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# Nested Particle Swarm Optimization and Grey Wolf Optimization for Phase Optimization in Orthogonal Frequency Division Multiplexing

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**Abstract:** In wireless communication systems, Multiple-Input Multiple-Out (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) were widely used technology. Spectrum utilization efficiency is needed to improve in OFDM technology for effective performance. A Nested Particle Swarm Optimization and Grey Wolf Optimization (HPSO-GWO) is proposed with the Low-Density Parity-Check (LDPC) coding scheme for minimizing the errors that occurred while transmitting the data bits over the MIMO-OFDM. The Nested PSO-GWO process involves in update the velocity of PSO using GWO method that helps to increases the convergence rate and balance the trade-off between exploration-exploitation process. The optimal velocity update in the PSO helps to escape from local optima trap in the search process and improve the efficiency of the model. Generally, the linear error-correcting codes are applied in Low-Density Parity-Check (LDPC) that is used to transmit the message in a noisy channel. Fast Fourier Transform (FFT), CP removal, and the Serial to Parallel (S/P) are accomplished as well as the received data bits are demodulated to obtain the output bits on the receiver side. The proposed method has 10-2 CCDF in 5.6 PAPR and the existing method requires more than 6 PAPR to achieve 10-2 CCDF.

**Keywords:** Fast Fourier transform, Grey wolf optimization, Multiple-input multiple-out, OFDM, Particle swarm optimization.

## 1. Introduction

The extensive usage of Wireless applications made limited Radio Frequency (RF) spectrum which is insufficient for future service demands. To achieve data transmission at a high rate in wireless systems, OFDM is applied due to its low-complexity, simple equalization and spectral efficiency implementation [1]. Amplitude variation of OFDM signal is sliced in time domain due to its multi-carrier nature that has a relatively large dynamic range that refers as Peak-to-Average Power Ratio (PAPR) [2]. Applied in non-linear High Power Amplifier (HPA), the OFDM signal is clipped in case of high PAPR that causes degrade in performance, radiation out-of-band, and distortion in-band. A wide dynamic range of expensive linear HPA is required in OFDM transmitters [3]. The base station of high power amplifiers is responsible for energy costs of a significant share in a communication system. HPA energy efficiency related to PAPR of the input signal is important for multi-carrier transmission in OFDM [4]. OFDM can be implemented using wavelet transform or Fast Fourier Transform (FFT). OFDM applied with cyclic prefix in impulse response length order provides powerlines over impulsive channels due to its robustness [5].

Recently, optimization methods with less search complexity were applied for the PTS technique which optimizes to reduce CM and PAPR in OFDM systems [6]. Most popular evolutionary methods of Grey Wolf Optimization, Ray Optimization, Gravitational Search Algorithm (GSA), Charged System Search (CSS), Biogeographic optimization algorithm (BBO), Differential Evolutionary Algorithm (DE), and Genetic Algorithm (GA) etc., were applied in OFDM [7]. PTS method phase factor sequence selection is a non-linear optimization problem and the presence of a large number of sub-blocks non-overlapping greatly affects the memory usage and greater

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complexity [8]. Some of the researches involve in applying jointly optimization of BER and PAPR performance to overcome the drawbacks of signal companding transform method [9, 10]. The contribution of the proposed method is given as follows:

1. Nested PSO-GWO method involves in update the velocity of the PSO method to balance the exploration-exploitation and increases the convergence rate.
2. The PSO-GWO method is proposed to minimize the error of transmission in MIMO-OFDM system. The PSO method increases the efficiency of the method and GWO method increases the convergence rate of the model.
3. The PSO-GWO is applied in Partial Transmit Sequence (PTS) of MIMO-OFDM system to mitigate the PAPR of the method.
4. The PSO-GWO method is evaluated for various FFT and modulation order to evaluate the performance of the method. The PSO-GWO method shows higher performance in various FFT and modulation order than existing method.

This paper is organized as follows: literature review on optimization methods used in existing research is given in Section 2 and the proposed method is explained in Section 3. The result of Nested PSO-GWO is given in Section 4, and a conclusion is given in Section 5.

## 2. Literature review

The high data rate is an essential quality in a wireless application and carrier modulation are used for trade-off achievement. Some of the researches in applying the optimization methods to increase the efficiency of OFDM. Recent and notable researches in optimization in OFDM were reviewed in this section.

Rao and Malathi, [11] proposed meta-heuristic optimization method and partial transmission sequence for phase factor improvement. Grey Wolf Optimization (GWO) method was applied to increase the efficiency of the developed method. The optimization method provides fast convergence and low complexity in data classification. The OFDM signal of peak power issue was mitigated by the phase factor component in partial transmit sequence. Three times over sampled the modulation and pilot sub-carriers were used to obtain sub-carries. The proposed method has higher performance than existing methods in OFDM signal optimization. GWO method has the limitation of lower performance in local search and slow convergence rate in the optimization due to GWO method provide higher weights to the local features.

Geetha and Mahadevaswamy, [12] proposed Slepian based flat-top window and harmonious kernel adaptive window for signal optimization for the elimination of noise and orthogonal maintenance. The amplitude measurement and stochastic resembling method were applied to lessen the information loss and window average out noise in the spectrum to reduce the PAPR. The proposed method solves the problem of sturdiness in channel dispersion, spectral effectiveness, bandwidth complication, computational difficulty, and date rate. The windowing and adaptive clipping technique were used to reduce the bit error rate in the model. The developed model has higher efficiency than the existing method in optimizing the signal. The stochastic resembling method creates information loss due to elimination of noise that increases BER of the model.

Sharif and Aghdam, [13] proposed a hybrid genetic algorithm in partial transmit sequence to decrease search complexity. The salient phase factor was an important aspect in the proposed method to reduce high PAPR. The local search operator was designed and embedded in a genetic algorithm to explore optimum phase factors. The 16-QAM modulated symbols are used for simulation and the developed method reduces search complexity and PAPR. Each chromosome represents a number of genes and phase factor sequence in phase factor. The developed method has higher efficiency compared to the conventional optimization algorithm in OFDM signal optimization. The developed method has the drawback of being easily trapped into local optima and the convergence rate of the model is low due to local search operator provide priority to local features in search.

Wu [14] applied concurrent independent (CTR) and independent (TR) for PAPR reduction. The joint optimization method effectively reduces the PAPR method by a considerable threshold and is higher than the conventional method. The MIMO radar of optimized OFDM waveforms avoids the grating lobes in the distance domain. The derivations are verified in the simulation result of the model. The approximate optima are applied in the model that reduces the convergence rate of the model.

Liu [15] applied Real valued Neural Network (NN) with PAPR reduction in low complexity. The real-valued NN was used to build the PAPR reduction module to achieve higher PAPR reduction. Receiving end was applied with PAPR decompression module to reconstruct the transmission signal and reduce system BER. PAPR decompression module and reduction module are trained jointly to reduce BER and PAPR. The trained model applies multiple parallel processing to reduce PAPR reduction of process rate to achieve PAPR reduction. The joint loss function optimization reduces the PAPR of the system and increases the BER that degrades the performance.

Aghdam. [16] applied improved Ant Colony Optimization (ACO) method to reduce PAPR values and computational cost of OFDM system. The improved ACO is combined with PTS in new representation of phase factor as a graph. The improved ACO model provides the considerable performance in terms of PAPR reduction. The improved ACO method has the limitation of stagnation and lower exploration-exploitation.

Simsir [17] applied Discrete version of Invasive Weed Optimization (DIWO) algorithm and integrated with PTS method. The DIWO method is applied to optimize the phase sequences in discrete phase and DIWO-PTS method achieves better solution with number of iteration. The DIWO method easily trap into local optima that reduces the efficiency of the model.

Li [18] applied PTS based Discrete Particle Swarm Optimization with threshold (PTS-DPSO-TH) method in OFDM system. The DPSO method reduces the PAPR of the system and threshold is used to reduces number of iteration. The DPSO method has limitation of local optima trap that increases the BER of the method.

## 3. Proposed method

In this research, a Nested PSO-GWO is proposed with the Low-Density Parity-Check (LDPC) coding scheme which is developed for minimizing the errors that occurred while transmitting the data bits over the MIMO-OFDM. Generally, the message transmission over noisy channels is carried out by Low-Density Parity-Check (LDPC) which are linear error correcting codes. Initially, the input bits are modulated using any one of the standard modulation techniques such as Fig. 1 shows Nested PSO-GWO method in phase optimization with Quadrature Phase Shift Keying (QPSK), Binary Phase Shift Keying (BPSK), and Quadrature Amplitude Modulation (QAM).

*Mathematical Model*

The PAPR phenomenon of a mathematical model is applied in the proposed model and OFDM model optimization is carried out. Time domain number of subcarriers is denoted as $X$ which is added in the system to provide maximum power. The average and maximum signal power ratio is PAPR signal as given in Eq. (1)

$$PAPR = \frac{P_{peak}}{P_{average}} \tag{1}$$

Where OFDM signal of average power is denoted as $P_{average}$ and OFDM signal peak power is denoted as $P_{peak}$ as given in Eq. (2)

$$PAPR = \frac{\max\left(x^2(t)\right)}{mean(x^2(t))} \tag{2}$$

Where signal amplitude is denoted as $x(t)$. The summation of $X$ sub-carriers is obtained for given signals is peak power. The maximum PAPR is given in Eq. (3).

$$PAPR_l = \frac{X_{max}}{\bar{X}} = X \tag{3}$$

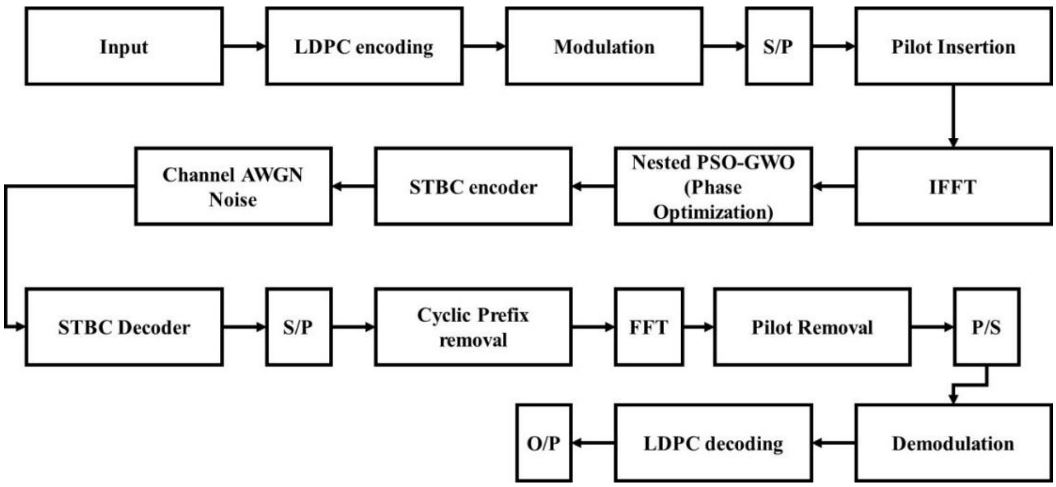


Figure. 1 The flow of the Nested PSO-GWO method

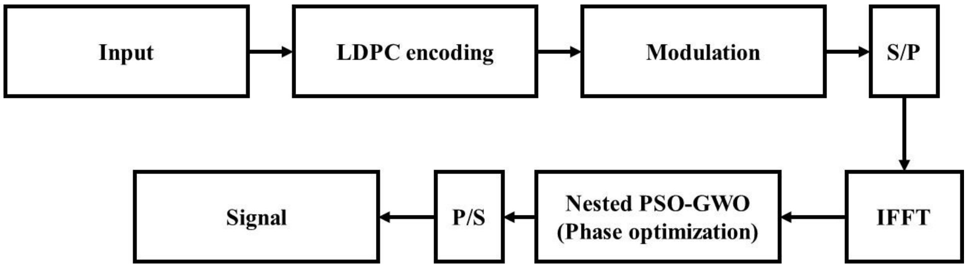


Figure. 2 Phase optimization using Nested PSO-GWO method

If sub-carriers increases, the $PAPR$ increases, Gaussian distribution function $p = 1, \dots, X$ is $P(Xp < PAPR_l) < 1$ and probability is given in Eq. (4).

$$\lim_{p \to \infty} \prod_{p=1}^{X} P\left(X_p < PAPR_l\right) = 0 \quad (4)$$

Signal probability of small $PAPR$ values is given in the above statement, and probability of large $PAPR$ if the $PAPR_l$ is given in Eq. (5).

$$\lim_{p \to \infty}\left(1 - \prod_{k=1}^{L} P(x_k < PAPR_l)\right) = 1 \quad (5)$$

Signal probability and PAPR of a mathematical model based on the threshold value of high PAPR. Fixed value of $PAPR_m$ decreases increase the signals of high PAPR value. Increases in sub-carrier value increase the probability and this tends to a value of one of $PAPR_m$ value. OFDM process is carried out using this mathematical model and this needs optimization method to achieve low $PAPR$ values in sub-carrier systems. The Nested PSO-GWO method is applied in the model to optimize for obtaining the less PAPR values.

### 3.1 Partial transmit sequence

The Partial Transmit Sequence (PTS) is widely applied to OFDM signals to mitigate peak power issues. As increases in a number of sub-blocks increases computational complexity cost. The $L$ sub-blocks is split from input data block $X$ with vector representation is given in Eq. (6).

$$X^l = \{X_0^1 X_1^l X_2^l \dots X_{K-1}^l\} \quad (6)$$

Sub-blocks summing is given in Eq. (7).

$$X = \sum_{l=0}^{L-1} X^l \quad (7)$$

In the frequency domain, $X^l$ is resultant sub-blocks of $X$ and IFFT is applied to bring back to the time domain. The output of IFFT is applied with a number of factors to undergo phase rotation, as in Eq. (8).

$$B_l = \exp(j\phi_l)\,, \phi_1 \in \left\{\frac{2\pi n}{W_{ph}} |\_(n = 0,1, \dots, W_{ph} - 1) \quad (8)$$

The proposed method applies phase rotation to reduce $L$ sub-blocks of the $PAPR$ and parallel to serial conversion is carried out to combine them to produce OFDM signal in terms of $\tilde{x}$, as in Eq. (9).

$$\tilde{x} = \sum_{l=0}^{L-1} B_l x^l \quad (9)$$

Unique OFDM symbol of $P = W_{ph}^L$ is obtained as output considering phase angles $W_{ph}$ are permitted.

The phase factor search in the sequential process in PTS reduces $PAPR$ in a physical scenario which complex one due to a large number of sub-carriers. The combinatorial optimization process is applied based on phase factor search. The Nested PSO-GWO method is applied to obtain low PAPR with less computation time to improve the system performance.

The model aggregates phase factor vectors of $B_l$ in search process and phase factor provides the minimum $PAPR$ that is considered in NP-complete Combinatorial Optimization (CO) problem. Eq. (9) provides objective function with minimum peak power of targets sub-carriers in $L$ blocks of OFDM signal. The finite set of range $0 \leq \phi_1 \leq 2\pi(0 \leq l \leq L - 1)$ is in phase factor constraint.

### 3.2 Nested PSO-GWO

Animal behaviour like bird flocking and fish schooling was adapted in the PSO algorithm to measure global optimization problems, where particle $i$ denotes every swarm. Particle position and velocity in PSO are updated as in Eqs. (10) and (11).

$$v_i^{t+1} = v_i^t + c_1 r_1\left(p_i^t - x_i^t\right) + c_2 r_2\left(g_{best} - x_i^t\right) \quad (10)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (11)$$

Where social parameters and cognitive are denoted as $c_1$ $and$ $c_2$, random numbers of uniform distribution in a range of [0, 1] is denoted as $r_1 and$ $r_2$, the global best value is denoted $g_{best}$, particle's best value is $p_i^t$, and a number of iterations is $t$. The velocity $v_i^{t+1}$ determines the exploration and exploitation of the search process. For higher velocity, exploitation process is high and for lower velocity, exploration process is high. Optimal velocity value is need to be obtain to provide the balance between the exploration and exploitation. The GWO model is applied to find the optimal velocity update in PSO model to increases the convergence rate and provide balance between the exploration and exploitation. The optimal velocity update in the PSO helps to overcome local optima trap. Grey wolves partition the crowd in hierarchy leadership into four groups alpha$(\alpha)$, beta $(\beta)$, delta $(\delta)$ and omega $(\gamma)$. The decision-making process is carried out using alpha $(\alpha)$ based on subordinate wolves beta $(\beta)$ assist. GWO has three major phases: prey attacking, encircling and searching. Every agent encircling behaviour is measured using Eq. (12).

$$d = \left|c.x_{p(t)} - x(t)\right|$$

$$x(t+1) = x_{p(t)} - a.d \tag{12}$$

Mathematical definitions of vectors $a$ and $c$ are given in Eq. (13),

$$a = 2l \times r_1 \; and \; c = 2 \times r_2 \tag{13}$$

Hunting behaviour simulation of prey location with better knowledge is present in alpha$(\alpha)$, beta $(\beta)$, and delta $(\delta)$, as given in mathematical definition in Eqs. (14) to (17).

$$\begin{gathered}\vec{d}_\alpha = |\vec{c}_1.\vec{x}_\alpha - \vec{x}| \\ \vec{d}_\beta = |\vec{c}_2.\vec{x}_\beta - \vec{x}| \\ \vec{d}_\delta = |\vec{c}_3.\vec{x}_\delta - \vec{x}|\end{gathered} \tag{14}$$

$$\begin{gathered}\vec{x}_1 = \vec{x}_\alpha - \vec{a}_1 \times (\vec{d}_\alpha) \\ \vec{x}_2 = \vec{x}_\beta - \vec{a}_2 \times (\vec{d}_\beta) \\ \vec{x}_3 = \vec{x}_\delta - \vec{a}_3 \times (\vec{d}_\delta)\end{gathered} \tag{15}$$

$$\vec{x}(t) = \frac{\vec{x}_1 + \vec{x}_2 + \vec{x}_3}{3} \tag{16}$$

$$\begin{gathered}\vec{a} = 2\vec{l} \times \vec{r}_1 - \vec{l} \\ \vec{c} = 2 \times \vec{r}_2\end{gathered} \tag{17}$$

Where the random value in the range $[-2l, 2l]$ is represented as $a$, the controlling parameter is denoted as $l$ that linearly declines from two to zero maximum values. Prey are attacked by grey wolves and random values are $|a| < 1$. Exploitation ability is attacking and searching prey, $a$ arbitrary value force to move the wolves far away from the prey. Enforcing the population members in prey diverging is $|a| > 1$. The PSO-GWO method is hybridized using the hybrid low-level co-evolution method. The exploration ability of the PSO method is applied for modification and exploitation in the GWO method improves the variant's strength to deliver. The first three agent's positions $(\vec{x}_\alpha, \vec{x}_\beta, and\ \vec{x}_\delta)$ are updated in search space in Eq. (18). The grey wolf exploration and exploitation are controlled using inertia constant $w$ instead of a normal mathematical equation. The Nested PSO-GWO method increases phase optimization computational efficiency.

$$\begin{gathered}\vec{d}_\alpha = |\vec{c}_1.\vec{x}_\alpha - w \times \vec{x}| \\ \vec{d}_\beta = |\vec{c}_2.\vec{x}_\beta - w \times \vec{x}| \\ \vec{d}_\delta = |\vec{c}_3.\vec{x}_\delta - w \times \vec{x}|\end{gathered} \tag{18}$$

The Nested PSO-GWO variants has position and velocity to indicate in Eqs. (19) and (20).

$$v_i^{t+1} = w \times \left(v_i^t + c_1 r_1 (x_1 - x_i^t) + c_2 r_2 (x_2 - x_i^t) + c_3 r_3 (x_3 - x_i^t)\right) \tag{19}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{20}$$

Where search agent is set as 30, number of iteration is 100, $l \in [2,0]$, $w = 0.5 + \frac{rand()}{2}$, and $c_1 = c_2 = c_3 = 0.5$.

## 4. Results

The Nested PSO-GWO is applied for phase optimization in the OFDM signal. The proposed PSO-GWO method is tested in the various FFT size in BER, symbol error and CCDF. The Nested PSO-GWO method is mainly compared with individual PSO and GWO method. Commonly applied methods like Genetic algorithm mutation provide considerable performance in feature selection and its crossover tends to limit the features in local search space and provide PSNR in range of 8 to 10 dB. The parameter settings of the model are shown in Table 1.

The proposed PSO-GWO method is tested in terms of BER for various FFT lengths of 64, 128 and 256, as given in Fig. 3 to 5. This shows that the

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Table 1. The parameter settings of the proposed method

| | |
|---|---|
| PSO | |
| Population size | 10 |
| Number of iteration | 100 |
| GWO | |
| Population size | 20 |
| Number of iteration | 100 |
| FFT size | 64,128,256,512,1024, |
| User carriers | 52,104,156,208,260, |
| Pilot cariers | 12,24,48,60,72, |
| Antenna | 2X2,2X4,4X2,4X4, |
| Subcarriers number of null/guard band | |
| Guard time or Cyclic prefix | 0 to 2e-6s |
| Modulation | 8QAM,16QAM,32QAM, 64QAM,256QAM |
| Oversampling factor | 1e6 HZ |
| Channel type | Rayleigh Channel |
| Noise | AWGN |

proposed PSO-GWO method has lower deviation in simulation from theoretical. Fig. 3 to 5 also shows that the developed method has lower BER and is suitable to apply for conventional processes.

The proposed PSO-GWO method and existing method CCDF in various FFT lengths, as given in Fig. 6 to 8. The proposed method has less CCDF compared to the existing methods in various FFT lengths. The PSO method has a second higher performance in CCDF due to its search capacity. The GWO method is a trap into local optima and PSO method has a lower convergence rate.

The symbol error of the proposed PSO-GWO and existing methods in various lengths of FFT is shown in Fig. 9, Fig. 10, and Fig. 11. This shows that the proposed method has lower deviation in simulation. The proposed PSO-GWO method has a lower error rate in the optimization than the existing method.

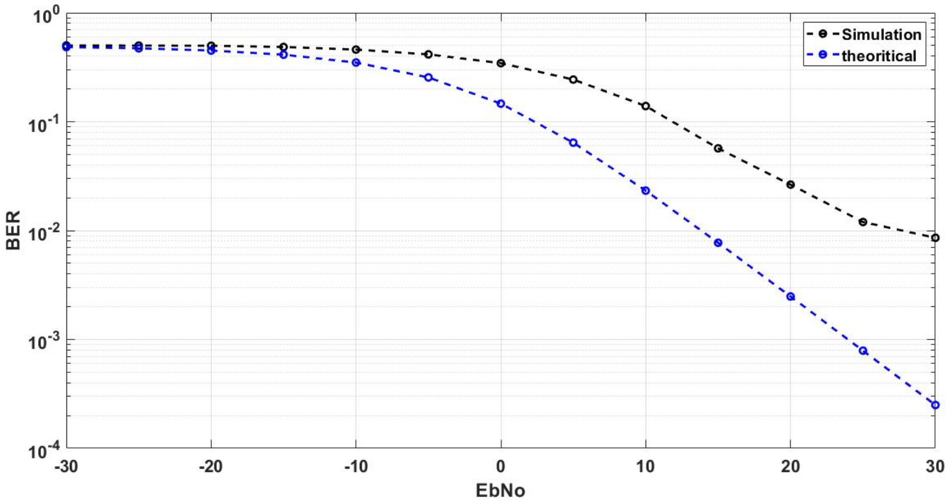


Figure. 3 BER of proposed PSO-GWO method in OFDM

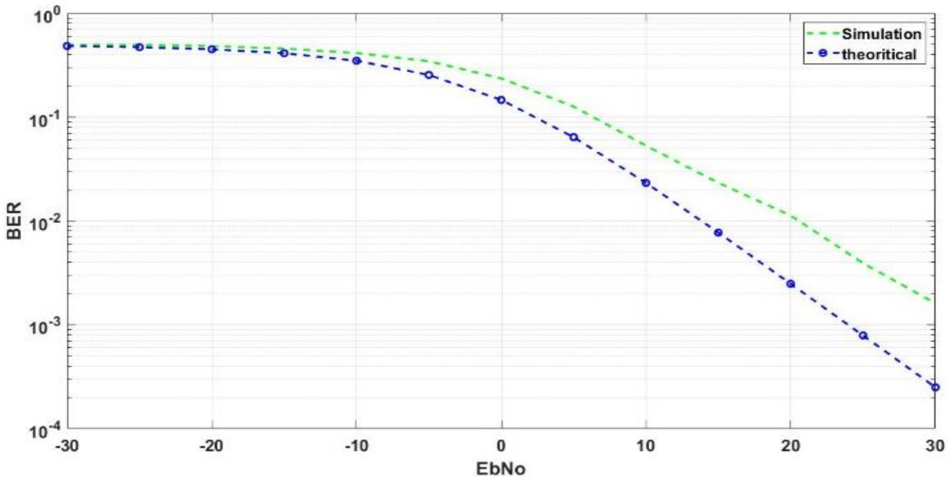


Figure. 4 PSO-GWO BER in 128 FFT

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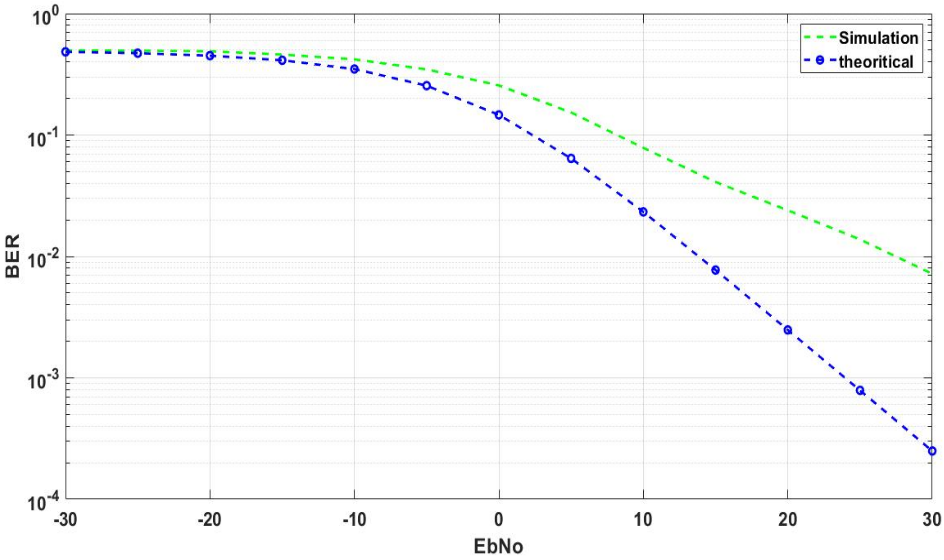


Figure. 5 The PSO-GWO BER in 256 FFT

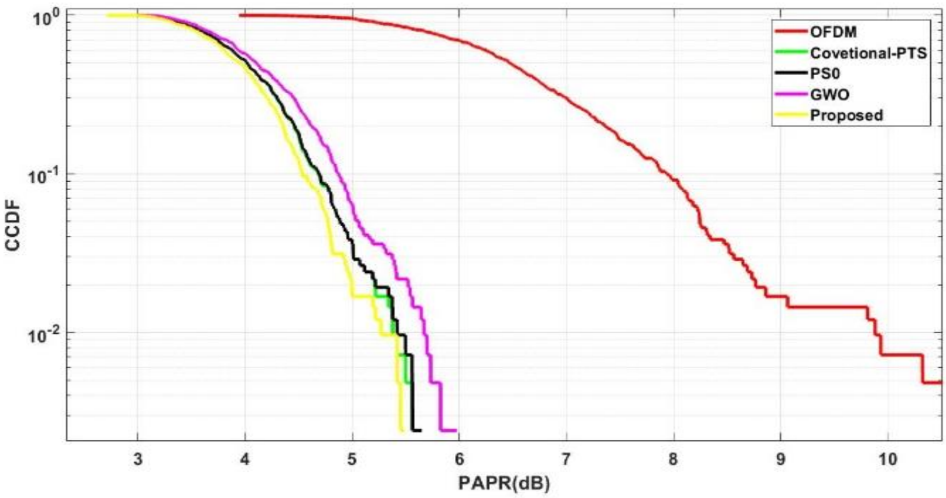


Figure. 6 The proposed PSO-GWO and existing method in 64 FFT

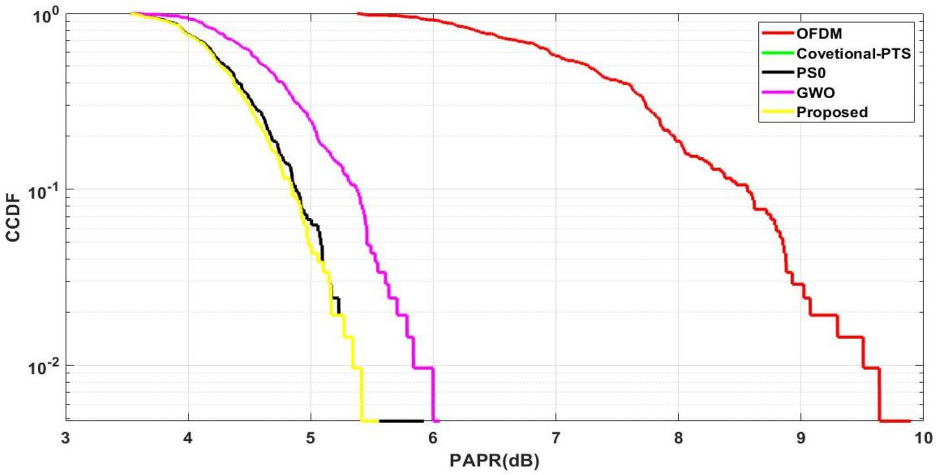


Figure. 7 The proposed PSO-GWO and existing method CCDF in 128 FFT

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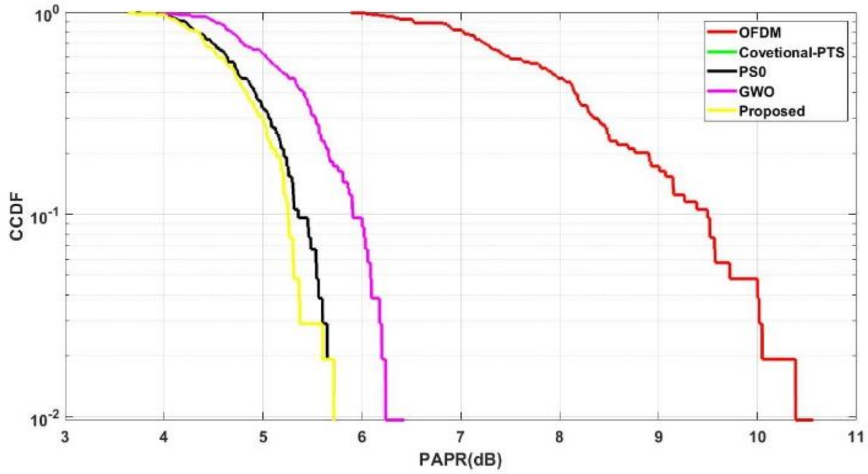


Figure. 8 The proposed and existing method CCDF in 256 FFT

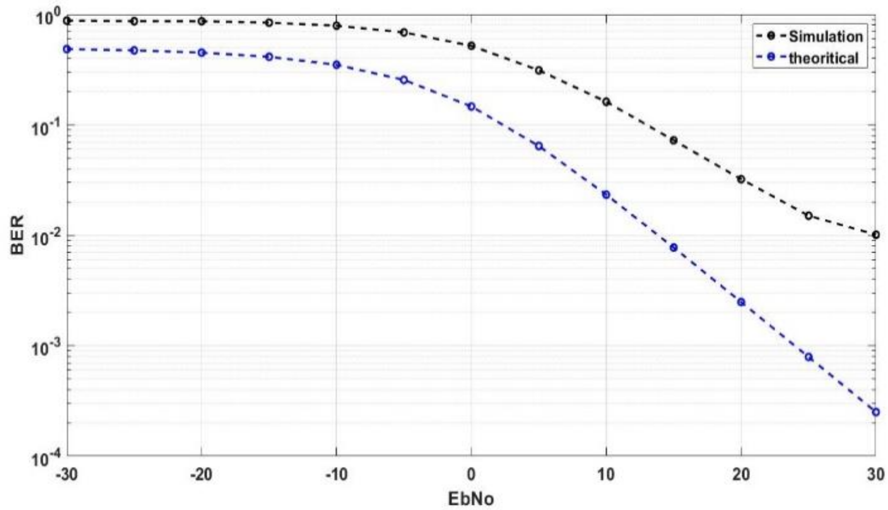


Figure. 9 The proposed PSO-GWO Symbol error in 64 FFT

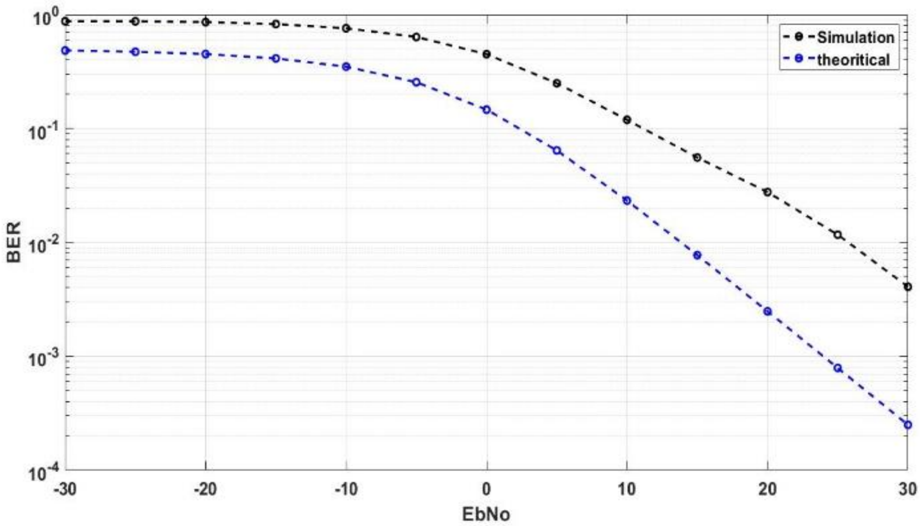


Figure. 10 The proposed PSO-GWO symbol error in 128 FFT

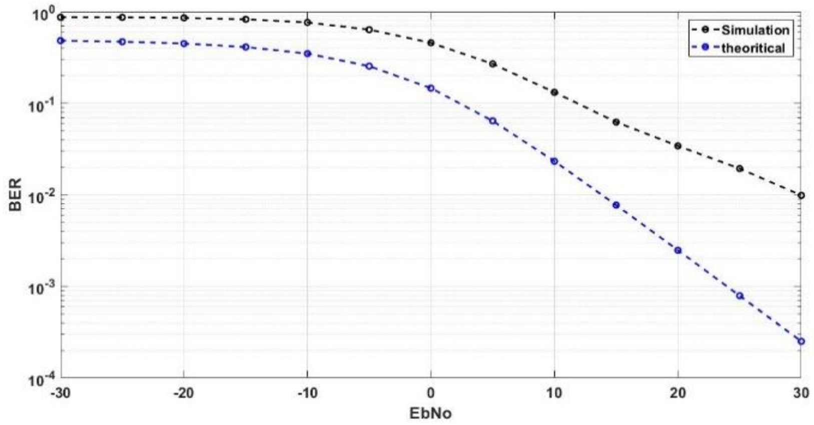


Figure. 11 The proposed PSO-GWO method in 256 FFT

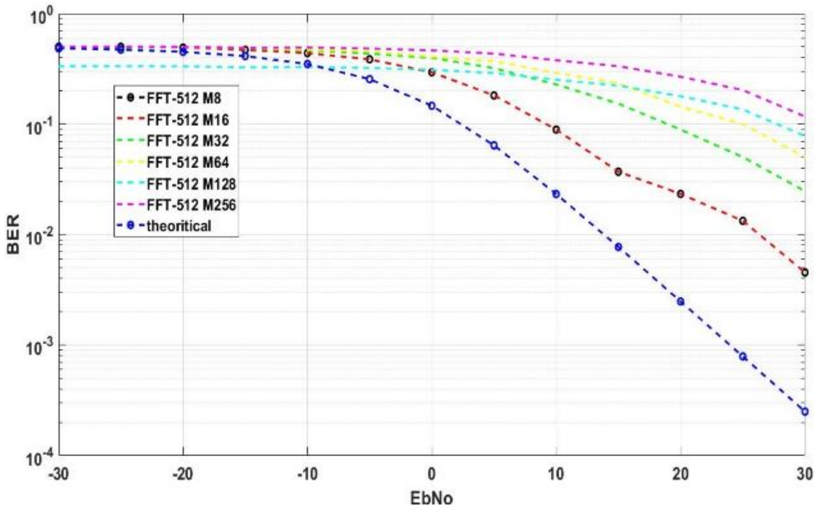


Figure. 12 BER of 512 FFT for various modulation order

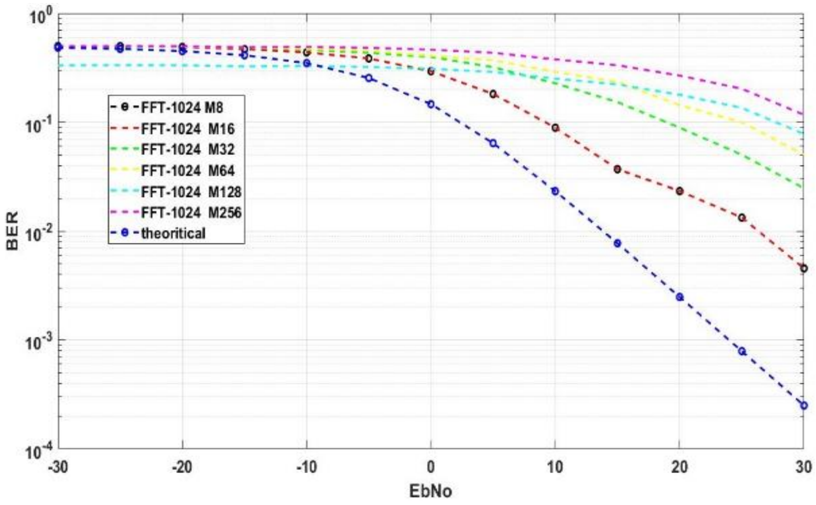


Figure. 13 BER of 1024 FFT for various modulation order

Table 2. Comparative analysis

| **Methods** | **PAPR (dB)** |
|---|---|
| Improved ACO [16] | 6.12 |
| DIWO-PTS [17] | 6.45 |
| PTS-DPSO-TH [18] | 6.23 |
| PSO-GWO | 6.05 |

Table 2 provides PAPR performance of improved ACO, DIWO-PTS, PTS-DPSO-TH and PSO-GWO method. The PSO-GWO method has higher efficiency in PAPR reduction due to escape from local optima trap and increases in convergence rate. The improved ACO method has limitation of stagnation, DIWO method has local optima trap, and PTS-DPSO-TH method has local optima trap. The PSO-GWO method has 6.05 dB PAPR, existing PTS-DPSO-TH has 6.23 dB PAPR value.

The BER of 512 FFT and 1024 FFT for various modulation orders are shown in Fig. 12 and 13. The M16 modulation order has a lower deviation than other modulation orders in the analysis.

## 5. Conclusion

The phase optimization in OFDM improves the efficiency of the wireless communication system. The existing methods involve phase optimization of OFDM which also has limitations of local optima and lower convergence. The PSO-GWO method is applied for OFDM phase optimization to reduce model error. The phase optimization is carried out in the OFDM signal based on the partial transmit sequence. The PSO-GWO method has the advantage of a fast convergence rate and effective search performance. The proposed and existing methods were tested in various lengths of FFT in OFDM signal optimization. The proposed method has higher efficiency than the existing method in the optimization process. The proposed method has 10-2 CCDF in 5.6 PAPR and the existing method requires more than 6 PAPR to achieve 10-2 CCDF. Modified optimization is applied to reduce the OFDM error rate in future work.

## Notation

| Symbol | Description |
|---|---|
| $c_1$ $and$ $c_2$ | social parameters and cognitive |
| $g_{best}$ | global best value |
| $i$ | Particle |
| $l$ | controlling parameter |
| $P_{average}$ | Average power of OFDM signal |
| $p_i^t$ | particle's best value |
| $P_{peak}$ | Peak power of OFDM signal |
| $PAPR_m$ | Fixed value of PAPR |
| $r_1$ $and$ $r_2$ | random numbers |
| $t$ | number of iterations |
| $v_i^{t+1}$ | Velocity of PSO |
| $W_{ph}$ | phase angles |
| $X$ | Time domain number of subcarriers |
| $x(t)$ | Signal amplitude |
| $X^l$ | Input data block of $L$ sub-blocks |
| $\alpha$ | Alpha |
| $\beta$ | Beta |
| $\gamma$ | Omega |
| $\delta$ | Delta |

## Conflicts of Interest

The authors declare no conflict of interest.

## Author Contributions

The paper background work, conceptualization, methodology, dataset collection, implementation, result analysis and comparison, preparing and editing draft, visualization have been done by first. The supervision, review of work and project administration, have been done by second author.

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