



Non-Orthogonal Algorithm with Fourier Transform Symmetry for Performance Enhancement of DCO-OFDM Systems

Mohamed S. Elbakry^{1,*}, Sherif k. Eldyasti², Khaled Ramadan^{3,4}

- ¹ Department of Electronics and Communications Engineering, Institute of Aviation Engineering and Technology (IAET), Giza, Egypt
² Arab Academy for Science and Technology & Maritime Transport, Smart Village Campus, Cairo, Egypt
³ Department of Telecommunication Engineering, college of engineering, Ahlia university, Manama, Bahrain
⁴ Department of Communications and Computer Engineering, The Higher Institute of Engineering at Al-Shorouk City, Cairo, Egypt

ARTICLE INFO

Article history:

Received 20 December 2023
Received in revised form 16 June 2024
Accepted 24 June 2024
Available online 10 August 2024

Keywords:

VLC; OFDM; DCO-OFDM; SIC

ABSTRACT

The direct current (DC) biased optical orthogonal frequency division multiplexing (DCO-OFDM) technique has been widely used in visible light communication (VLC) systems due to its ease of installation. In this study, the Fourier symmetry (FT) scheme is proposed for the DCO-OFDM systems using BPSK modulation scheme. Furthermore, the proposed FT symmetry scheme is used either for increasing the data rate of the system or for enhancement the bit error rate (BER) system performances. In addition, the non-orthogonal algorithm (NOA) combined with the FT symmetry scheme is proposed for improving the DCO-OFDM system using QPSK modulation scheme. In the proposed NOA algorithm, the successive interference cancellation (SIC) is used at receiver to overcome interfering between real and imaginary parts. In the simulation, different transforms such as Fast Fourier transform (FFT), discrete cosine transform (DCT) and discrete Wavelet transform (DWT) are applied in the proposed schemes. Finally, simulation results show that the proposed schemes can significantly increase the overall system performance compared to the conventional scenario via different measure of performance such as BER, power spectral density (PSD) and peak to average power ratio (PAPR).

1. Introduction

In contrast to RF systems, visible light communication (VLC) modifies the current passing through active light emitting diodes (LEDs) and repurposes the illumination power for communication. Thus, optical devices are used to produce, perceive, and change electrical energy to optical energy as an alternative of antennas. The VLC systems provide significant advantages over RF systems in the following areas: large spectrum, good security, and simple implementation, immunity to electromagnetic interference; and inherent robustness against eavesdropping are some of the other benefits [1, 2]. Due to these fundamental advantages, the VLC system may be helpful for supporting the internet of things (IoT) in the light fidelity system [3], in the medical healthcare system to provide

* Corresponding author.

E-mail address: m_sobhy_elbakry@yahoo.com

<https://doi.org/10.37934/araset.50.1.7887>

data service and monitoring in locations with radio frequency limits [4] and integrated with non-orthogonal multiple access (NOMA) [5-8].

At high data rates in a VLC system, the bandwidth-limited LED channel and indoor multipath propagation delays can result in significant inter-symbol interference (ISI) [9]. When this happens, orthogonal frequency division multiplexing (OFDM) [10-14] emerges as a desirable choice since it not only makes it possible to minimize the ISI at a reasonable cost, but also increases the data rate [15-24]. The DCO-OFDM system is proposed where the bipolar output signal is upshifted using DC-biasing levels before conducting a clipping operation. The reason for using this system is because it continues to transport data at the fastest rate even after using Hermitian symmetry with $N/2$ subcarriers and a 50% transmitted data rate ratio. Because of the extra DC-biasing level provided to the transmitted signal, this system performs worse in terms of BER than other current systems [25, 26]. In the DCO-OFDM systems with increasing number of subcarriers, the peak to average power ratio (PAPR) has also increased [27, 28]. There are many researches for improving the spectral efficiency for DCO-OFDM systems [29, 30].

In this paper, the symmetry property of the Fourier transform (FT) is first proposed used for doubling the system throughput compared to that of the conventional system based on the Hermitian symmetry property for BPSK modulation scheme. On the other hand, using the symmetry property of the Fourier transform may increase the system complexity, which is the cost. For higher modulation order the concept of non-orthogonal algorithm (NOA) is proposed. In the proposed NOA algorithm, the real part and the imaginary part of the complex output of the IFFT is added together to generate real values to be suitable for VLC transmission. In the proposed NOA algorithm, an optimized fractional power parameter is used to outperform the DCO-OFDM system. In the receiver architecture, the successive interference cancellation (SIC) is used for real part and imaginary part recovery. In fact, the OFDM can be implemented via IDFT and DFT pairs. On the other hand, other orthogonal transforms can be used instead of IDFT/DFT pairs like IDCT/DCT, or IDWT/DWT. All these transforms can be used for OFDM implementation under the condition of orthogonality property. The main differences between these transforms is the basis function that can be used. For example, the DCT have the property of energy compaction that directly improves the system performance [31]. For the case of wavelet transform, the DWT offers certain advantages over the corresponding DFT-based OFDM [32, 33]. Hence, the proposed schemes for DCO-OFDM using different transforms like FFT, DCT, and DWT are proposed. As a result, the proposed schemes are compared with that of the corresponding conventional scheme, which gives a superiority and increase the overall system data of the proposed scheme.

This document is organized as follows: in Section 2, we define the system model for the proposed DCO-OFDM utilizing various transforms; in Section 3, simulation findings are presented that are utilized to verify the theoretical analysis; and in Section 4, we present our results.

2. The Proposed System Models

2.1 The Proposed Ft Symmetry System Model

Using the symmetry of the Fourier transform, the suggested DCO-OFDM of BPSK system model is depicted as a block diagram in Fig. 1. The input to the IFFT block is BPSK (i.e., real valued bits) is represented the input to the IFFT block:

$$X_k = [X_0 X_1 \dots \dots X_{N-1}] \quad (1)$$

According to Figure 1, the output of the time domain sample points can be obtained as:

$$x_n = \frac{1}{N} \sum_{k=0}^{N-1} X_k \exp\left(\frac{j2\pi kn}{N}\right), \quad 0 \leq n \leq N - 1 \quad (2)$$

According to the FT property, the second part of $N/2$ length of the IFFT output in Equation (2) is ignored. This is followed by a new arrangement of the symbols as the imaginary part is followed by that of the real part. So, the resulting vector output is returned again to vector of length N . As a result, the output of the symmetric mapping block can be written as:

$$\chi_n = \{\Re[x_0 \ x_1 \ \dots \ x_{N/2-1}] \ , \ \Im[x_0 \ x_1 \ \dots \ x_{N/2-1}]\} \quad (3)$$

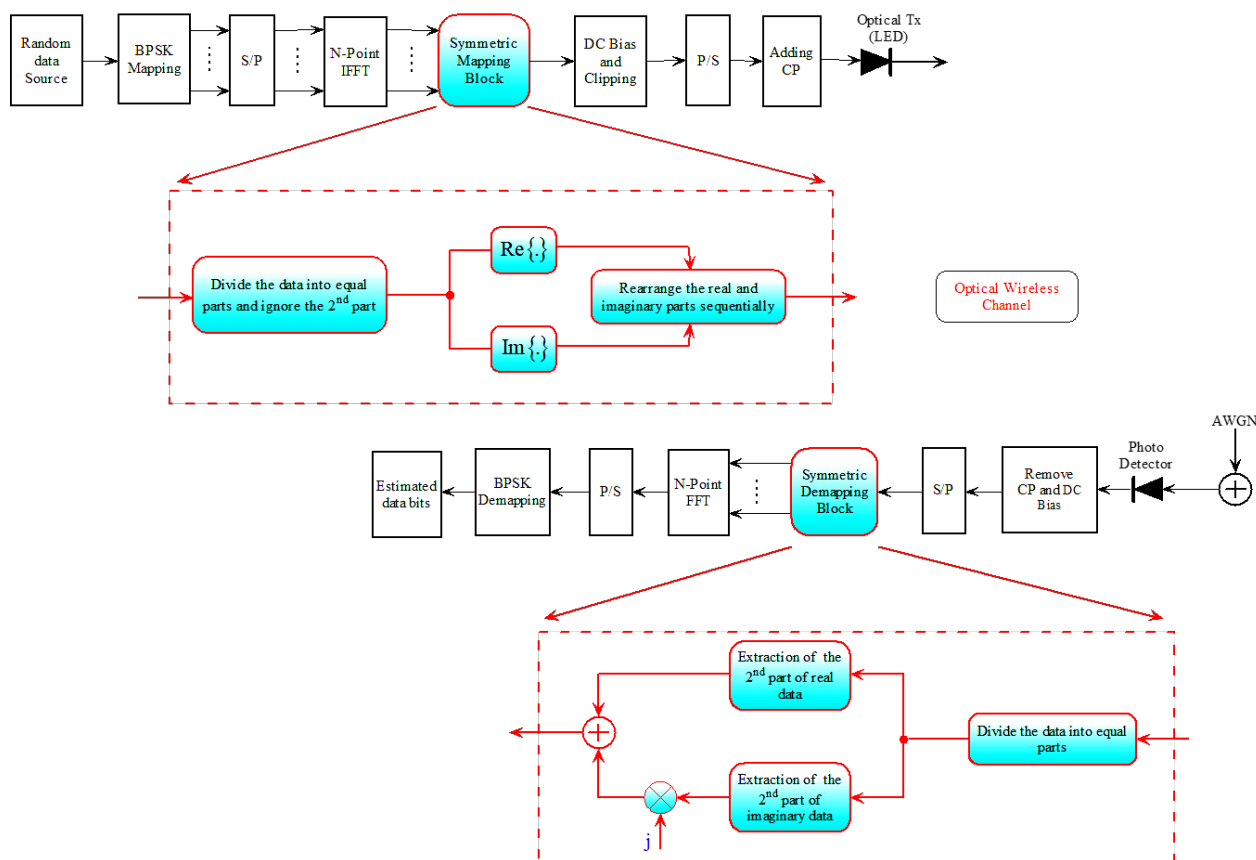


Fig. 1. The block diagram of the DCO-OFDM system model using the proposed FT symmetry scheme.

The DCO-OFDM signal is therefore produced as real values with length N rather than $2N$ as in the traditional DCO-OFDM system as a result of the output of the symmetric mapping block. However, it might have negative values, which would still make it unsuitable for intensity modulation. To keep all negative samples at zero, a DC bias is added. The received signal might be expressed in various ways at the receiver side:

$$r'_n = \chi'_n + w_n \quad (4)$$

where, r'_n represents the received signal $r'_n \in \mathbb{R}^{N \times 1}$, χ'_n denotes the transmitted signal after DC bias and clipping process and w_n is AWGN. In the recovery process, the received signal (r'_n) is divided in to two parts as:

$$\text{First part} = [r_0 \ r_1 \ \dots \ \dots \ r_{N/2-1}] \quad (5)$$

$$\text{Second part} = [r_{N/2} \ r_{N/2+1} \ \dots \ r_N] \tag{6}$$

The output of the real part and the output of the imaginary part are extended as:

$$\psi_1 = [r_0 \ r_1 \ \dots \ r_{N/2-1} \ 0 \ r_{N/2-1} \ r_{N/2-2} \ \dots \ r_1 \ r_0] \tag{7}$$

$$\psi_2 = [r_{N/2} \ r_{N/2+1} \ \dots \ r_N \ 0 \ -r_N \ -r_{N-1} \ \dots \ -r_{N/2+1} \ -r_{N/2}] \tag{8}$$

Now, the Equation (7), and (8) are combined as real and imaginary as:

$$\psi = \psi_1 + j\psi_2 \tag{9}$$

Finally, the FFT block is applied and followed by BPSK demapping in order to recover that transmitted data bits.

2.2 The Proposed Noa with Ft Symmetry System Model

Figure 2 shows the block diagram for the proposed DCO-OFDM system model that makes use of the NOA combined with FT symmetry.

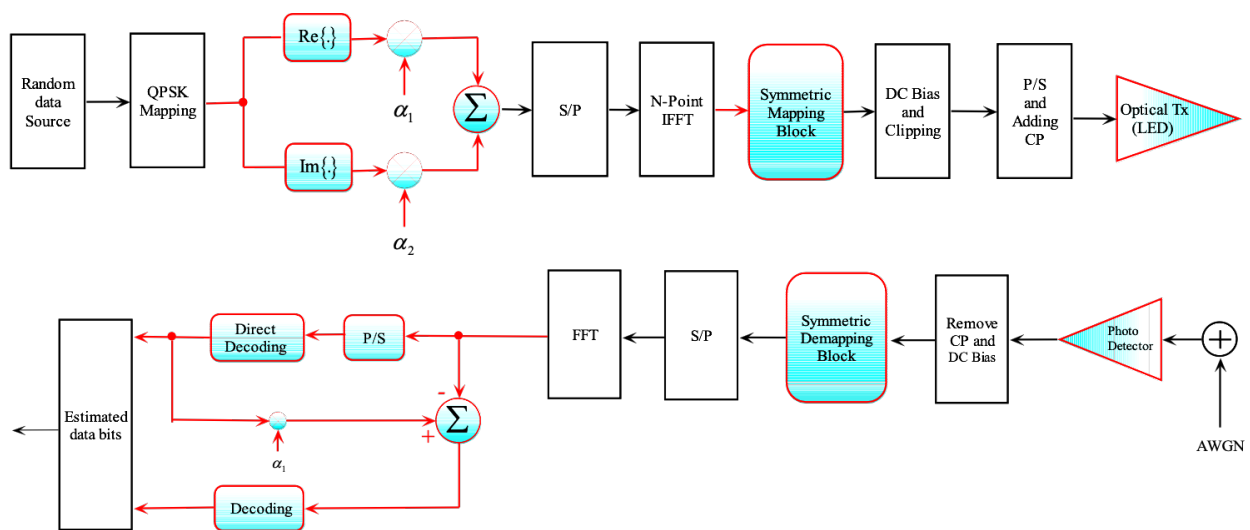


Fig. 2. The block diagram of the proposed NOA algorithm combined with FT scheme

Firstly, a random data source is used, this is followed by QPSK mapping, and separation of each part as a real and imaginary parts. The input to the IFFT block is grouped into two vectors, each of them has a length of N . By using the NOA algorithm, each vector is weighted with amount of the total power. Hence, the input to the IFFT block can also be written as follows:

$$Z_k = \sqrt{\alpha_1} \Re\{A_k\} + \sqrt{\alpha_2} \Im\{A_k\} \tag{10}$$

where A_k denotes the output component of QPSK which is complex value and $\alpha_i, i \in \{1, 2\}$ are the weights, which represent the percentage of the power amount assigned for each vector, $\alpha_1 + \alpha_2 = 1$, the values of α must be specified optimally with minimum BER performance, which discussed in

the simulation results and analysis section. Up to this point, the signal has been transformed to be real numbers. The output of the time domain sample points is:

$$z_n = \frac{1}{N} \sum_{k=0}^{N-1} Z_k \exp\left(\frac{j2\pi kn}{N}\right), \quad 0 \leq n \leq N - 1 \quad (11)$$

Based on the proposed FT, the output of the symmetric mapping block in Figure 2 can be formulated as:

$$y_n = \{\Re[z_0 z_1 \dots z_{N/2-1}], \Im[z_0 z_1 \dots z_{N/2-1}]\} \quad (12)$$

To ensure that all samples are nonnegative values a DC biasing and clipping process are applied. At the receiver side, the DC bias is removed, the received signal is formulated as:

$$Y_n = y'_n + w_n \quad (13)$$

In the recovery process, the received signal (Y_n) is divided in to two parts as:

$$\text{First part} = [Y_0 Y_1 \dots Y_{N/2-1}] \quad (14)$$

$$\text{Second part} = [Y_{N/2} Y_{N/2+1} \dots Y_N] \quad (15)$$

where, $Y_n \in \mathbb{R}^{N \times 1}$, the output of the real part and the output of the imaginary part are extended as:

$$\zeta_1 = [Y_0 Y_1 \dots Y_{N/2-1} \quad 0 \quad Y_{N/2-1} Y_{N/2-2} \dots Y_1 Y_0] \quad (16)$$

$$\zeta_2 = [Y_{N/2} Y_{N/2+1} \dots Y_N \quad 0 \quad -Y_N - Y_{N-1} \dots -Y_{N/2+1} - Y_{N/2}] \quad (17)$$

Now, the Equation (16), and (17) are combined as real and imaginary as:

$$\zeta = \zeta_1 + j\zeta_2 \quad (18)$$

Finally, the FFT block is applied followed as:

$$Q = \sqrt{\alpha_1} \Re\{A_k\} + \sqrt{\alpha_2} \Im\{A_k\} + w_n \quad (19)$$

Now, direct decoding is applied to recover the strong optimized vector as, which is corresponding to the terms $\sqrt{\alpha_1} \Re\{A_k\}$. In the proposed NOA algorithm, the SIC procedure will be used for recovery the transmitted data bits by subtracting Equation (19) from the direct estimated vector as shown in Figure. 2.

3. Results

In this section, the proposed schemes will be evaluated using the following simulation parameters of FFT size $N = 1024$, CP length 256, AWGN and ceiling bounce channel model and number of iterations is 1000. Figure 3(a) shows the amplitude of random BPSK symbols, and the corresponding amplitude after Hermitian symmetry for the conventional DCO-OFDM. Figure 3(b) shows the output

of IFFT and the clipped signal for conventional DCO-OFDM. Figure 3(c) shows the real and imaginary parts of the IFFT output using BPSK and Fig. 3d shows the transmitted signal for the proposed FT scheme. In comparison to the typical DCO-OFDM system that uses a diverse transform, Figure 3(e) displays the BER performance versus SNR of the proposed FT scheme.

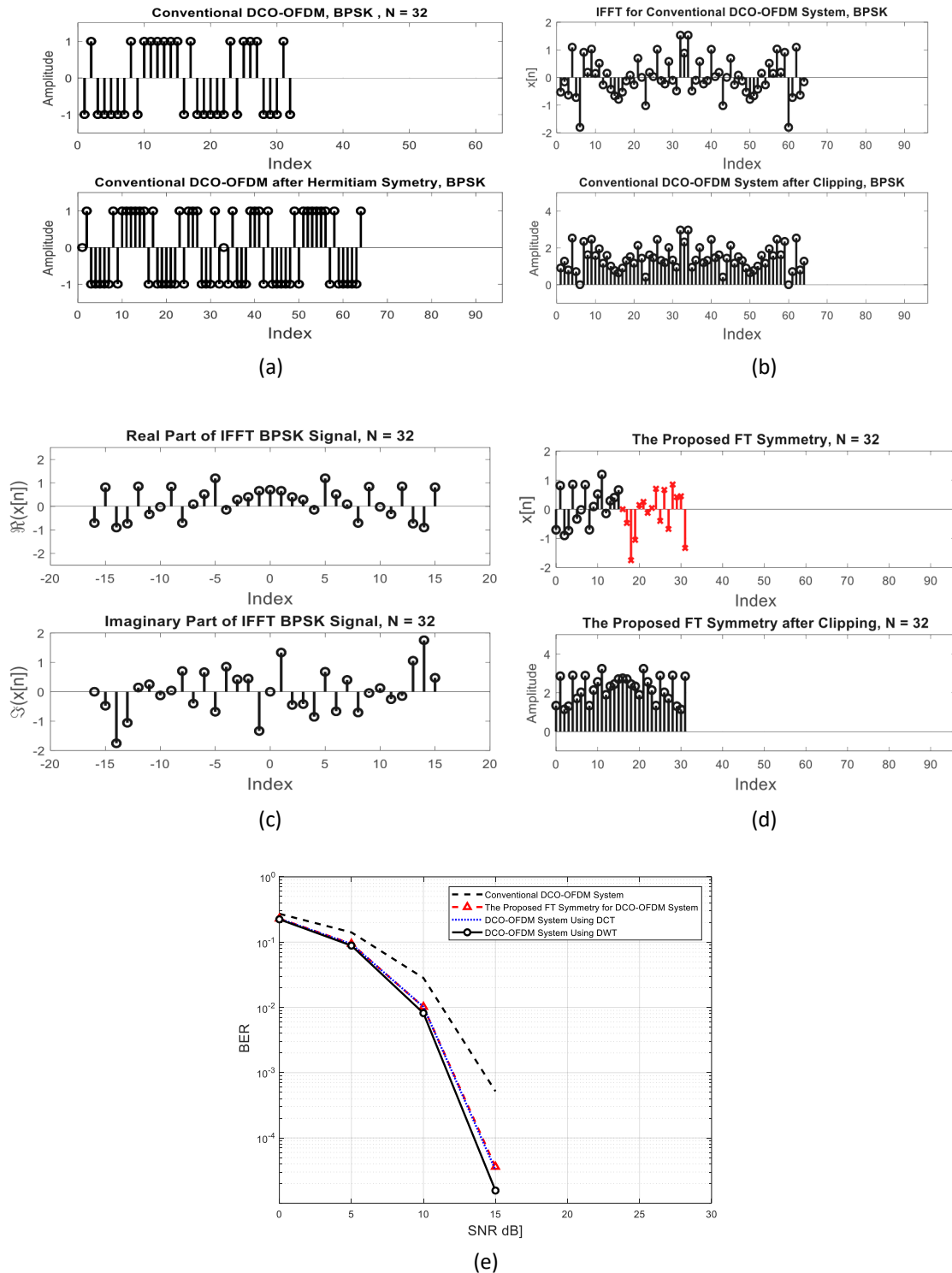


Fig. 3. (a) The output of BPSK scheme and the output of Hermitian symmetry for conventional DCO-OFDM (b) The IFFT output and the clipping output of the conventional DCO-OFDM for BPSK scheme (c) The real and imaginary parts output of IFFT using BPSK (d) The proposed FT symmetry output with/without clipping (e) The BER vs. SNR of different DCO schemes

It is clear from Figure 3(a) and Figure 3(b) that, the Hermitian symmetry leads to double the length of transmitted signal for the conventional DCO-OFDM systems to be suitable for transmission and Fig. 3b shows that the real part has an even symmetry, while the imaginary part has an odd symmetry. Finally, Figure 3(d) shows the operation of the proposed FT scheme with and without clipping, which ignores the second part of the real and imaginary parts output in Figure 3(c), and re-arrange the first part of the real and imaginary parts in successive arrange. In contrast to the traditional DCO-OFDM system, the suggested FT scheme's BER performance is improved by 3 dB, as can be seen in Figure 3e. The proposed NOA combined with FT symmetry for QPSK modulation scheme will be evaluated using several transforms NOA-FFT, NOA-DCT and NOA-DWT. The proposed NOA algorithm depends on the fractional power coefficient (α) so, the fractional power coefficient will be optimized to achieve minimum BER performance as illustrated in Figures 4(a), 4(b), and 4(c). As a result, the BER performance versus the SNR will be checked at these values as shown in Figure 4(d).

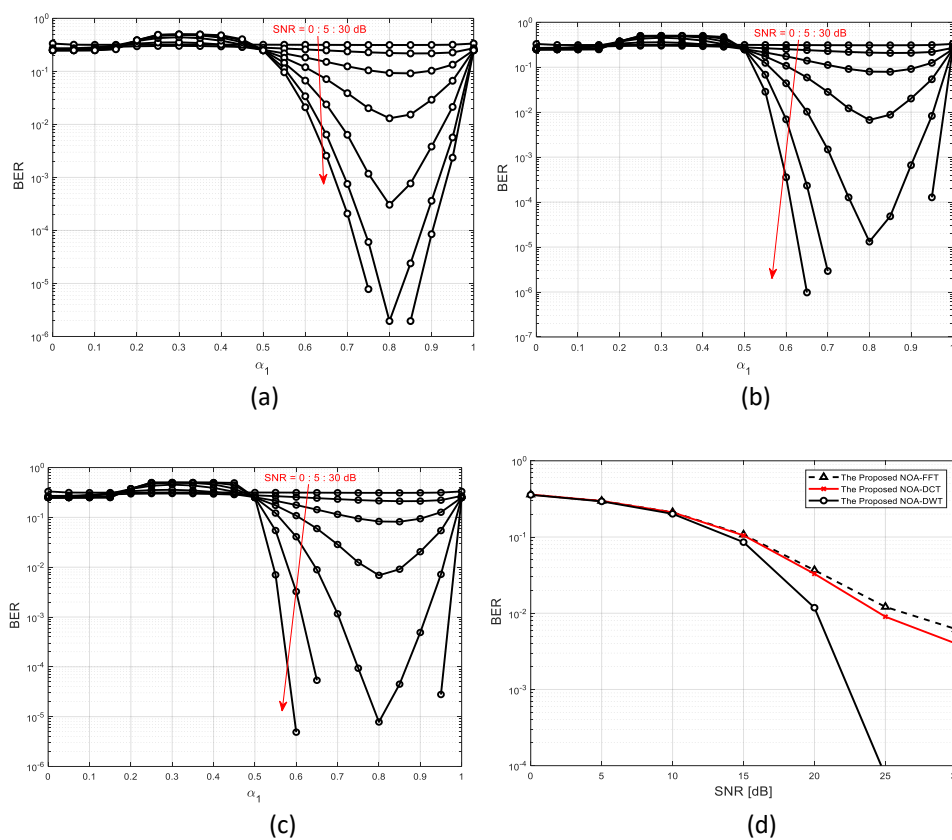


Fig. 4. The BER vs. fractional power coefficient (α_1) (a) NOA-FFT scheme (b) NOA-DCT scheme (c) NOA-DWT scheme. (d) The BER vs. SNR of different proposed NOA-DCO using different transforms

Figures 4(a), 4(b) and 4(c) of the proposed NOA-FFT, NOA-DCT and NOA-DWT show that the minimal BER performance can be achieved at fractional power coefficient of $\alpha_1 = 0.2$ and $\alpha_2 = 0.8$. Figure 4(d) shows the BER performance versus the SNR of the proposed schemes, which indicates that all the proposed scheme of NOA-DWT has an error free as the SNR is greater than 20 dB. As shown in the previous figure, the proposed NOA-DWT scheme outperforms the BER performance in comparison with traditional schemes. Finally, Figure 5 shows the power spectral density (PSD) of various DCO systems while Figure 6 shows the CCDF versus the PAPR of the proposed NOA schemes using different transforms. It is clear from Figure 5 that, the proposed schemes based on DCO NOA, and that of based on the FT symmetry gives a better characteristic than that of conventional DCO-

OFDM system in terms of the bandwidth requirements. It is clear from Figure 6 that the proposed NOA-DWT has lower PAPR than other proposed schemes, which gives a superiority of the use of DWT than other transforms.

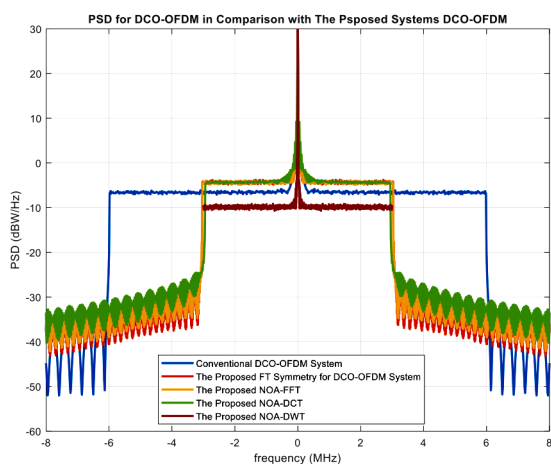


Fig. 5. The BER vs. SNR of different proposed NOA-DCO using different transforms

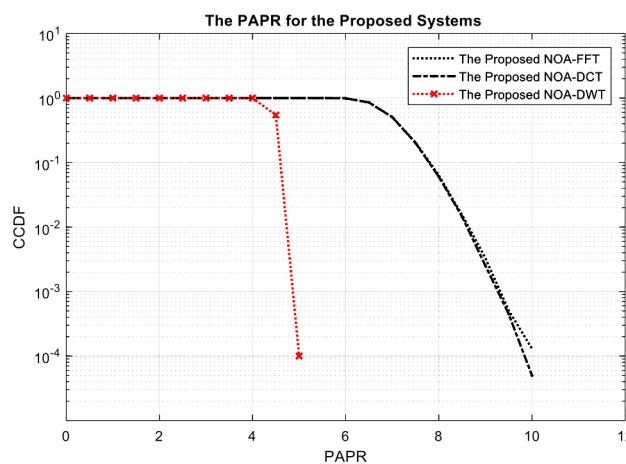


Fig. 6. The CCDF vs. the PAPR of different NOA-DCO systems using different transforms

4. Conclusions

In this study, we suggested various DCO-OFDM systems employing various transforms and contrasted them with the traditional DCO-OFDM system. In the proposed FT scheme, the symmetry property of the Fourier transformed for BPSK modulation scheme is applied, which directly doubles the length of the transmitted bits, doubling the system throughput over the conventional system. Hence, the proposed FT scheme may increase system complexity, which is the cost. For higher modulation order (i.e., QPSK), the NOA algorithm combined with the FT scheme is proposed. In the proposed NOA algorithm, the real and imaginary parts output of modulation scheme will be added together as real values using optimal parameters. Instead of the Fourier transform, the system is modulated in the second suggested section using various transforms such as DCT and DWT. These systems employ the same principle as the preceding suggested portion and modulated using QPSK modulation. The measure of performance is BER, PSD and PAPR. Last but not least, the proposed system exhibits a notable improvement in terms of BER, bandwidth consumption, and PAPR when compared to the traditional DCO-OFDM systems.

References

- [1] Index, Cisco Visual Networking. "Global mobile data traffic forecast update, 2016–2021 white paper." *Cisco: San Jose, CA, USA* 7 (2017): 180.
- [2] Jovicic, Aleksandar, Junyi Li, and Tom Richardson. "Visible light communication: opportunities, challenges and the path to market." *IEEE communications magazine* 51, no. 12 (2013): 26-32. <https://doi.org/10.1109/MCOM.2013.6685754>
- [3] Mohammed, Abdulwahid, Mohammed El-Bakry, Hassan Mostafa, and Abd El-Hady A. Ammar. "Doubling the number of connected devices in narrow-band internet of things while maintaining system performance: An stc-based approach." *arXiv preprint arXiv:2208.10112* (2022). <https://doi.org/10.48550/arXiv.2208.10112>
- [4] Khan, Latif Ullah. "Visible light communication: Applications, architecture, standardization and research challenges." *Digital Communications and Networks* 3, no. 2 (2017): 78-88. <https://doi.org/10.1016/j.dcan.2016.07.004>

- [5] Elbakry, Mohamed S., Amira A. Amer, and Tawfik Ismail. "Enhancing Performance of Downlink NOMA-Based C-RAN Topology through Optimal User Pairing and Dynamic Power Allocation Scheme." *IEEE Access* (2023). <https://doi.org/10.1109/ACCESS.2023.3322231>
- [6] Hesham, Hamis, and Tawfik Ismail. "Hybrid NOMA-based ACO-FBMC/OQAM for next-generation indoor optical wireless communications using LiFi technology." *Optical and Quantum Electronics* 54, no. 3 (2022): 201. <https://doi.org/10.1007/s11082-022-03559-1>
- [7] Swelam, W., N. Rashad, and M. H. Abd ElAzeem. "Millimetric Broadband Ankh Key Antenna for 5G Applications." *Journal of Advanced Research in Applied Mechanics* 42, no. 1 (2018): 7-11.
- [8] Yao, K. C., A. Moawad, Ali Mansour, and Roland Gautier. "Spectrum sensing by scattering operators in cognitive radio." *Journal of Advanced Research in Applied Mechanics* 45, no. 1 (2018): 13-19.
- [9] Hei, Yongqiang, Jiao Liu, Huaxi Gu, Wentao Li, Xiaochuan Xu, and Ray T. Chen. "Improved TKM-TR methods for PAPR reduction of DCO-OFDM visible light communications." *Optics Express* 25, no. 20 (2017): 24448-24458. <https://doi.org/10.1364/OE.25.024448>
- [10] Julia, Aidatul, Azlina Idris, Nur Asfarina Idrus, Kaharuddin Dimiyati, and Murizah Kassim. "Performance of PAPR for Different Modulation Technique Using Cluster Scrambling Codeword Shifting Technique in F-OFDM Systems." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 31, no. 2 (2023): 255-267. <https://doi.org/10.37934/araset.31.2.255267>
- [11] Sulong, Siti Maisurah, Azlina Idris, Darmawaty Mohd Ali, and Noorazlina Mohamid Salih. "Enhancement Cascaded Least Square of RLS and NLMS for Wireless Communication System." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 32, no. 2 (2023): 222-233. <https://doi.org/10.37934/araset.32.2.22233>
- [12] Elbakry, Mohammed S., Hamed F. Elshenawy, and Abdelhady A. Ammar. "Improved carrier frequency offset correction for OFDM systems based on type-2 Control loop." In *2014 31st National Radio Science Conference (NRSC)*, pp. 157-166. IEEE, 2014. <https://doi.org/10.1109/NRSC.2014.6835072>
- [13] El-Bakry, Mohammed S., Hamed F. El-Shenawy, and Abd El-Hady A. Ammar. "C16. Improved carrier frequency offset correction for OFDM systems based on dual bandwidth and clustered pilot tones." In *2015 32nd National Radio Science Conference (NRSC)*, pp. 229-239. IEEE, 2015. <https://doi.org/10.1109/NRSC.2015.7117835>
- [14] Elbakry, Mohamed S. "Performance Evaluation of Wireless Multi-Carrier (MC) Communication Systems." *arXiv preprint arXiv:2210.07243* (2022). <https://doi.org/10.48550/arXiv.2210.07243>
- [15] Jiang, Yufei, Yunlu Wang, Pan Cao, Majid Safari, John Thompson, and Harald Haas. "Robust and low-complexity timing synchronization for DCO-OFDM LiFi systems." *IEEE Journal on Selected Areas in Communications* 36, no. 1 (2017): 53-65. <https://doi.org/10.1109/JSAC.2017.2774419>
- [16] El-Bakry, Mohammed S., Hamed A. El-Shenawy, and Abd El-Hady A. Ammar. "A symbol time compression for ICI reduction in high mobility OFDM systems." In *2017 29th International Conference on Microelectronics (ICM)*, pp. 1-4. IEEE, 2017. <https://doi.org/10.1109/ICM.2017.8268816>
- [17] El-Bakry, Mohammed S., Hamed A. El-Shenawy, and Abd El-Hady A. Ammar. "A time inversion and symbol time compression (TI-STC) scheme for ICI cancellation in high mobility OFDM systems." In *2017 Japan-Africa Conference on Electronics, Communications and Computers (JAC-ECC)*, pp. 82-85. IEEE, 2017. <https://doi.org/10.1109/JEC-ECC.2017.8305779>
- [18] Afifi, Mohamed Yasin I., Mohamed S. Elbakry, El-Sayed SA Soliman, and A. A. Ammar. "An efficient technique for out-of-band power reduction for the eliminated cp-stc-shaped system for 5g requirements." *International Journal of Electrical and Computer Engineering* 10, no. 5 (2020): 5306. <https://doi.org/10.11591/ijece.v10i5.pp5306-5315>
- [19] Elbakry, Mohamed S., and Khaled Ramadan. "A time-mirroring (TM) scheme for ici mitigation in time-varying channel for digital video broadcasting (DVB) systems." *Telecommunications and Radio Engineering* 82, no. 3 (2023). <https://doi.org/10.1615/TelecomRadEng.2022037017>
- [20] Ramadan, Khaled, and Mohamed S. Elbakry. "Efficient equalization and carrier frequency offset compensation for underwater wireless communication systems." *Annals of Data Science* 9, no. 6 (2022): 1201-1221. <https://doi.org/10.1007/s40745-022-00449-x>
- [21] Elbakry, Mohamed S. "Performance Evaluation of Wireless Multi-Carrier (MC) Communication Systems." *arXiv preprint arXiv:2210.07243* (2022). <https://doi.org/10.48550/arXiv.2210.07243>
- [22] El-Mahallawy, Mohamed, and Adly Tag Eldien. "Performance enhancement of UWA-OFDM communication systems based on FWHT." *International Journal of Communication Systems* 32, no. 16 (2019): e3979. <https://doi.org/10.1002/dac.3979>
- [23] El-Mahallawy, Mohamed, Adly S. TagEldien, and Salah S. Elagoz. "Performance enhancement of underwater acoustic OFDM communication systems." *Wireless Personal Communications* 108 (2019): 2047-2057. <https://doi.org/10.1007/s11277-019-06508-6>

- [24] Mohamed, Salma D., Ivan Andonovic, Hossam MH Shalaby, and Moustafa H. Aly. "Performance of Optical OFDM Systems in Atmospheric Turbulence Channel." *Journal of Advanced Research in Applied Mechanics* 36, no. 1 (2017): 10-17.
- [25] Eltoukhi, Muhammed Abd El-Aziz, Mohammed Abd-Elnaby, Sami A. El-Dolil, and Fathi E. Abd El-Samie. "Efficient coding techniques for ado-ofdm in im/dd systems." *Photonic network communications* 36 (2018): 128-139. <https://doi.org/10.1007/s11107-018-0762-z>
- [26] Ramadan, Khaled, Basem M. ElHalawany, and Mohamed S. Elbakry. "Performance improvement for DCO-OFDM and ACO-OFDM systems using symbol time compression." *Telecommunication Systems* 84, no. 1 (2023): 77-100. <https://doi.org/10.1007/s11235-023-01027-z>
- [27] Zhou, Ji, Yaojun Qiao, Zhuo Cai, and Yuefeng Ji. "An improved scheme for Flip-OFDM based on Hartley transform in short-range IM/DD systems." *Optics express* 22, no. 17 (2014): 20748-20756. <https://doi.org/10.1364/OE.22.020748>
- [28] Ma, Shuai, Tiantian Zhang, Songtao Lu, Hang Li, Zhongwen Wu, and Shiyin Li. "Energy efficiency of SISO and MISO in visible light communication systems." *Journal of Lightwave Technology* 36, no. 12 (2018): 2499-2509.
- [29] Sobhy, Andrew, Shaimaa ElSayed, and Abdelhalim Zekry. "Enhancing the performance of optical VLC system based on asymmetric symmetric subcarriers OFDM." *International Journal of Communication Systems* 33, no. 10 (2020): e4226. <https://doi.org/10.1002/dac.4226>
- [30] Elbakry, Mohamed S., Abdulwahid Mohammed, and Tawfik Ismail. "Throughput improvement and PAPR reduction for OFDM-based VLC systems using an integrated STC-IMADJS technique." *Optical and Quantum Electronics* 54, no. 7 (2022): 418. <https://doi.org/10.1007/s11082-022-03802-9>
- [31] Mandyam, Giridhar D. "Sinusoidal transforms in OFDM systems." *IEEE Transactions on Broadcasting* 50, no. 2 (2004): 172-184. <https://doi.org/10.1109/TBC.2004.828375>
- [32] Gupta, Deepak, Vipin B. Vats, and Kamal K. Garg. "Performance Analysis of DFT-OFDM, DCT-OFDM, and DWT-OFDM Systems in AWGN Channel." In *2008 The Fourth International Conference on Wireless and Mobile Communications*, pp. 214-216. IEEE, 2008. <https://doi.org/10.1109/ICWMC.2008.66>
- [33] Zhang, Haixia, Dongfeng Yuan, Mingyan Jiang, and Dalei Wu. "Research of DFT-OFDM and DWT-OFDM on different transmission scenarios." *IEEE ICITA* (2004): 8-11.