO}|^2\}/E\{|x_{ICACO}|^2\} \quad (5)$$

Table.3. Average PAPR

Optical Modulation	Value in dB
ACO-OFDM	12.63
CACO-OFDM	9.01
IACO-OFDM	7.66
ICACO-OFDM	7.65

5. CONCLUSION

Though Optical wireless communication is an age-old technology it is gaining importance due to multicarrier modulation techniques that results in high data rate transmission and the utilization of unlicensed light spectrum for large bandwidth applications. Due to its favored features, it can support high data rate requirement in case of 5G networks and also support mass device connectivity in case of internet of things. It is always a challenging to enhance the power efficiency of the system. Applying channel coding techniques enhances the power efficiency by reducing the SNR value for a targeted BER. Though CACO-OFDM outperforms ACO-OFDM in terms of power efficiency but peak to average power ratio is same in both the cases. An attempt is made by modifying the block diagram of ACO-OFDM by introducing suppressed carrier frequency division multiplexing. Through the simulation results it is noted that CACO-OFDM requires 4.5dB less power to achieve a target BER of 10-4. N-Point FFT with 2N-Point IFFT at the transmitter side reduces the PAPR. Proposed method ICACO has reduced value of PAPR as compared to CACO-OFDM. Therefore, proposed SC-FDM in CACO-OFDM helps us to have a system with better power efficiency and reduced value of PAPR.

REFERENCES

[1] J. Armstrong, "OFDM for Optical Communications", *Journal of Lightwave Technology*, Vol. 27, No. 3, pp. 189-204, 2009.

[2] J. Kahn and J. Barry, "Wireless Infrared Communications", Proceedings of IEEE, Vol. 85, No. 2, pp. 265-298, 1997.

[3] H. Elgala, R. Meshleh and H. Haas, "Indoor Optical Wireless Communication: Potential and State-of-the Art", *IEEE Communication Magazine*, Vol. 49, No. 9, pp. 56-62, 2011.

[4] S.B. Weinstein and P.M. Ebert, "Data Transmission by Frequency-Division Multiplexing using the Discrete Fourier Transform", *IEEE Transactions on Communication Technology*, Vol. 19, No. 5, pp. 628-634, 1971.

[5] Zelalem Hailu Gebeyehu, Philip Kibet Langat and Ciira Wa Maina, "BER Performance of Stratified ACO-OFDM for Optical Wireless Communications over Multipath Channel", *Journal of Computer Networks and Communications*, Vol. 23, No. 1, pp. 1-14, 2018.

[6] S. D. Dissanayake and J. Armstrong, "Comparison of ACO-OFDM, DCO-OFDM and ADO-OFDM in IM/DD Systems", *Journal of Lightwave Technology*, Vol. 31, No. 7, pp. 1063-1073, 2013.

[7] Dobroslav Tsonev, Sinan Sinanovic and Harald Haas, "Novel Unipolar Orthogonal Frequency Division Multiplexing (U-OFDM) for Optical Wireless", *Proceedings of IEEE Conference on Vehicular Technology*, pp. 6-9, 2012.

[8] N. Fernando, Y. Hong and E. Viterbo, "Flip-OFDM for Unipolar Communication Systems", *IEEE Transactions on Communications*, Vol. 60, No. 12, pp. 3726-3733, 2012.

[9] Jayasudha Koti and B.K. Mishra, "Performance Analysis of Unipolar Communication Techniques for Optical Wireless Communication", *Proceedings of IEEE Conference on Networking, Embedded and Wireless Systems*, pp. 1-12, 2018.

[10] Andrew J. Viterbi, "Convolutional Codes and their Performance in Communication Systems", *IEEE Transactions on Communications*, Vol. 19, No. 5, pp. 751-772, 1971.

[11] Jayasudha Koti and B.K. Mishra, "Comparitive Analysis of ACO-OFDM and CACO-OFDM for Indoor Optical Wireless Communication", *Proceedings of IEEE Conference on Microwave Integrated Circuits, Photonics and Wireless Networks*, pp. 1-9, 2019.

[12] Jurong Bai, Chenfei Cao, Yi Yang, Feng Zhao and Xiangjun Xin, "Peak-to-Average Power Ratio Reduction for DCO-OFDM Underwater Optical Wireless Communication System based on an Interleaving Technique", *Journal of Optical Engineering*, Vol. 57, No. 8, pp. 1-15, 2018.

[13] Abbas Ali Sharif, "PAPR Reduction of Optical OFDM Signals in Visible Light Communications", *ICT Express*, Vol. 5, No. 3, pp. 202-205, 2019.