An Intelligent Detoxification Function of Liver Algorithm-Partial Transmit Sequence (IDFLA-PTS) for the Reduction of Peak to Average Power Ratio in Underwater Acoustic OFDM Communication

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Abstract-Intelligent algorithms in artificial intelligence have brought several benefits to digital signal processing. The boom in machine learning and intelligent systems provides new perspectives and methods to solve many research problems in Underwater Acoustic (UWA) Orthogonal Frequency Divisional Multiplexing (OFDM) communication. Partial transmit sequence is a tremendous technique for the mitigation of high Peak-to-Average Power Ratio (PAPR) in OFDM communication systems, but finding the optimum phase factors has still a few problems. In this paper, a Partial Transmit Sequence (PTS) based on an Intelligent Detoxification Function of Liver Algorithm-Partial Transmit Sequence (IDFLA-PTS) is proposed for the mitigation of PAPR in the UWA OFDM communication systems. This algorithm reduces the PAPR and the complexity of the proposed UWA OFDM model. The IDFLA-PTS is also compared with the Genetic Algorithm-Partial Transmit Sequence (GA-PTS). Besides this, the Bit Error Rate (BER) performance of the IDFLA-PTS is shown when a High Power Amplifier (HPA) is used for the BELLHOP channel model. The experimental results of the proposed IDFLA-PTS method achieved nearly optimum results with fair complexity as compared to GA-PTS and boosted the BER performance.

Keywords-underwater acoustic communication; OFDM; PAPR; Intelligent Detoxification Function of Liver Algorithm-Partial Transmit Sequence (IDFLA-PTS)

I. Introduction

The research on OFDM has been explored due to its distinct advantages over other techniques for wireless communication systems [1, 2]. Due to its optimum results, now many kinds of research have taken steps in underwater communication and exploration [3]. For any communication network, a system should be noiseless, with less multipath delay, and with less Doppler shift [4]. Underwater Acoustic Sensing Networks (UWASNs) are formed by deploying different underwater acoustic transmitters and receivers which monitor the ocean. The battery deployed modems are installed, which consumes more power depending on its applications. For short-range communications this is not an issue, but for long-

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range UWA applications, it is necessary to save battery power. The OFDM system is utilized for high-speed communication, but due to its major drawback of PAPR, researchers have contributed a lot to mitigate it up to the maximum level. PAPR has bit error degradation and leads to nonlinear distortion and affects the power efficiency of power amplifiers in the underwater communication systems [5]. Therefore, the mitigation of PAPR has become a competitive and worth thinking research to have soft, reliable, and long-range communication in UWA communication. Linearly operating powerful amplifiers are needed for high peaks, but designing and manufacturing those powerful amplifiers is comparatively costly [6, 7].

A power amplifier is in the saturation region during high PAPR creating inter-symbol interference among subcarriers, manipulates thus the original signal resulting in lower BER performance. To avoid this scenario, the average power of the transmitting signal is reduced. But reducing the average power will lead to a reduction of BER performance as well as the Signal to Noise Ratio (SNR). However, to reduce the peak power of the signal, much research has been done previously [8-11]. Therefore, many researchers prefer to solve the problem of high PAPR by reducing the peak power of the transmitting signal. After experiments and simulations, many researchers have developed PAPR reduction methods like clipping, selective mapping, tone injection and reserved carriers, active constellation, coding, and partial transmit sequence [12-14]. Although clipping is the simplest technique, it clips the signals with unwanted peaks and distorts the communicating signal and increases BER. On the other hand, few techniques cause inefficient energy increment of the signal, such as tone injection, tone reservation, and active constellation. Selective mapping (SLM) is also an efficient technique having better performance than others, as it has no energy increment and it does not distort the communication signal, but it still is rather complex [15-17]. The PTS is the only efficient technique due to its distortionless feature with the least complexity. In this paper, we propose a PTS technique based on the Intelligent Detoxification Function of Liver algorithm (IDFLA) to minimize PAPR and acquire better performance than the GA-PTS system. The IDFLA is a self-efficacy algorithm that is extracted from medical science. It removes the toxic substances from the bloodstream and balances the hormonal level. Besides this, it breaks down fats and makes them more easily digestible.

II. RELATED WORK

A lot of work has been proposed to mitigate PAPR, but few researches have been found to use intelligent computing techniques. Therefore, the research on using various machine learning and deep learning algorithms still seeks attention for future generation networks. A few major articles are discussed below for both UWA OFDM communication networks and terrestrial networks. Authors in [18] proposed a novel method to reduce PAPR and nonlinear distortion at the receiver side using a machine learning algorithm. This method is named Frequentative Decision Feedback (FFB). This work was proposed for underwater acoustic OFDM communication. An energy-efficient underwater acoustic OFDM communication system was introduced in [19] without using any intelligent algorithm for the reduction of PAPR. The authors used PTS as a PAPR mitigation tool. An artificial bee colony-based SLM technique was proposed in [16]. The authors used selective mapping as a PAPR reduction technique. However, the computational complexity was too high. The Particle Swarm Optimization (PSO) method was used to mitigate the PAPR of the OFDM signal in [20]. This technique was based on adaptive PSO. This method also lacked in reducing the complexity of the overall system while searching the optimal combination of phase factors. Genetic Algorithm (GA) was proposed in [21-24] for PAPR mitigation. An efficient method using SLM Wavelet-OFDM (WOFDM) was used, which is based on a genetic machine learning algorithm. The optimum phase factors were searched using GA. In [25] the authors introduced a novel research, also based on GA. This technique performs well in reducing the peak signals in an OFDM system. The Tone Reservation (TR) method was used, which is based on the selection of the Peak Reduction Tone (PRT). However, finding an optimal PRT set of data is problematic, because the complexity of the system is increased exponentially while searching the PRT data set. This method also uses TR-based clipping which creates distortion and degrades the BER performance.

The current paper proposes a novel IDLFA approach with a lesser computational complexity. The proposed IDLFA-PTS based algorithm easily searches the optimum phase factors in PTS method and gives improved performance.

III. SYSTEM MODEL

The transmitted OFDM signal with N subcarriers in terms of the continuous-time domain can be expressed as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_k \, e^{j2\pi f_k t}, \;\; 0 \le t < NT \quad (1)$$

where $x(t)$ denotes the OFDM signal, f is the spacing of subcarriers, and NT indicates the data block interval, which carries useful information. The above equation can be written in terms of the discrete-time domain as:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi f_k n}, \;\; n = 0,1,\ldots,N-1 \quad (2)$$

Here, the PTS technique is utilized, which focuses on the discrete-time domain hence taking into consideration (2). The main drawback of the OFDM communication system is the varying high peaks. The varying power of such high peaks is much greater than the average power when the subcarriers are added after the modulation block. The PAPR is the resultant of the ratio of maximum transferred signal power (power of varying high peaks) to the average transferred power.

$$\mathrm{PAPR} = \frac{\max|x_n|^2}{E[|x_n|^2]} \quad (3)$$

The mathematically expected value of the OFDM signal can be defined by the E[.] operator. A function used to observe the overall performance of PAPR reduction is known as a Complementary Cumulative Distribution Function (CCDF), which is the most prominent way in the reduction of PAPR. Specifying PAPR(1) is higher than PAPR(0) (threshold level) and can be given as:

$$\mathrm{CCDF} = P(\mathrm{PAPR}(1) > \mathrm{PAPR}(0)) \quad (4)$$

$$\mathrm{CCDF} = 1 - (1 - e^{-\mathrm{PAPR}(0)})^{N} \quad (5)$$

In Figure 1, the bit-stream of digitally inserted inputs is mapped with the constellation. After QPSK modulation symbols are further divided into subcarriers of length N. These subcarriers are added in a serial to parallel converter block to convert them into parallel for fast computation. The Inverse Fast Fourier Transform (IFFT) is applied to reduce the computational complexity instead of the more complex Inverse Discrete Fourier Transform (IDFT). The signal is then passed through a parallel to serial conversion to transmit the generated signal serially. After adding a Cyclic Prefix (CP), the signal is transmitted through an underwater acoustic channel. The process at the receiver end is the reverse. After removing the cyclic prefix, the serial bit stream is modified into parallel form. The parallel moving data are then demodulated by Fast Fourier Transform (FFT). Hence, the resulted data are converted from the frequency domain to the time domain. Thus, the serial signal at the receiving end has been improved, which is then compared with the transmitted source generated signal.

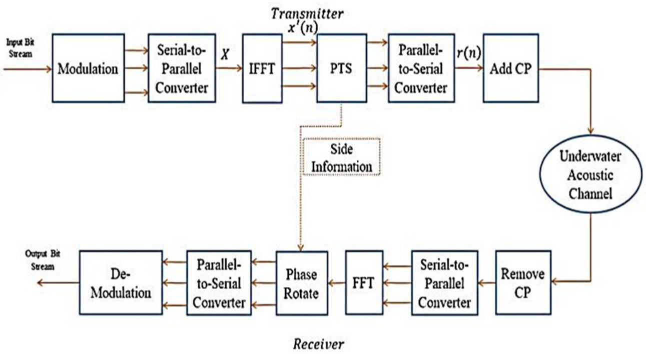

Fig. 1. Block diagram of the system model.

IV. PTS TECHNIQUE FOR PAPR REDUCTION

A block of input stream data N (Symbols) is sub-divided into M disjoint sub-blocks using the partitioning method denoted as:

$$X = \sum_{m=0}^{M-1} X^{m} \quad (6)$$

Generally, PTS has adopted 3 primary partitioning methods for the better reduction performance of PAPR, which are the interleaving scheme, the adjacent scheme, and the pseudo-random scheme. To choose less complex and best PAPR reduction performance, a pseudo-random scheme has been implemented in our proposed model. Sub-blocks are further oversampled by a factor of $(L-1)N$ zero paddings to estimate the value of PAPR in the continuous-time domain. IFFT is applied on the oversampled sub-blocks of size LN and transferred sub-blocks as:

$$X^{m} = [x_1{}^{m}, x_2{}^{m}, \ldots . x^{m}{}_{LN-1}] \text{ where } 0 \leq m \leq -1 \quad (7)$$

The n-th symbols of $x(n)$ signal can be generated by the product of the m-th sub-blocks (X^{m}) with phase factors (bm) and summed up after applying IFFT. The OFDM signal after the PTS technique of phase rotated sub-blocks with the lowest PAPR is:

$$x(n) = \sum_{m=0}^{M-1} bm\, X^{m} \quad (8)$$

where bm is the phase factor that can be defined as:

$$bm = [b_1, b_2, b_3, \ldots \ldots, b_{m-1}] = \arg\min\left(\max\left|\sum_{m-1}^{M} bm\, X^{m}\right|\right) \quad (9)$$

The partial transmit sequence is the IFFT of sub-blocks (X^{m}). The selection of phase factors is the real aim of the PTS scheme. But comprehensively finding the optimal phase factors suffer from exponential complexity, so the choice is very much limited to specific elements to reduce the phase factor (bm) complexity.

V. IDFLA FOR PTS

The IDFLA simulates the refining of blood and the maintenance of hormonal levels. The hepatic vein (a particular vein of the liver) carries alcohol and drugs to the liver for detoxification. Here nutrients are equivalent to phase factors. $b_i = [b_{i1}, b_{i2}, \ldots \ldots . b_{m-1}]$, where i is taken up to the maximum number of substances denoted by max Am, which represents the maximum substances carried out by the vein towards the liver. To obtain optimal nutrients (vitamins, i.e. B12), the hepatic vein carries out alcohol and drug substances, from which the liver utilizes vitamins and eliminates the toxic (waste) materials from the body. In IDFLA-PTS, the source of the nutrients in terms of phase factor can be expressed as:

$$X_{new} = \theta(X_{old} - X_{threshold}) \quad (10)$$

where $X_{threshold}$ is the threshold value up to which the liver controls the nutrients, X_{old} is the old value of substances for detoxification, and θ is the user-generated random variable within the specified limit of range taken as $\theta = [+1, \ldots . -1]$. The proposed IDLFA-PTS model is depicted in Figure 2.

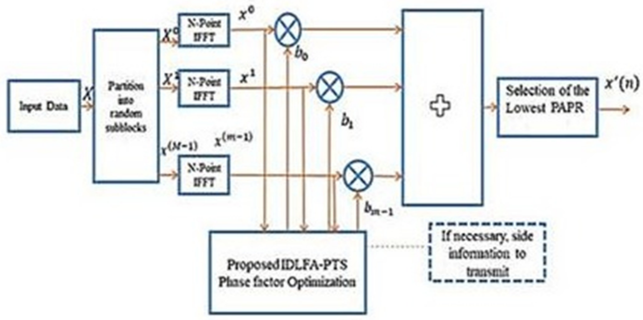

Fig. 2. Block diagram of the proposed IDFLA-PTS.

The optimal value defines the Beneficial Nutrients (BN) required for a healthy body and will be considered as the best solution. The BN in terms of mathematical form can be given as:

$$BN = \frac{1}{1+f}, \ldots \ldots, X_{new} \geq 0 \quad (11)$$

and it does not operate if $\{\mathrm{Halt}, \ldots, X_{new} < 0\}$ where X_{new} is the representation of the minimal expected value of PAPR in underwater acoustic communication. The liver collects all the substances to differentiate them with intelligent principles into beneficial nutrients and toxic substances, and then accepting the suitable nutrients according to their required level. The probability (Pr) of accepting nutrients is:

$$\text{Pr} = \frac{\text{acceptable nutrients}}{\text{summation of all acceptable nutrients}} \quad (12)$$

After accepting the nutrients, the liver looks for new alcoholic contaminated food and allows the food with nutrients. The liver repeats the whole detoxification process after some time in order to accept the remaining nutrients. An intelligent liver considers other substances as toxic and sends them to the waste part, and continues its function in order to maintain the health of the body.

$$\text{Possible BN} = (\text{Pr} \times X_{\text{old}}) - T_{\text{limit}-5} \quad (13)$$

$$\text{if value is } \geq \text{threshold}, \quad \text{then limit} = -5$$

$$\text{if value is } < \text{threshold}, \quad \text{then put limit} = 0$$

The steps defined are repeated in a continuous-time cycle to generate the possible beneficial nutrients. In the IDFLA-PTS algorithm, continuous-time cycle and possible beneficial nutrients are made to find the desired phase factors.

The steps of the proposed IDFLA-PTS algorithm are:

1. Set up the threshold value.
2. Take a random number θ within the specified range to generate a new phase factor.
3. Determine the best-fit phase factor by solving (11).
4. This value continues up to the given limit.
5. Go back to step 2 until the halt condition is not achieved. This process continues to generate the possible solutions.
6. New generated phase factor is calculated by (10) and the best fit is solved using (11).
7. Then the probability of beneficial nutrients can be achieved by (12).
8. Considering the remaining substance as toxic after multiple iterations, it starts the detoxification of new random contaminated food using (13).
9. The whole process is repeated until the beneficial nutrients for maintaining the health of the body are acquired.
10. Set and memorize the best fit values.

VI. SIMULATION AND EXPERIMENTAL RESULTS

In order to achieve optimum results of our proposed model, experiments were carried out in an underwater tank, while simulations were performed in MATLAB 2017b using the BELLHOP channel. The experiments in the water tank proved to have better results.

A. Simulations

In this section, simulation results and numerical analysis of the proposed IDFLA-PTS are given. The MATLAB version 2017b was used, the number of subcarriers during simulations in an underwater OFDM system is N=512, and QPSK modulation was employed. The Bellhop ray tracing communication channel was utilized. In the PTS technique, the partitioning is random. The number of sub-blocks was M = 128, 256, 512, along with W=4 selected phase factors. The phase factors became bm ∈ ±1. The PAPR in IDFLA-PTS and GA-PTS were compared and their comparison with different numbers of sub-blocks was conducted in terms of complexity. The best fit phase factor was chosen and then the sequence was generated as bm = [b1, b2, bm−1]. In GA-PTS, the selection of b is random. The parameters that are implemented in the simulation are given in Table I. Figure 3 illustrates the performance of PAPR in the original OFDM signal and IDFLA-PTS. In IDFLA-PTS, by considering the sub-block number M = [128, 256, 512]. The PAPR of the conventional OFDM signal can be observed in the Figure, which is 11.22dB when the CCDF of PAPR is 10^{-3}. The ideal exact IDFLA measurement is 7.4dB, while the observed PAPR of the proposed IDFLA-PTS with different sub-blocks, i.e. 128, 256, and 512 is 8.2dB, 7.7dB, and 7.59dB respectively. It is observed that taking a greater number of M (sub-blocks) decreases PAPR. The improved performance and PAPR comparison of IDFLA-PTS and GA-PTS with M = [128, 256, 512] sub-blocks are shown in Figure 4.

TABLE I. SIMULATION SYSTEM PARAMETERS

Serial number	Parameters	Data
1	Length of FFT points	8192
2	Number of subcarriers	512
3	Cyclic prefix time	21.56ms
4	Sound speed	1500m/s
5	Sampling frequency	96kHz
6	Signal modulation type	QPSK
7	OFDM symbol number	24
8	Modulation order	4
9	Up sampling rate	2
10	Maximum multipath delay	12ms
11	Bandwidth	6KHz

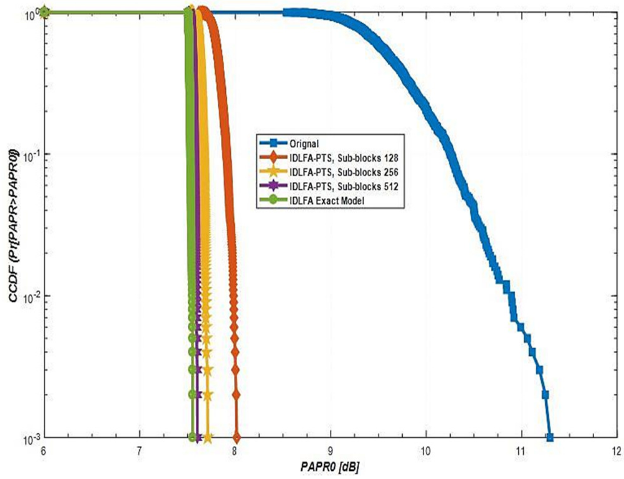

Fig. 3. PAPR comparison of IDFLA-PTS, exact IDFLA-PTS, and original OFDM signal.

The simulation of GA-PTS at M=2048 was an additional task in order to check the improved performance. After taking the mentioned sub-blocks, the PAPR values of GA-PTS were 8.62dB, 8.02dB, 7.65dB, and 7.5dB respectively. So, the difference in the PAPR of both methods for the same number of sub-blocks was 0.42dB, 0.32dB, and 0.06dB respectively. Concluding after the comparison, one can see that the performance of the proposed IDFLA-PTS method is better, faster, and more cost-effective, as it converges to 7.65dB at M=512, which has similar PAPR at M=2048 in the GA-PTS, i.e. 7.5dB, so the cost is decreased 4 times in the IDFLA-PTS method. In Table II, the PAPR of IDFLA-PTS and GA-PTS is illustrated with a different number of sub-blocks. The original signal has a PAPR of 11.2dB, while the optimum exact PAPR is 7.4dB.

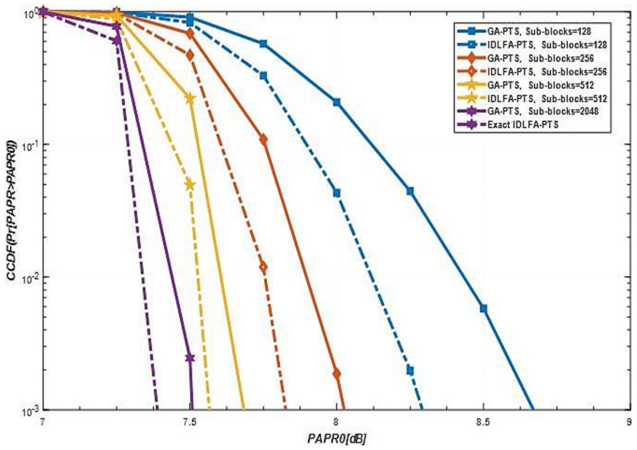

Fig. 4. PAPR comparison of IDFLA-PTS, GA-PTS, and exact IDFLA-PTS.

TABLE II. REDUCTION OF PAPR WITH IDFLA-PTS AND GA-PTS

PAPR reduction method	Number of sub-blocks	PAPR (dB)
IDFLA-PTS	128	8.2
IDFLA-PTS	256	7.7
IDFLA-PTS	512	7.55
GA-PTS	128	8.6
GA-PTS	256	8.02
GA-PTS	512	7.65
GA-PTS	2048	7.5

TABLE III. UWA BELLHOP CHANNEL SIMULATION PARAMETERS

Parameters	Processing Data
Surface height	100 m
Transmitter side depth, transducer (TX)	25 m
Receiver side depth hydrophone (RX)	40 m
Distance between TX and RX	3 km
Frequency range	8-12kHz

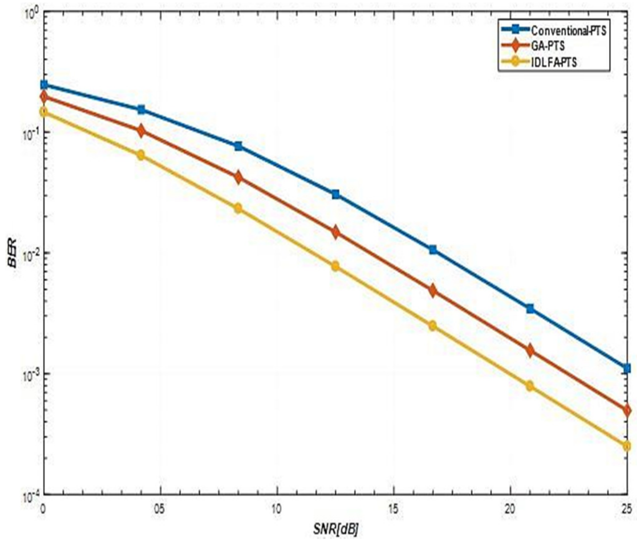

Fig. 5. Comparison of proposed IDFLA-PTS, GA-PTS, and conventional-PTS in terms of BER.

The parameters used in the Bellhop channel configuration are mentioned in Table III. In the simulation, the Bellhop channel is executed in MATLAB window containing all the features of shallow water. We supposed surface height (depth) of 100m, the transducer is dipped in water up to the depth of 25m, and the depth of hydrophone was kept at 40m while the distance of the hydrophone (RX) and transducer (TX) was 3km. For a better understanding of the proposed method, the BER vs. SNR of IDFLA-PTS with GA-PTS and conventional PTS are compared. The best-fit algorithm in UWA communication must produce less BER and higher SNR thus creating a better environment for communication. Figure 5 shows the BER performance over the range of SNR. It is observed that IDLFA-PTS has better performance than the traditional methods. The parameters mentioned in Table I are taken into consideration. The yellow line determines the BER curved line of the IDFLA-PTS method that has better performance than GA-PTS. The red curved line determines the BER of the GA-PTS. It is noticed that using the GA gave a slightly more BER. The blue curve shows the BER of the conventional-PTS. From Figure 5, it is clear that the proposed method IDFLA-PTS performs better with lower BER and higher SNR, which determines the best performance for an underwater and acoustic system..

B. Experiment

To observe the simulated idea of the proposed IDFLA model, we did experiments at Harbin Engineering University on the June, 1, 2020. The transducer (transmitter) and receiver (hydrophone) were placed at different depths (25m and 40m respectively) in a water tank. The distance between the hydrophone and transducer was 3km, which is similar to the simulation parameters. The experimental layout is shown in Figure 6, which portraits the experimental setup and the underwater acoustic tank channel.

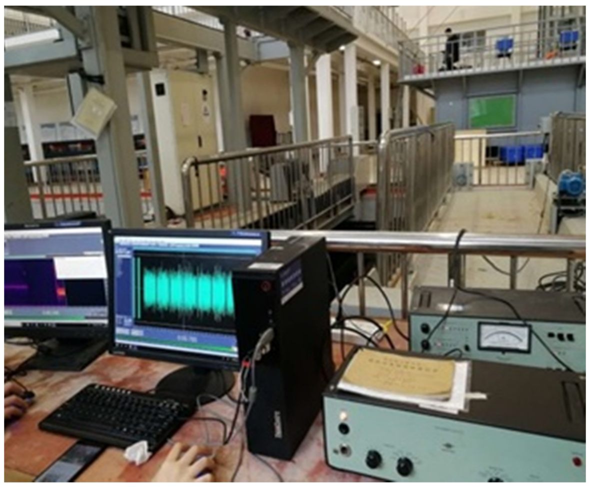

Fig. 6. Experimental setup in underwater acoustic tank channel.

The transmitter was connected with the computer via a power amplifier. The parameters given in Table I were employed in the experiments. The signal was generated from the signal generator and was transmitted through an underwater acoustic channel. After hitting the surrounding boundaries of the water tank, the acoustic signal creates various paths at the receiver side (multipath). When acoustic signals with different frequencies are transmitted, then peaks are overlapped, and high peaks are also observed which affects the performance of the signal's BER. For PAPR reduction, we introduced the IDFLA-PTS algorithm, which selects the optimum phase factors, and provides better BER performance. The transmission of the signal is efficient in the proposed method. During the signal transmission, multiple high peaks occurred in the underwater acoustic channel. The high peaks passed through the proposed algorithm block, where they were further calculated and informative peaks were reduced by the iterative process. In Figure 7, the impulse response of the underwater tank channel is illustrated. It is mainly relying on the sound speed, ranging from 1490m/s to 1500m/s. Hence, one can observe several time delays with normalized amplitude due to the nature of the UWA channel. The signal suffers from multipath when reaching the receiver side. Figure 8 shows the simulated and experimental BER curves of the proposed IDFLA-PTS algorithm. It is noted that the curves are close to each other with only a slight difference between them. This proves our method to be very feasible for practical applications.

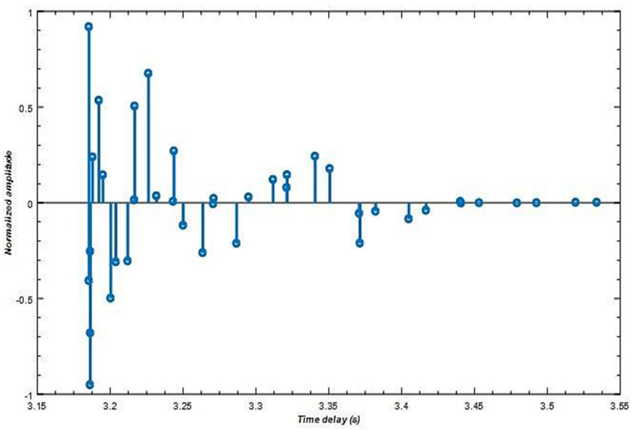

Fig. 7. Channel impulse response of the underwater tank with the IDFLA-PTS algorithm.

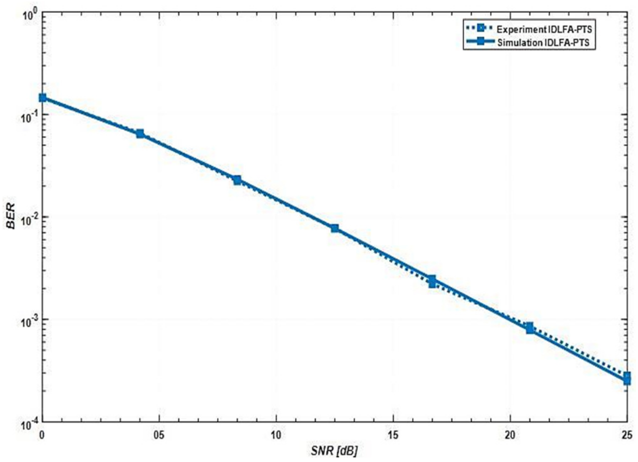

Fig. 8. BER comparison of the proposed IDFLA-PTS, simulation and experiment.

VII. Conclusion and Future Work

In this paper, the IDFLA-PTS is proposed for the UWA OFDM communication system. It is verified that the proposed method has better performance than other intelligent PAPR reduction techniques. The IDFLA algorithm is independent of other complex parameters that can affect in-band and out-band distortion. The proposed IDFLA-PTS method was compared with GA-PTS with varying number of sub-blocks and achieved optimum PAPR. It is concluded that the IDFLA-PTS method proved to be efficient, less complex, while it reduces PAPR with enhanced BER performance. The IDFLA-PTS algorithm can be implemented in the future for the reduction of PAPR with other methods in order to create a less complex and efficient UWA OFDM communication system.

Acknowledgments

This research was funded by the Natural Science Foundation of China (Grant No. U1809212), the Shandong Provincial Natural Science Foundation, China (Grant No. ZR2017MD019), the China Postdoctoral Science Foundation (Grant No. 2017M621248).

References

[1] S. Zhou and Z. Wang, *OFDM for Underwater Acoustic Communications*. New York, NY, USA: John Wiley & Sons, 2014.

[2] L. Y. X. Cheng, L. Yang, and X. Cheng, *Cooperative OFDM Underwater Acoustic Communications*. New York, NY, USA: Springer, 2016.

[3] E. M. Sozer, M. Stojanovic, and J. G. Proakis, "Underwater acoustic networks," *IEEE Journal of Oceanic Engineering*, vol. 25, no. 1, pp. 72–83, Jan. 2000, https://doi.org/10.1109/48.820738.

[4] X. Ma, T. Wang, L. Li, W. Raza, and Z. Wu, "Doppler Compensation of Orthogonal Frequency Division Multiplexing for Ocean Intelligent Multimodal Information Technology," *Mobile Networks and Applications*, vol. 25, no. 6, pp. 2351–2358, Dec. 2020, https://doi.org/10.1007/s11036-020-01609-0.

[5] J. Wu, G. Qiao, and X. Qi, "The Research on Improved Companding Transformation for Reducing PAPR in Underwater Acoustic OFDM Communication System," *Discrete Dynamics in Nature and Society*, vol. 2016, Apr. 2016, Art. no. e3167483, https://doi.org/10.1155/2016/3167483.

[6] S. Ding, S. Li, J. Liu, H. Wang, Z. Gu, and L. Gu, "A low complexity PTS algorithm for PAPR reduction in OFDM system based on hamming distance," in *14th International Symposium on Communications and Information Technologies*, Incheon, South Korea, Sep. 2014, pp. 499–502, https://doi.org/10.1109/ISCIT.2014.7011963.

[7] J. Han, S. Kim, K. Kim, S. Chun, and K. Son, "Design of OFDM System for High Speed Underwater Communication," in *International Conference on Computational Science and Engineering*, Vancouver, BC, Canada, Aug. 2009, vol. 2, pp. 988–992, https://doi.org/10.1109/CSE.2009.543.

[8] C. Lin and F. Yong, "A Novel PTS Scheme for PAPR Reduction in OFDM Systems Using Riemann Sequence," in *International Conference on Artificial Intelligence and Computational Intelligence*, Taiyuan, China, Sep. 2011, pp. 554–560, https://doi.org/10.1007/978-3-642-23887-1_71.

[9] A. Goel, P. Gupta, and M. Agrawal, "SER analysis of PTS based techniques for PAPR reduction in OFDM systems," *Digital Signal Processing*, vol. 23, no. 1, pp. 302–313, Jan. 2013, https://doi.org/10.1016/j.dsp.2012.08.018.

[10] M. Bala, M. Kumar, and K. Rohilla, "Low-Complexity PAPR Reduction of OFDM Signals Using Partial Transmit Sequence (PTS)," *International Journal of Engineering and Innovative Technology*, vol. 3, no. 11, pp. 144–147, 2014.

[11] Y. Y. Rahmatallah and S. Mohan, "Peak-To-Average Power Ratio Reduction in OFDM Systems: A Survey And Taxonomy," *IEEE Communications Surveys Tutorials*, vol. 15, no. 4, pp. 1567–1592, 2013, https://doi.org/10.1109/SURV.2013.021313.00164.

[12] R. J. Baxley, C. Zhao, and G. T. Zhou, "Constrained Clipping for Crest Factor Reduction in OFDM," *IEEE Transactions on Broadcasting*, vol. 52, no. 4, pp. 570–575, Dec. 2006, https://doi.org/10.1109/TBC.2006.883301.

[13] J. Wu, "Iterative Compressive Sensing for the Cancellation of Clipping Noise in Underwater Acoustic OFDM System," *Wireless Personal Communications*, vol. 103, no. 3, pp. 2093–2107, Dec. 2018, https://doi.org/10.1007/s11277-018-5897-9.

[14] X. Li and L. J. Cimini, "Effects of clipping and filtering on the performance of OFDM," in *47th Vehicular Technology Conference. Technology in Motion*, Phoenix, AZ, USA, May 1997, vol. 3, pp. 1634–1638, https://doi.org/10.1109/VETEC.1997.605835.

[15] B. M. Lee, Y. S. Rim, and W. Noh, "A combination of selected mapping and clipping to increase energy efficiency of OFDM systems," *PLOS ONE*, vol. 12, no. 10, 2017, Art. no. e0185965, https://doi.org/10.1371/journal.pone.0185965.

[16] X. Cheng, D. Liu, S. Feng, H. Fang, and D. Liu, "An artificial bee colony-based SLM scheme for PAPR reduction in OFDM systems," in *2nd IEEE International Conference on Computational Intelligence and Applications*, Beijing, China, Sep. 2017, pp. 449–453, https://doi.org/10.1109/CIAPP.2017.8167258.

[17] P. K. Sharma, R. K. Nagaria, and T. N. Sharma, "Power Efficiency Improvement in OFDM System using SLM with Adaptive Nonlinear Estimator," *World Applied Sciences Journal*, vol. 7, pp. 145–151, 2009.

[18] X. Ma, W. Raza, Z. Wu, M. Bilal, Z. Zhou, and A. Ali, "A Nonlinear Distortion Removal Based on Deep Neural Network for Underwater Acoustic OFDM Communication with the Mitigation of Peak to Average Power Ratio," *Applied Sciences*, vol. 10, no. 14, Jan. 2020, Art. no. 4986, https://doi.org/10.3390/app10144986.

[19] W. Raza, X. Ma, A. Ali, Z. A. Shah, and G. Mehdi, "An Implementation of Partial Transmit Sequences to Design Energy Efficient Underwater Acoustic OFDM Communication System," *International Journal of Computer Science and Information Security*, vol. 18, no. 4, pp. 19–26, Jul. 2020.

[20] A. A. Parandoosh, J. Taghipour, and V. T. Vakili, "A Novel Particle Swarm Optimization for PAPR Reduction of OFDM Systems," in *International Conference on Control Engineering and Communication Technology*, Shenyang, China, Dec. 2012, pp. 681–684, https://doi.org/10.1109/ICCECT.2012.174.

[21] M. S. El-Mahallawy, E. A. A. Hagras, and S. A. Fathy, "Genetic algorithm for PAPR reduction in SLM wavelet-OFDM systems," in *International Conference on Computer, Control, Informatics and Its Applications*, Bandung, Indonesia, Oct. 2014, pp. 136–140, https://doi.org/10.1109/IC3INA.2014.7042615.

[22] M. Lixia, M. Murroni, and V. Popescu, "PAPR reduction in multicarrier modulations using Genetic Algorithms," in *12th International Conference on Optimization of Electrical and Electronic Equipment*, Brasov, Romania, May 2010, pp. 938–942, https://doi.org/10.1109/OPTIM.2010.5510543.

[23] E. Giacoumidis, X. Q. Jin, A. Tsokanos, and J. M. Tang, "Statistical Performance Comparisons of Optical OFDM Adaptive Loading Algorithms in Multimode Fiber-Based Transmission Systems," *IEEE Photonics Journal*, vol. 2, no. 6, pp. 1051–1059, Dec. 2010, https://doi.org/10.1109/JPHOT.2010.2092422.

[24] A. Ali, B. Chen, W. Raza, A. H. Samo, and A. Ali, "Reduction of PAPR by Convolutional Neural Network with Soft Feed-back in an Underwater Acoustic OFDM Communication," in *International Bhurban Conference on Applied Sciences and Technologies*, Islamabad, Pakistan, Jan. 2021, pp. 899–904, https://doi.org/10.1109/IBCAST51254.2021.9393026.

[25] Y. Wang, W. Chen, and C. Tellambura, "A PAPR Reduction Method Based on Artificial Bee Colony Algorithm for OFDM Signals," *IEEE Transactions on Wireless Communications*, vol. 9, no. 10, pp. 2994–2999, Oct. 2010, https://doi.org/10.1109/TWC.2010.081610.100047.

[26] W. Raza, X. Ma, A. Ali, A. Ali, A. Raza, and S. Shaikh, "Performance Analysis of Selective Mapping in Underwater Acoustic Orthogonal Frequency Division Multiplexing Communication System," *Engineering, Technology & Applied Science Research*, vol. 11, no. 1, pp. 6696–6702, Feb. 2021, https://doi.org/10.48084/etasr.3941.

[27] Y. Wang, W. Chen, and C. Tellambura, "Genetic Algorithm Based Nearly Optimal Peak Reduction Tone Set Selection for Adaptive Amplitude Clipping PAPR Reduction," *IEEE Transactions on Broadcasting*, vol. 58, no. 3, pp. 462–471, Sep. 2012, https://doi.org/10.1109/TBC.2012.2191029.

[28] J. Jake, E. Mwangi, and K. Langat, "Spectral Re-Growth Suppression in the FBMC-OQAM Signal Under the Non-linear Behavior of a Power Amplifier," *Engineering, Technology & Applied Science Research*, vol. 9, no. 5, pp. 4801–4807, Oct. 2019, https://doi.org/10.48084/etasr.3097.

[29] A. Elsanousi and S. Ozturk, "Performance Analysis of OFDM and OFDM-MIMO Systems under Fading Channels," *Engineering, Technology & Applied Science Research*, vol. 8, no. 4, pp. 3249–3254, Aug. 2018, https://doi.org/10.48084/etasr.2209.

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