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Original Article

A Novel PTS-SIGWO Algorithm for Minimization of PAPR in FBMC/OQAM System

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Abstract - *The orthogonal frequency division multiplexing (OFDM) method was the most well-known and attractive technique utilized in wireless communication for large-scale data transfer at a high rate. OFDM has been widely employed as a more effective multicarrier modulation approach in various radio frequency wireless communication standards. But the drawback of OFDM is high Peak-to-Average Power Ratio (PAPR) and low Bit Error Rate (BER) performance. These problems can be overcome using a multicarrier filter bank with an offset quadrature amplitude modulation (FBMC/OQAM) system. For PAPR minimization in high-speed wireless communication systems, effective approaches are required. An effective technique to lower the PAPR is partial transmit sequence (PTS). In this paper, a PTS based on the Swarm Intelligence Grey Wolf Optimization method (PTS-SIGWO) is suggested and used in the FBMC/OQAM system to minimize the PAPR and increase the BER performance. In this paper, the subcarrier phase factor search in the PTS technique is enhanced by implementing a meta-heuristic algorithm called GWO. The suggested GWO achieves nearly optimal performance with a less number of iterations by balancing the exploration and exploitation phases when searching for peak power carriers. The simulation results are generated using the MATLAB tool. The results of the suggested technique demonstrate that PAPR and computational complexity have been effectively reduced, and BER performance has increased compared to other techniques. The proposed method has a PAPR of 3.3dB; other methods require more than 4dB to achieve a CCDF of 10^{-3}.*

Keywords - *BER, FBMC, GWO, OQAM, PAPR, PTS, SIGWO, Spectral efficiency.*

1. Introduction

Orthogonal frequency division multiplexing (OFDM), which has a significant spectral efficiency (SE), flexibility on a multipath fading channel, a high data transmission rate, and minimal intersymbol interference(ISI), has emerged as a successful strategy in the modern era [1]. Its multi-carrier technology contributes to its excellent bandwidth efficiency. By dividing the bandwidth into a number of orthogonal sub-carriers, the impact of multi-path fading and delay is decreased [2]. OFDM is regarded as an effective modulation technology in wireless communication systems, including IEEE 802.16 wireless metropolitan area networks, digital audio broadcasting, IEEE 802.11 wireless local area networks, and digital video broadcasting [3-4]. The limited Radio Frequency (RF) spectrum created by the increasing number of Wireless applications is not enough to meet future demand for service. Due to its minimal complexity, simple equalization, and implementation of SE, OFDM is used in wireless systems to accomplish data transfer at a high rate [5] due to the multi-carrier structure of OFDM signals, which have a very high Peak-to-Average Power Ratio (PAPR). When used in nonlinear High Power Amplifiers (HPA), clipping the OFDM signal due to high PAPR results in performance degradation. OFDM transmitters need costly linear HPA with a broad dynamic range [6]. A significant amount of a communication system's energy expenses relate to the base station with HPA. For multi-carrier transmission in OFDM, HPA energy efficiency is associated with the PAPR of the input signal is essential. Wavelet transforms, or Fast Fourier Transform (FFT), can be used to implement OFDM. The problem with OFDM is high PAPR. Due to the distortion produced by the nonlinear properties of both the ADC and the HPA, the high PAPR limits its capabilities [7]. Therefore, it is essential to lower the PAPR of OFDM signals. The literature has reported on a number of methods for reducing PAPR. FBMC/OQAM can be used to overcome the problems of OFDM. The FBMC/OQAM has minimal inter-carrier interference (ICI) and ISI. FBMC/OQAM is a good choice for 5G multicarrier transmission systems due to these benefits. High PAPR is one of the drawbacks of FBMC/OQAM. When a signal with a large PAPR is transmitted through the power amplifier at the transmitting side, it enters a nonlinear region where signal distortion is simple to produce, which increases the system's Bit Error Rate (BER) and lowers system performance [8].

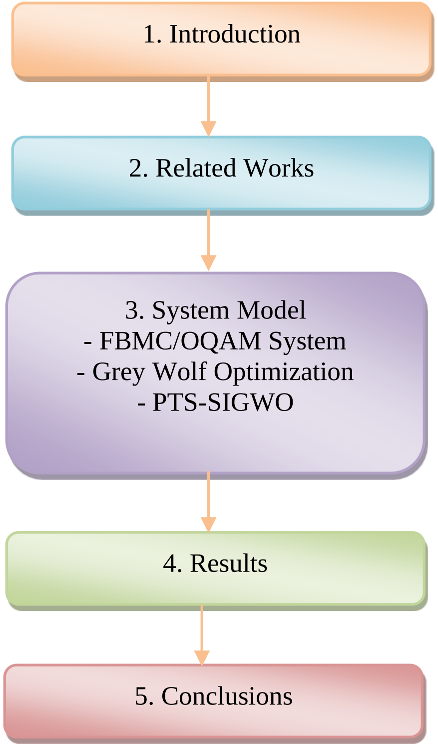

Fig. 1 Paper organization

As a result, lowering the PAPR is important to reduce the cost of the FBMC/OQAM system. Due to the overlap between the adjacent FBMC/OQAM signals, researchers have suggested a few solutions to the PAPR issue for FBMC-OQAM. Selective mapping (SLM), partial transmit sequence (PTS), and tone reserve(TR) are a few of the techniques. However, these extended/joint schemes include the benefits of the basic PAPR reduction methods and can perform better.

Muller and Huber first suggested PTS in 1997. To lower the PAPR of the signal, the approach is to split the input data blocks into a number of sub-blocks in a certain form, perform phase weighting and combining processing on the sub-blocks, and then choose a group of symbols with the lowest PAPR for transmission [9]. PTS is the most extensively researched PAPR reduction method because it effectively reduces PAPR in the FBMC system. However, the conventional PTS approach cannot be applied directly to the FBMC/OQAM system because of the overlapped arrangement of adjacent data blocks. Therefore, a number of researchers have modified PTS to lower the PAPR of the FBMC/OQAM system. The major goal of this research is to examine the best PAPR method and evaluate its performance compared to other methods. In this paper, we propose a novel PTS-SIGWO to lower the PAPR in FBMC/OQAM system while ensuring that the new method does not add any distortion or out-of-band(OoB) radiation. The suggested method achieves nearly optimal performance with a less number of iterations by balancing the exploration and exploitation phases when searching for peak power carriers. The proposed method provides low computational complexity, low PAPR and good BER performance. The paper organization is represented in figure 1.

2. Related Works

A wireless application must have a high data rate to work properly, and carrier modulation is utilized to achieve the trade-off. Some studies have focused on using optimization approaches to improve FBMC/OQAM efficiency. This section examined significant and recent studies on optimization in FBMC/OQAM. Bi-layer partial transmission sequence based on a genetic algorithm (GA-BPTS) is suggested in [10]. It employs a GA for searching for suboptimal phase factors in the double-layer PTS structure. The system's computational complexity can be extremely lowered, and its PAPR is not too high. In [11], PTS with DFT spreading was suggested lower the PAPR. The outcomes indicate that the PAPR performs better than conventional techniques. However, it has a low spectrum efficiency and high complexity. An overlapped PTS (OPTS) with the artificial bee colony (ABC) method was presented in [12]. Converting the PTS scheme to an OPTS scheme and employing the ABC method provide better PAPR and reduce the system's computing cost. The sparse partial transmission Sequence (sparse PTS) approach described in [13] directly optimizes the position of the observed signal peak. The tone reservation (TR) technique is then used to lower PAPR. In [14], a low-complexity hybrid processing technique based on PTS (H-PTS) was presented. This algorithm processed the phase factor of PTS using a two-layer search and, in order to minimize computational complexity, used an effective algorithm for estimating the PAPR value. Improved bi-layer partial transmit sequence and iterative clipping and filtering (IBPTS-ICF) approach in [15] substantially reduced the PAPR of FBMC/OQAM signal by combining PTS with nonlinear clipping and filtering techniques. However, the IBPTS-ICF becomes more complex as the number of sub-blocks increases. In order to decrease PAPR and signal distortion segmental PTS (S-PTS) method is explained in [16]. In this, spitting the overlapping signal into multiple segments, multiplied by various phase rotation factors in each segment, and reduced interference by adding zero value. A PTS-based Multi block for joint optimization dynamic programming (MBJO-PTS-DP) is represented in [17]. The PAPR of the FBMC was greatly lowered with this technique, although it had a high computational cost. [18] presented a PTS-based method that revised the multiplied phase sequence. Hybrid SLM-PTS was added to the approach to improve PAPR reduction. The hybrid SLM–PTS was added by Discrete Hartley transform (DHT) to resolve the computational complexity, but there is no improvement in BER performance. [19] combined phase vectors with the swarm intelligence method firefly optimization to produce the phase optimization technique. The PTS approach did not produce a better trade-off between complexity and PAPR minimization for many sub-blocks. A hybrid approach for FBMC/OQAM systems

PAPR reduction based on SLM and PTS was suggested in[20]. An artificial bee colony(ABC) technique was used to minimize the computing cost. In [21], the conventional TR method with deep clipping to eliminate the peaks of FBMC/OQAM signals without reducing the performance of BER and performance in PAPR reduction was improved. Iterative filtering and an effective companding transform approach were used in [22] to examine the improvement of PAPR in FBMC/OQAM signals. The suggested approach provided better results regarding PAPR reduction and computing complexity and was free from OOB radiation. To reduce the high PAPR in FBMC/OQAM, a PTS-based technique was represented in [23]. The proposed method reduces the peak power and complexity. [24] suggested a flat-top window with a Slepian basis and a harmonious kernel adaptive window for noise removal and orthogonal preservation. The suggested approach resolves the spectrum efficiency, bandwidth complexity, computational complexity, and date rate issues.

The model's BER was decreased by windowing and the adaptive clipping approach. The approached model is more effective than other methods. To reduce search complexity, [25] presented a hybrid GA in PTS. The salient phase factor was essential to the suggested approach to lower high PAPR. When optimizing OFDM signals, the suggested approach is more efficient than the conventional optimization algorithm. For the purpose of reducing PAPR, [26] implemented concurrent independent and independent. The joint optimization approach is more successful than the conventional method and effectively lowers the PAPR method by an appropriate threshold. [27] implemented the PTS technique and the discrete version of the Invasive Weed Optimization (DIWO) algorithm. In the discrete phase, the phase sequences are optimized using the DIWO technique, and the DIWO-PTS approach provides a better result with more iterations. The PTS-DPSO-TH approach was used in [28]. The PAPR of the system is decreased using the DPSO approach, and the number of iterations is decreased using a threshold. The BER performance increases. [29] suggested a PTS and meta-heuristic optimization approach for improving phase factors. The Grey Wolf Optimization (GWO) increased the system's effectiveness. The PTS phase factor component contributed to reducing the signal's peak power problem. In order to find sub-carriers, the modulation was three times oversampled. The suggested approach provides better performance than other techniques.

3. System Model

3.1. FBMC/OQAM System

The FBMC method was first presented in the 1960s. The FBMC is an advancement on OFDM [30]. FBMC is the most effective for future wireless communications among the several multi-carrier modulation techniques. The FBMC/OQAM transceiver is shown in Figure 2. OFDM and FBMC/OQAM can be implemented quickly using the FFT algorithm. Fast implementation schemes of FBMC/OQAM include Frequency Spreading-FFT (FS-FFT) and Poly Phase Network-FFT (PPN-FFT). PPN-FFT is less complex than FS-FFT because it suppresses ISI efficiently without using frequency expansion and CPs. In this case, PPN-FFT is used to implement FBMC-OQAM quickly. After channel coding and symbol mapping, symbols are modulated using OQAM. Subcarriers are kept orthogonal through OQAM preprocessing [34]. During OQAM preprocessing, complex symbols are processed both in real and imaginary parts, and half a symbol period is interlaced within a time interval so that transmission symbols are formed. Subcarriers are formed by dividing a delay into real and imaginary parts. At sampling time, all neighboring subcarriers have orthogonal distribution [30]. After performing IFFT on the transmission symbols, the Prototype Filter(PF) banks with various offsets are filtered. The modulation of fast multi-carrier technology is then realized by superimposing and transmitting the synthesized signals in the time domain.

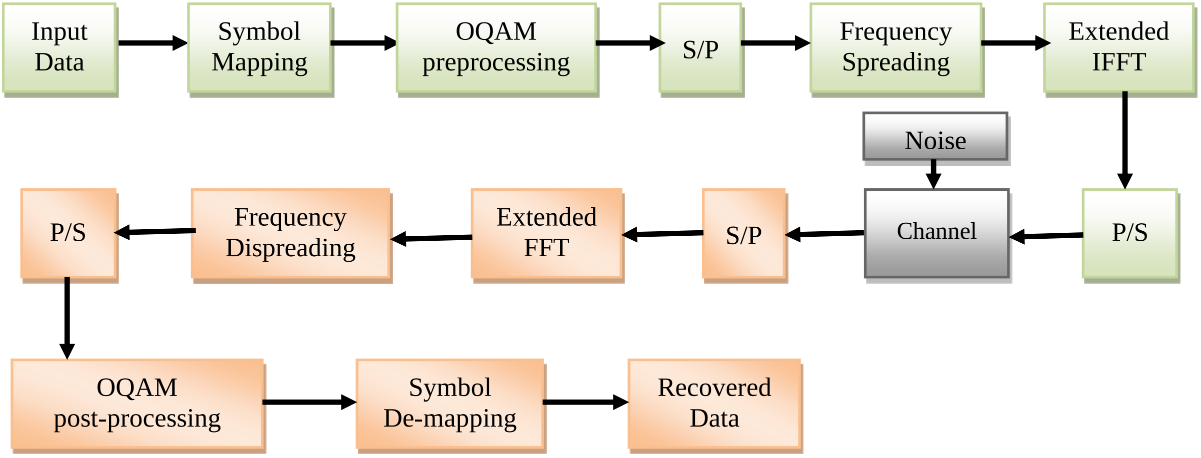

Fig. 2 FBMC/OQAM block diagram

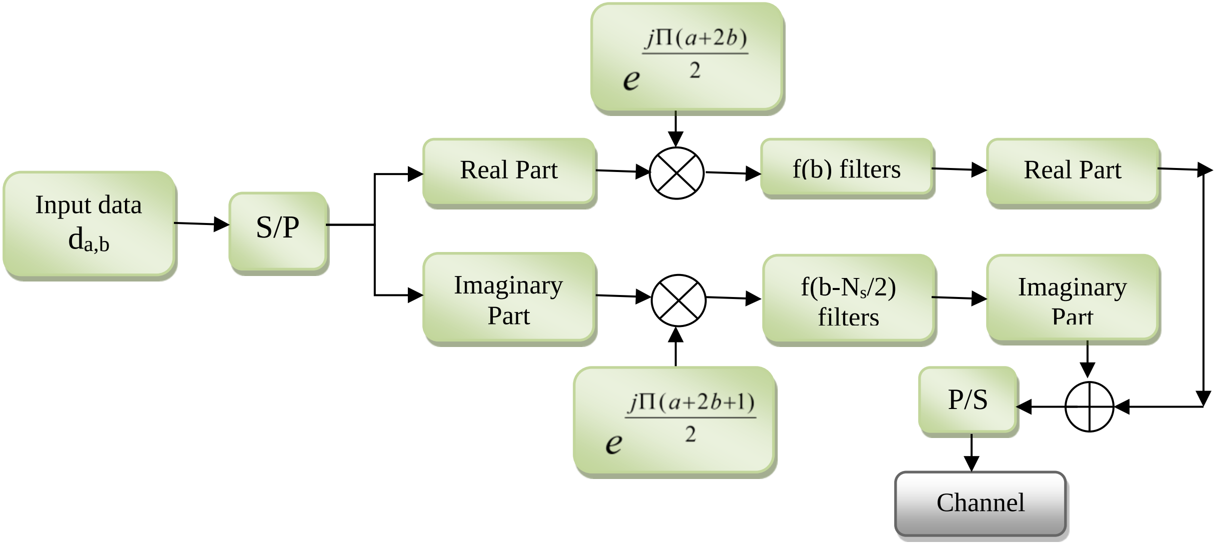

Fig. 3a FBMC/OQAM Transmitter

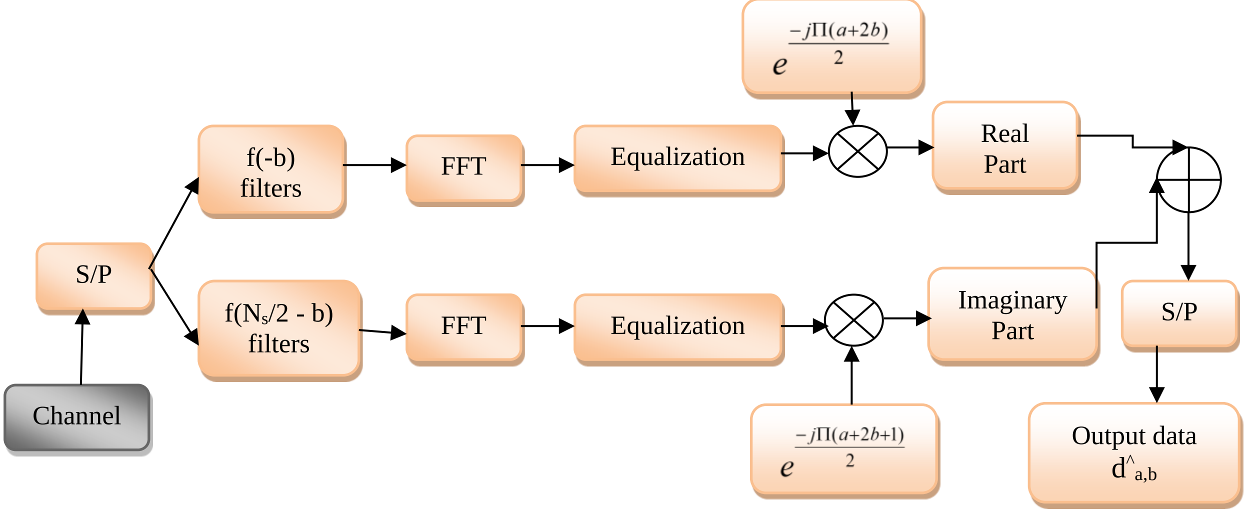

Fig. 3b FBMC/OQAM receiver

Additionally, a set of symmetrical PFs are used, which work similarly to the transmitter's PF banks. First, PF banks with various offsets filter the original signal. This signal is then reconstructed using FFT and OQAM. In OQAM, the real portion of the signal modulated to the subcarrier is taken, and it is then rebuilt into the complex signal by mutually converting the real and complex numbers. The system block diagram for FBMC/OQAM, which utilizes the FFT/IFFT of OFDM, is represented in Figure 3.

Consider $d_{a,b}(t)$ are the complex transmitted symbols at a^{th} subcarrier in the b^{th} symbol and the shape of each subcarrier using well-localized transmitted PF is $f_{a,b}(t)$, then the FBMC/OQAM signal can be represented as :

$$x(t) = \sum_{a=0}^{N_c-1} \sum_{b=0}^{N_s-1} d_{a,b}(t) f_{a,b}(t) \quad (1)$$

Where

$$f_{a,b}(t) = f(t - n\tau_{ri}) e^{j2\Pi a\varepsilon t} e^{j\theta_{a,b}} \quad (2)$$

Here the number of subcarriers is N_c, the number of symbols is N_s, the PF function is *f(t)*, the time period between the imaginary and real is τ_{ri}, the interval between adjacent subcarriers is $\varepsilon = \frac{1}{2\tau_{ri}} = \frac{1}{T_s}$, the period of the symbol is T_s and phase factor is $\theta_{a,b}$ is given by

$$\theta_{a,b} = \frac{(a+b)\Pi}{2} - ab\Pi \quad (3)$$

The expression for the product of the transmitting and receiving filters is

$$\langle f_{a,b}(t), f_{p,q}(t) \rangle_{\Re} = \Re\{\int_{-\infty}^{\infty} f_{p,q}^{*}(t) f_{a,b}(t) dt\} \quad (4)$$

$$= \Re\left\{\int_{-\infty}^{\infty} f^{*}(t - \tau_{ri} q) f(t - \tau_{ri} b) e^{j\varepsilon t 2\Pi(a-p)} e^{\frac{j\Pi(a-p+b-q)}{2}} dt\right\} \quad (5)$$

It is possible to restore the outgoing signal accurately when the basis function $f_{a,b}(t)$ meets the orthogonal condition in Equation (6).

$$\langle f_{a,b}(t), f_{p,q}(t)\rangle_{\Re} = \delta_{a,p}.\delta_{b,q} \tag{6}$$

where δ indicates the impulse function and it is given by

$$\delta_{a,b} = \begin{Bmatrix} 1; a = b \\ 0; a \neq b \end{Bmatrix} \tag{7}$$

The discrete-time domain expression for FBMC/OQAM signal is

$$x(k) = \sum_{a=0}^{N_c-1} \sum_{b=0}^{N_s-1} d_{a,b}(k)\, f\left(k - \frac{bN_c}{2}\right) e^{j\theta_{a,b}} e^{\frac{j2\Pi a\left(k-\frac{N_l-1}{2}\right)}{N_c}} \tag{8}$$

Where

$$f_{a,b}(k) = f\left(k - \frac{bN_c}{2}\right) e^{j\theta_{a,b}} e^{\frac{j2\Pi a\left(k-\frac{N_l-1}{2}\right)}{N_c}} \tag{9}$$

Here, the PF length is N_l. The discrete-time domain expression for FBMC/OQAM signal can also be represented as :

$$x(k) = \sum_{b=0}^{N_s-1} s_b(k) \tag{10}$$

$$x_b(k) = \sum_{a=0}^{N_c-1} d_{a,b}\,(k) f\left(k - \frac{bN_c}{2}\right) e^{j\theta_{a,b}} e^{\frac{j2\Pi a\left(k-\frac{N_l-1}{2}\right)}{N_c}} \tag{11}$$

Here $x_b(k)$ is b^{th} data block signal. High PAPR is one of the main drawbacks of the FBMC system. Utilizing FBMC, complex symbols are modulated at several subcarriers and produce a high PAPR. A PAPR can be calculated by dividing peak power by average power.

The PAPR can be expressed as :

$$PAPR = \frac{Peak\ Power}{Average\ Power} \tag{12}$$

$$PAPR_n = \frac{Max|x(t)|^2}{E[|x(t)|^2]} \tag{13}$$

$$PAPR_{dB} = 10.log_{10}(PAPR) \tag{14}$$

To measure PAPR performance, the FBMC/OQAM system uses the complementary cumulative distribution function (CCDF).

$$CCDF = P_p(PAPR \geq \alpha) = 1 - (1 - e^{-\alpha})^{N_c} \tag{15}$$

Here the probability of an event is P_p and threshold value is α.

3.2. PTS-SIWO

Muller and Huber proposed PTS in 1997. The high PAPR of the system is significantly decreased by PTS [31]. In the PTS technique, N_s symbols are partitioned into S disjoint sub-blocks. The IFFT is performed independently for each sub-block, and then the phase factor r_u is applied to each sub-block. Phase factors are chosen to reduce the PAPR of a combined signal of all sub-blocks.

The frequency domain representation of the FBMC/OQAM signal is

$$x_n = [x_n^0, x_n^1, x_n^2, \ldots., x_n^{S-2}, x_n^{S-1}] \tag{16}$$

$$x_n = \sum_{u=0}^{S-1} r_u\ IFFT[X_n^u] \tag{17}$$

$$x_n = \sum_{u=0}^{S-1} r_u\ x_n^u \tag{18}$$

The phase factors are selected to reduce the PAPR, and expressed as follows

$$\left[\tilde{r}_0, \tilde{r}_1, \tilde{r}_2, \ldots., \tilde{r}_{S-2}, \tilde{r}_{S-1}\right] = \underset{\left[\tilde{r}_0, \tilde{r}_1, \tilde{r}_2, \ldots., \tilde{r}_{S-2}, \tilde{r}_{S-1}\right]}{\arg\min} \left[Max\left|\sum_{u=0}^{S-1} r_u x_n^u\right|^2\right] \tag{19}$$

The time domain signal of the FBMC/OQAM with the minimum PAPR is

$$\tilde{x}_n = \sum_{u=0}^{S-1} \tilde{r}_u\ x_n^u \tag{20}$$

The process of selecting the optimum phase factors is obviously computationally complex as it involves exhaustively searching across all possible combinations of phase factors. Phase factors are generally selected from a set of elements in order to decrease search complexity. As the number of sub-blocks increases, the search complexity increases exponentially[31].

3.3. Grey Wolf Optimization (GWO)

A population-based meta-heuristics approach is called GWO. In nature, gray wolves have a hierarchy of leadership and a mechanism for hunting. The GWO was proposed in 2014 by Seyedali Mirjalili et al. [32]. At the top of the food chain, the wolves live in packs of 5 to 12 individuals. As shown in Figure 5, every group member has a strict social dominance hierarchy.

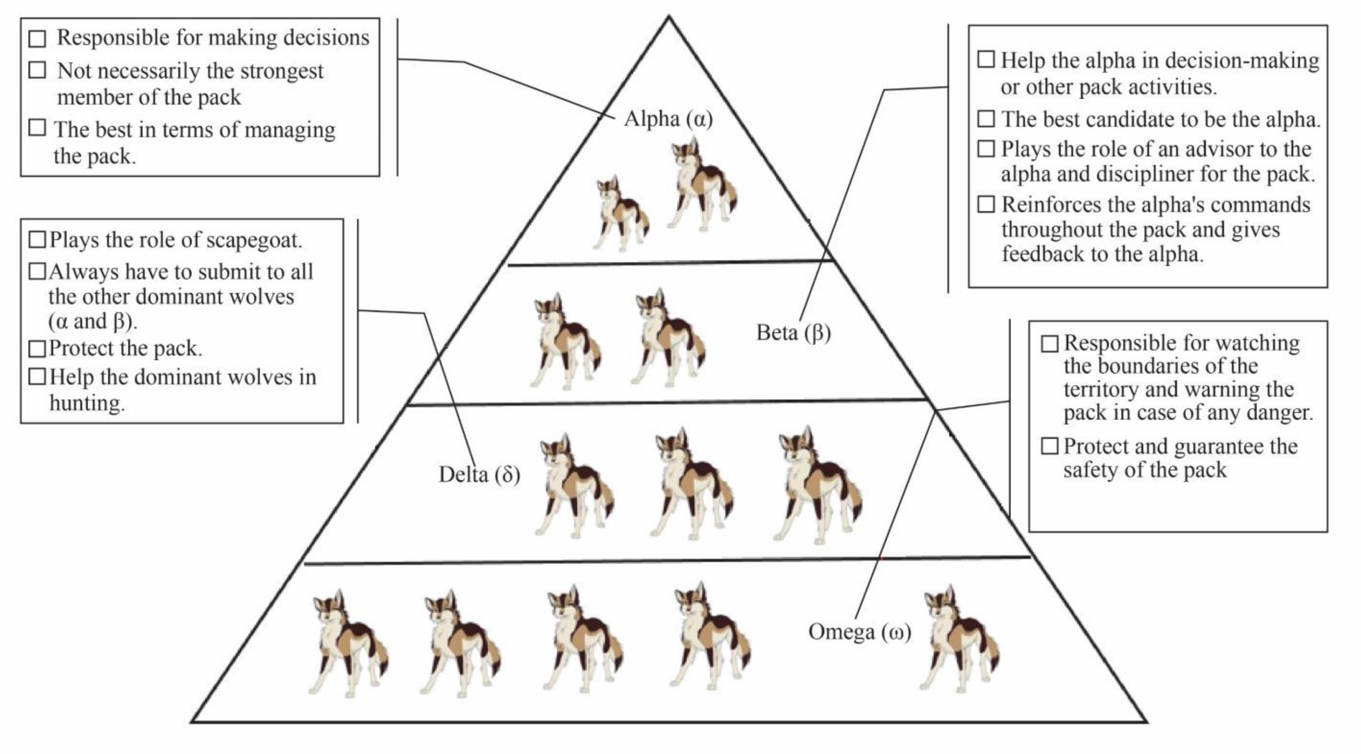

Fig. 5 Hierarchy of grey wolf [33]

Fig. 6 Hunting behavior of grey wolves [32]

The strongest wolf in the group is known as α. Members of the group should obey instructions of the α. Tracking, encircling, and attacking the prey are the three essential parts of hunting. A mathematical model of the GWO algorithm is developed to find the best solution. The leader α makes the decision. The female and other group members provide the best solutions for the second β and third δ. The remaining solutions are referred to as ω, and the hunt is directed by α, β and δ. Former pack members will give orders to wolf ω. As part of its hunting process, it first exactly identifies the prey. In order to approach the prey, it forms a circle. Using the vector functions, this can be written as :

$$\vec{U} = \left|\vec{V}.\vec{X}_p(i) - \vec{X}(i)\right| \tag{21}$$

$$\vec{X}(i+1) = \vec{X}_p(i) - \vec{W}.\vec{U} \tag{22}$$

Where current iteration is i, vector coefficients are $\vec{V}$ and $\vec{W}$, prey vector position is $\vec{X}_p$(i), grey wolf position vector is $\vec{X}$. The vectors $\vec{V}$ and $\vec{W}$ can be represented as

$$\vec{W} = 2\,\vec{l}.\vec{r_1} - \vec{l} \tag{23}$$

$$\vec{V} = 2\vec{r_2} \tag{24}$$

For each iteration, the vector $\vec{l}$ decreases from 2 to 0, and the random vectors $\vec{r}_1, \vec{r}_2$ set between 0 and 1.

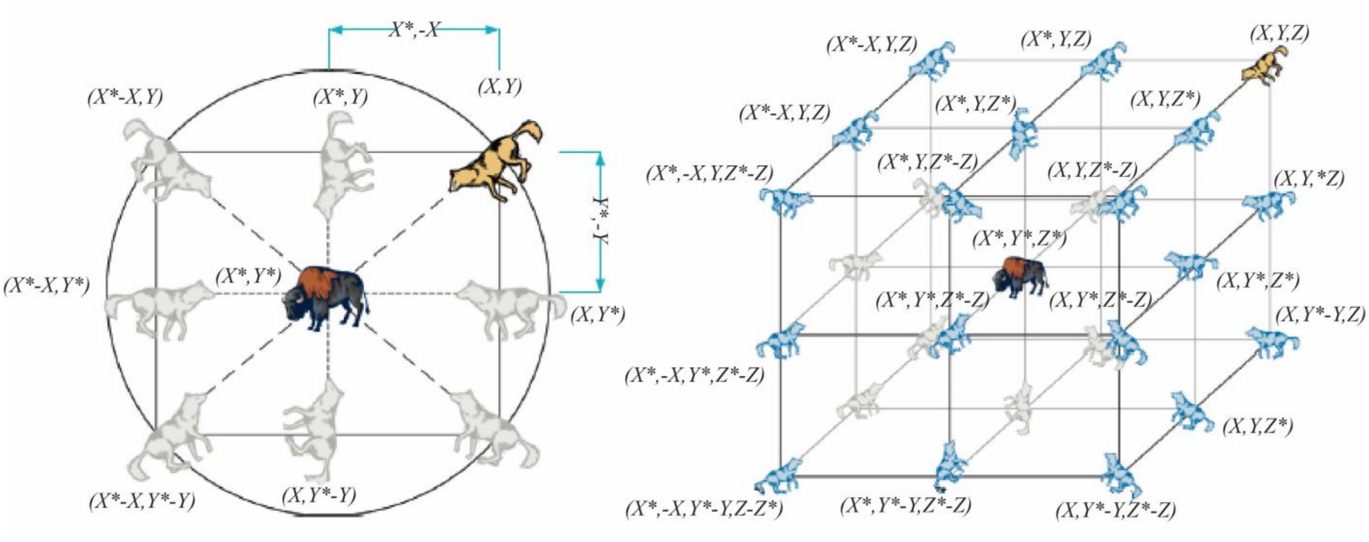

Fig. 7 2-D & 3-D position vectors and possible locations[32]

2-D and 3-D position vectors and a few possible neighbors are shown in Figure 7 to demonstrate the impacts of equations (23) and (24), and the final position is shown inside the circle depending on the decision space. The location of the grey wolf is provided as (x, y), and the location of the prey is stated as (x*, y*). In order to obtain the best position, $\vec{V}$=[1,1] and $\vec{W}$ =[1,0] must be regulated. In order to calculate the activity of the prey, any one node can be selected to calculate $\vec{r}_1$, $\vec{r}_2$, and a gray wolf can be placed at any random position. Prey can be recognized by grey wolves and encircled by them.

In most cases, the α guides the hunt. α, β, and δ usually perform hunting operations. To represent this hunting behavior, it is necessary to make an assumption about the position of the potential prey and the best solution. As an optimization algorithm, the proposed algorithm updates the position of the prey to determine the best solution for getting closer to the prey. For this, the following are suggested,

$$\vec{U_\alpha} = \left|\vec{V_1}.\vec{X_\alpha} - \vec{X}\right|; \qquad \vec{U_\beta} = \left|\vec{V_2}.\vec{X_\beta} - \vec{X}\right|;$$

$$\vec{U_\delta} = \left|\vec{V_3}.\vec{X_\delta} - \vec{X}\right| \tag{25}$$

$$\vec{X_1} = \vec{X_\alpha} - \vec{W_1}.\vec{U_\alpha}\,; \qquad \vec{X_2} = \vec{X_\beta} - \vec{W_2}.\vec{U_\beta}\,; \qquad \vec{X_3} = \vec{X_\delta} - \vec{W_3}.\vec{U_\delta} \tag{26}$$

$$\vec{X}(i+1) = \frac{\vec{X_1}+\vec{X_2}+\vec{X_3}}{3} \tag{27}$$

We reduce the $\vec{l}$ value in order to approach the prey. As $\vec{l}$ reduces $\vec{W}$ also reduces and $\vec{W}$ changes from [- 2l, 2l], where l is reduced from 2 to 0.

The next location of a search agent may be in any position between its present location and the location of the prey when random values $\vec{W}$ are in the range [-1, 1]. Based on the locations of the α, β, and δ, the GWO algorithm enables its search agents to update their positions and attack the prey. The α, β, and δ positions are primarily used by grey wolves to Search for prey. To find prey, they separate themselves from each other. Wolves attack prey whenever |$\vec{W}$|<1. In order to find a fitter prey, gray wolves diverge from their prey when |$\vec{W}$|>1. The random values of the $\vec{V}$ are in[0,2]. In order to estimate the probability of hunting the prey, the GWO optimization process is used. This procedure is repeated until the exact position of the prey is found.

Fig. 8 Flowchart

4. Results and Discussion

Table 1. Simulation parameters

Parameter	Value
FFT Length	1024
Population Size	20
Number of Iteration	100
Sub Carriers	128
Pilot Carriers	12, 24, 48, 60, 72
Cyclic Prefix	64
Modulation	OQAM
Oversampling Factor	8
Channel	AWGN
Overlapping Factor	4
Data blocks	10^{-3}

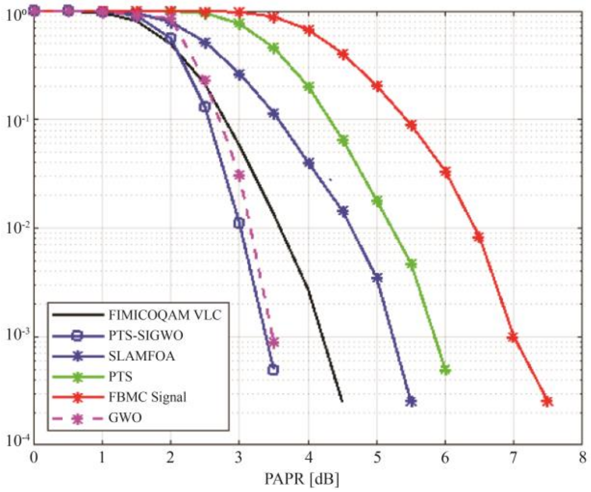

Fig. 9 PAPR performance

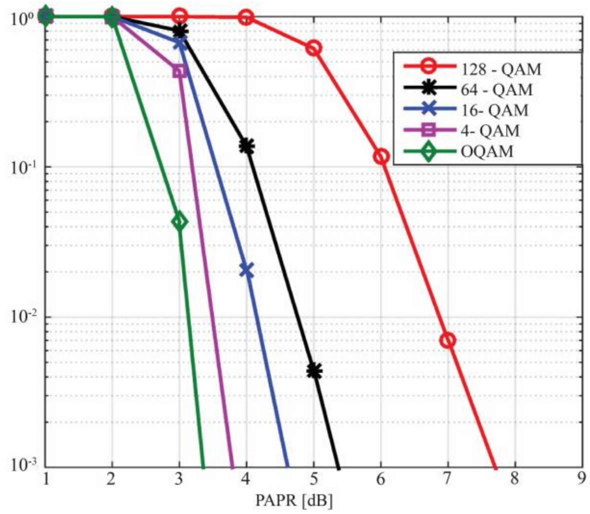

Fig. 10 PAPR for different QAM values

Table 2. PAPR Analysis

Method	**PAPR(dB) values at CCDF =**	
	10^{-2}	**10^{-3}**
FBMC Signal	6.3	7
PTS	5.2	5.9
SLM-MFOA	4.7	5.2
FBMC/OQAM-VLC	3.6	4.2
GWO	3.2	3.5
PTS-SIGWO	3	3.3

This section presents the simulation results of the proposed method by comparing it with other methods in terms of PAPR, PSD, Spectral efficiency and BER performance. The performance of the suggested system can be illustrated by comparing the results with the FBMC/OQAM-VLC, SLM-MFOA, GWO and PTS. Table 1 shows the simulation parameters for the model.

Figure 9 shows the PAPR performance of the system. From Figure 9, the peak power at the CCDF=10^{-3} for the proposed method is 3.3dB; FBMC/OQAM-VLC, GWO, and SLM-MFOA methods provide 4.2dB, 3.5dB and 5.2dB, respectively. The suggested method provides lower PAPR compared to other methods. The PAPR values for different methods are represented in Table 2.

The BER performance of the proposed system is presented in figure 11. Noise and ISI affect the efficiency of a nonlinear amplifier and increase the BER. Based on the results, it is clear that the proposed method provides a good BER performance than other methods. At CCDF of 0.01, the SNR of the proposed method gives 8dB, FBMC/OQAM-VLC gives 9.3dB, SLM-MFOA gives 10dB, PTS-ACO gives 14dB, and PTS-GA gives 15.1dB. The SNR values are 12.5dB, 14.2dB and 16dB for the PTS-SIGWO, FBMC/OQAM-VLC and SLM-MFOA at CCDF of 0.001. So, it concludes that the proposed method reduces BER more efficiently than existing methods. Table 3 shows the PAPR and BER analysis for various modulation signals.

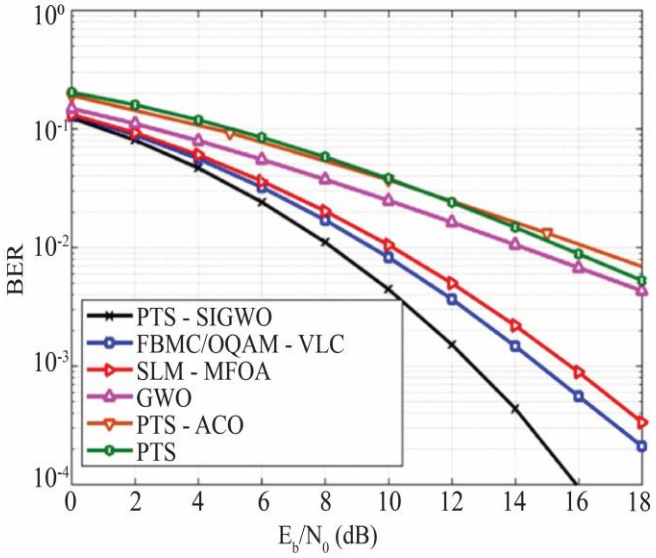

Fig. 11 BER Performance

Table 3. PAPR and BER Analysis

Modulation Signal	**PAPR (dB) values at CCDF**		**SNR (dB) values at CCDF**		
	10^{-2}	**10^{-3}**	**10^{-2}**	**10^{-3}**	**10^{-4}**
4 - QAM	3.4	3.9	10.3	13	14.7
16 - QAM	4.1	4.7	12	14.6	16
64 - QAM	4.9	5.2	14	18.2	22
128 - QAM	6.7	7.8	15.8	20.8	
OQAM	3.1	3.3	10.1	12.5	14.2

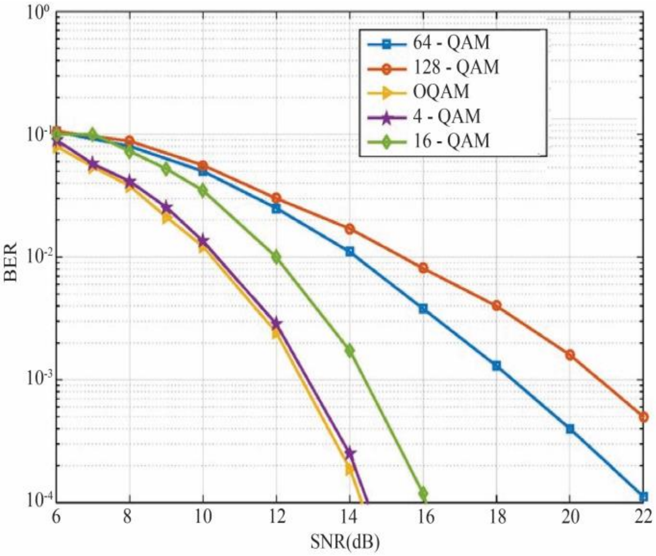

Fig. 12 BER for different QAM values

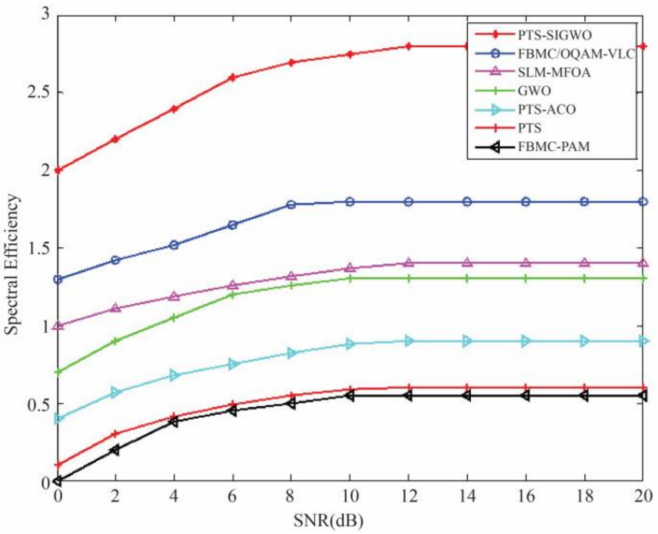

Fig. 13 Spectral efficiency

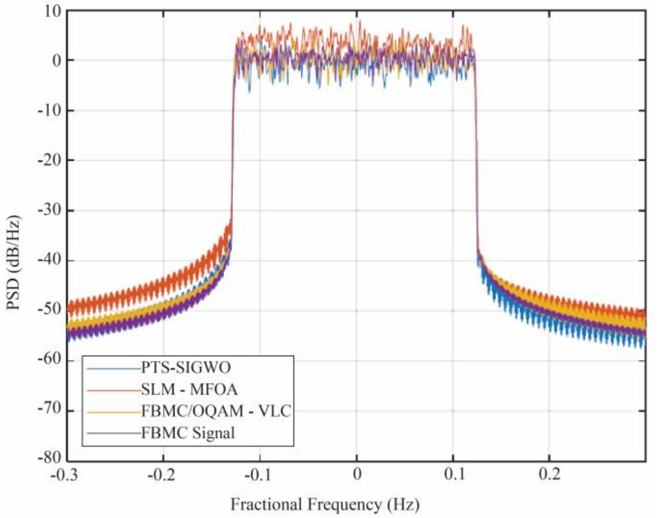

Fig. 14 PSD

The performance of the FBMC/OQAM system can be evaluated by spectral efficiency(SE). For an SNR of 20 dB, the SE of the proposed method is 2.8. The SE of FBMC/OQAM-VLC, SLM-MFOA, GWO, PTS-ACO, PTS and FBMC-PAM is 1.8, 1.4, 1.35, 0.9, 0.6 and 0.5, respectively. As illustrated in Figure 13, the proposed method provides better spectrum efficiency as compared to the FBMC/OQAM-VLC, SLM-MFOA, GWO, PTS-ACO and other methods. Figure 14 shows the simulated power spectral density (PSD) of PTS-SIGWO, SLM-MFOA, FBMC/OQAM-VLC and original FBMC. Compared to SLM-MFOA and FBMC/OQAM-VLC, the PTS-SIGWO has lower OOB emission by -3 dB, and -2 dB, respectively, when a fractional frequency offset of 0.2 Hz is considered.

5. Conclusion

The FBMC system will play an important role in the future world of high-speed communications. FBMC system has a drawback of PAPR. In this article, we present the PTS-SIGWO method to increase the system's performance. According to simulation results, this method has reduced the PAPR. To decrease PAPR and BER values, many different types of approaches, such as phase rotation, clipping, and coding, are employed. PTS and SLM are the most often utilized techniques for lowering a PAPR. In a wireless communication system, employing PTS reduces the PAPR from the FBMC signal. Wireless communication systems can be made more efficient with phase optimization in FBMC. In order to reduce the PAPR and BER of FBMC, the PTS-SIGWO method is applied. A phase optimization is performed in the FBMC signal according to the PTS. The proposed method has a PAPR of 3.3 dB; other methods require more than 4 dB to achieve a CCDF of 10^{-3}. Hence, it is concluded that the proposed approach can be considered effective in reducing computational complexity, BER and PAPR.

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References

[1] Sen-Hung Wang et al., “A Novel Low-Complexity Preceded OFDM System with Reduced PAPR,” *IEEE Transactions on Signal Processing*, vol. 63, no. 6, pp. 1366-1376, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[2] Pingyuan Yu, and Shubo Jin “A Low Complexity Tone Reservation Scheme Based on Time Domain Kernel Matrix for PAPR Reduction in OFDM Systems,” *IEEE Transactions on Broadcasting*, vol. 61, no. 4, pp. 710-716. 2015. [CrossRef] [Google Scholar] [Publisher Link]

[3] Vaigandla, Karthik Kumara, and J.Benita, “Selective Mapping Scheme Based on Modified Forest Optimization Algorithm for PAPR Reduction in FBMC System,” *Journal of Intelligent and Fuzzy Systems*, pp. 1-15, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[4] Karthik Kumar Vaigandla, SandyaRani Bolla, and RadhaKrishna Karne, “A Survey on Future Generation Wireless Communications-6G: Requirements, Technologies, Challenges and Applications,” *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 10, no. 5, pp. 3067-3076, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] Abbas Ali Sharifi, and Hojjat Emami, “PAPR Reduction of Asymmetrically Clipped Optical OFDM Signals: Optimizing PTS Technique Using Improved Flower Pollination Algorithm,” *Optics Communications*, vol. 474, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Karthik Kumar Vaigandla, and J.Benita, "PRNGN - PAPR Reduction using Noise Validation and Genetic System on 5G Wireless Network," *International Journal of Engineering Trends and Technology*, vol. 70, no. 8, pp. 224-232, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[7] Karthik Kumar Vaigandla, and J.Benita, "Novel Algorithm for Nonlinear Distortion Reduction Based on Clipping and Compressive Sensing in OFDM/OQAM System," *International Journal of Electrical and Electronics Research*, vol. 10, no. 3, pp. 620-626, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] S.H. Müller, and J.B. Huber "OFDM with Reduced Peak-to-Average Power Ratio by Optimum Combination of Partial Transmit Sequences," *Electronics Letters*, vol. 33, no. 5, pp. 368-369, 1997. [CrossRef] [Google Scholar] [Publisher Link]

[9] Siying Lv et al., "Genetic Algorithm Based Bilayer PTS Scheme for Peak-to-Average Power Ratio Reduction of FBMC/OQAM Signal," *IEEE Access*, vol. 8, pp. 17945-17955, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[10] Nahla Ali Mohamed Al Harthi, Zhongfeng Zhang, and Seungwon Choi, "FBMC-OQAM PAPR Reduction Schemes," *Proceedings of 2020 International Conference on Information and Communication Technology Convergence*, pp. 148-150, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Pitchaya BOONTRA et al., "A PAPR reduction for FBMC-OQAM Signals using ABC-OPTS Scheme," *Proceedings of 2019 21st International Conference on Advanced Communication Technology*, pp. 115-119, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[12] Shuang Ren et al., "Sparse PTS Scheme Based on TR Schemes for PAPR Reduction in FBMC-OQAM Systems," *IET Communications*, vol. 12, no. 14, pp. 1722-1727, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[13] Zongmiao He et al., "Low-complexity PTS Scheme for PAPR Reduction in FBMC-OQAM Systems," *IEEE Communications Letters*, vol. 22, no. 11, pp. 2322-2325, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] Junhui Zhao, Shanjin Ni, and Yi Gong, "Peak-to-Average Power Ratio Reduction of FBMC/OQAM Signal Using a Joint Optimization Scheme," *IEEE Access*, vol. 5, pp. 15810-15819, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[15] Chen Ye et al., "PAPR Reduction of OQAM-OFDM Signals Using Segmental PTS Scheme with Low Complexity," *IEEE Transactions on Broadcasting*, vol. 60, no. 1, pp. 141-147, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[16] Daiming Qu, Shixian Lu, and Tao Jiang, "Multi-Block Joint Optimization for the Peak-to Average Power Ratio Reduction of FBMC-OQAM signals," *IEEE Transactions on Signal Processing*, vol. 61, no. 7, pp. 1605-1613, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[17] Mounira Laabidi, and Ridha Bouallegue, "Three Implementations of the Tone Reservation PAPR Reduction Scheme for the FBMC/OQAM System," *IET Communication*, vol. 13, no. 7, pp. 918-925, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[18] Kakara Satyavathi, and B. Rama Rao, "Modified Phase Sequence in Hybrid PTS Scheme for PAPR Reduction in OFDM Systems," *Innovations in Electronics and Communication Engineering*, pp. 327-333 2019. [CrossRef] [Google Scholar] [Publisher Link]

[19] Mangal Singh, and Sarat Kumar Patra, "On the PTS Optimization Using the Firefly Algorithm for PAPR Reduction in OFDM Systems," *IETE Technical Review*, vol. 35, no.5 pp. 441-455, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[20] Sumina Sidiq et al., "PAPR Minimization of FBMC/OQAM Scheme by Hybrid SLM and PTS using Artificial: Bee-Colony Phase -Optimization," *Arabian Journal for Science and Engineering*, vol. 46, pp. 9925-9934, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[21] Salima Senhadji, Yassine Mohammed Bendimerad, and Fathi Tarik Bendimerad, "New Scheme for PAPR Reduction in FBMC-OQAM Systems Based on Combining TR and Deep Clipping Techniques," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 3, pp. 2143-2152, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[22] V. Sandeep Kumar, "Joint Iterative Filtering and Companding Parameter Optimization for PAPR Reduction of OFDM/OQAM Signal," *AEU-International Journal of Electronics and Communications*, vol. 124, pp. 153365–153371, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] A. Hanprasitkum et al., "Improved PTS Method with New Weighting Factor Technique for FBMC-OQAM Systems," *19th International Conference on Advanced Communication Technology*, pp. 143-147, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[24] M. N. Geetha, and U. B. Mahadevaswamy, "Performance Evaluation and Analysis of Peak to Average Power Reduction in OFDM Signal," *Wireless Personal Communications*, vol. 112, pp. 2071-2089, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[25] Abbas Ali Sharifi, and Mehdi Hosseinzadeh Aghdam, "A Novel Hybrid Genetic Algorithm to Reduce the Peak-to-Average Power Ratio Of OFDM Signals," *Computers and Electrical Engineering*, vol. 80, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[26] Wenhua Wu et al., "Joint optimization of PAPR Reduction Based on Modified TR Scheme for MIMO-OFDM Radar," *Digital Signal Processing*, vol. 80, pp. 27-36, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[27] Şakir Şimşir, and Necmi Taşpınar, "An Improved PTS Scheme Based on a Novel Discrete Invasive Weed Optimization Algorithm for PAPR Reduction in the UFMC Signal," *Neural Computing and Applications*, vol. 33, no. 23, pp. 16403-16424, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[28] Lei Li et al., "Partial Transmit Sequence Based on Discrete Particle Swarm Optimization with Threshold About PAPR Reduction in FBMC/OQAM System," *IET Communications*, vol. 16, no. 2, pp. 142-150, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[29] R. S. Suriavel Rao, and P. Malathi, "A Novel PTS: Grey Wolf Optimizer-Based PAPR Reduction Technique in OFDM Scheme for High-Speed Wireless Applications," *Soft Computing*, vol. 23, pp. 2701-2712, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[30] Karthik Kumar Vaigandla, and Benita J, "Study and Analysis of Multi Carrier Modulation Techniques - FBMC and OFDM, *Materials Today: Proceedings*, vol. 58, no. 1, pp. 52-56, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[31] Karthik Kumar Vaigandla, Dr. J. Benita, "Study and Analysis of Various PAPR Minimization Methods," *International Journal of Early Childhood Special Education*, vol. 14, no. 3, pp.1731-1740, 2022. [Google Scholar]

[32] Seyedali Mirjalili, Seyed Mohammad Mirjalili, and Andrew Lewis "Grey Wolf Optimizer," *Advances in Engineering Software*, vol. 69, pp. 46–61. 2014. [CrossRef] [Google Scholar] [Publisher Link]

[33] Raja Masadeh, Abdullah Alzaqebah, and Amjad Hudaib, "Grey Wolf Algorithm for Requirements Prioritizatio," *Modern Applied Science,* vol. 12, no. 2, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[34] Karthik Kumar Vaigandla, and J. Benita, "A Novel PAPR Reduction in Filter Bank Multi-Carrier (FBMC) with Offset Quadrature Amplitude Modulation (OQAM) Based VLC Systems," *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 11, no. 5, pp. 288-299, 2023. [CrossRef] [Publisher Link]