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Enhanced Artificial Bee Colony, Square Root Raised Cosine Precoding, and Mu law Compandor for Optimization of MIMO-OFDM System

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***Abstract*—The efficiency and high-speed data transfer rate of the communication system are increased based on Orthogonal Frequency Division Multiplexing (OFDM). The existing research in OFDM involves applying optimization methods to improve the system's efficiency. The high Peak Average Power Ratio (PAPR) value is a major limitation in the OFDM system, and this provides distortion due to the non-linear High-Power Amplifier (HPA). Local optima trap and lower convergence are two main limitations in existing optimization methods. This research proposes Enhanced Artificial Bee Colony (ABC) optimization method with a precoding-compandor technique to increase the efficiency of the OFDM system. Enhanced ABC method is applied with Boltzmann search to increase the exploitation capacity of the optimization efficiency. The selective mapping technique is applied to transform the candidate signal in the system. The ABC method increases exploration, and Boltzmann search increases exploitation. The enhanced ABC method increases the exploitation process that helps to overcome local optima traps and lower convergence. Square Root Raised Cosine (SRRC) precoding and Mu law compandor techniques were applied to reduce the PAPR. The Discrete Cosine Transform (DCT) technique is applied for domain conversion in the OFDM system. The proposed method has a convergence rate of 6.4069, and the existing one has a 6.4033 convergence rate. The enhanced ABC method provides higher efficiency in the MIMO-OFDM system regarding Symbol Error Rate (SER), PAPR, and Bit Error Rate (BER).**

***Keywords*—Enhanced artificial bee colony; orthogonal frequency division multiplexing; square root raised cosine precoding.**

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I. INTRODUCTION

In wireless communication, OFDM technology achieves a high data transmission rate. In the time domain, MIMO-OFDM signals have a large dynamic range, denoted as PAPR. The OFDM signal is clipped due to high PAPR when applied to non-linear HPA at the transmitter end. In OFDM systems, high PAPR is a major problem task for communication systems [1]. Multi-Input Multi-Output (MIMO) is a promising technology to improve Energy Efficiency (EE), Spectral Efficiency (SE), and capacity of multi-user networks by applying a Base Station (BS) with several antennas. The OFDM provides high side-lobes that cause out-of-band (OOB) radiation, demand strict synchronization and higher PAPR. New multi-carrier design waveforms are important to overcome the OFDM system [2]. Many PAPR reduction techniques, such as post-coding, pre-coding, PTS, SLM, filtering, and clipping, were applied in the MIMO-OFDM system [3]. The signal amplitude is clipped to in-band distortion and a predefined level in the clipping technique. The PTS and SLM techniques reduce high PAPR probability and send side information to the receiver, reducing bandwidth efficiency. Post-coding and pre-coding methods reduce the PAPR without affecting the BER performance, which requires additional processing and side information [4], [5].

In the OFDM system, various methods, such as clipping, probability, and coding techniques, are applied to reduce PAPR and BER in the system. The amplitude filtering and clipping method are introduced to reduce PAPR in the OFDM signal. The output signal is controlled based on a threshold value considering amplitude clipping [6]. The filtering method is mostly used in the OFDM system to regulate the PAPR, and sub-carrier power amplitude power is reduced to its limit to minimize the peak power. SLM algorithm presents the various data blocks to represent the information [7, 8]. PTS and SLM are two effective PAPR reduction techniques that suffer high computation complexity by applying Inverse

Discrete Fourier Transform (IDFT) [9, 10]. The contribution of the proposed method is discussed as follows:

- Enhanced ABC is proposed for optimizing the MIMO-OFDM system with the Boltzmann search process to increase the optimization efficiency. The Enhanced ABC method increases the model's exploitation capacity, improving the performance.
- SRC precoding and Mu law companding were applied to reduce the PAPR of the proposed method. The enhanced ABC method escapes from the local optima trap and increases the convergence of the optimization.

The OFDM is a promising technique in communication systems and novel broadcasting. OFDM-based systems face the problem of high PAPR that degrades the performance of the communication system. Some notable research in applying precoding and companding techniques to minimize PAPR in OFDM systems was reviewed in this section.

Sayyari et al. [11] proposed Dummy Sequence Insertion (DSI) and precoding techniques for efficiently reducing PAPR. The dummy sequence generation method was applied and a significant reduction of BER and PAPR was achieved compared to PTS based method and precoding technique. A hybrid PAPR reduction method based on precoding and DSI techniques considerably reduces the PAPR signal. The side information was not required for this method and did not degrade the BER performance of the system. A dummy sequence was created with the input data sequence to generate the signal of the first candidate. The IFFT was used to pass the signal, and if the PAPR value was less than the threshold, then the system transmitted the signal.

Mounir et al. [12] proposed hybrid precoding-companding techniques to minimize the out-of-band (OOB) radiation, BER, and PAPR in the OFDM system. The SRC precoding and Log companding were applied to minimize the PAPR of the system. The AWGN, Rayleigh, and HPA channels were considered in the proposed model in the OFDM system. The hybrid method provides higher performance than the PTS method in PAPR reduction. The hybrid method reduces OOB radiation and the BER in the OFDM system. The developed method minimizes the system's Error Vector Magnitude (EVM). The developed method increases the High-Power Amplitude (HPA) efficiency and reduces the PAPR in the system.

Yadav et al. [13] proposed a hybrid method of New Error Function (NERF) and Discrete Fourier Transform (DFT) precoder for reduction of PAPR. The companding technique of NERF reduces DFT of precoded OFDM signal and the precoder of DFT reduces PAPR. The hybrid method minimizes the PAPR and BER in the system than existing methods. The hybrid method is more efficient than other methods over the Rayleigh fading channel in the OFDM system.

Kaba and Patil [14] applied precoder Non-Orthogonal Multiple Access (NOMA) to reduce the PAPR in downlink NOMA. The developed method aims to reduce the PAPR and BER for NOMA multiusers. Discrete Cosine Transform (DCT), Zadof Chu Transform (ZCT), and Walsh Hadamard Transform (WHT) were diverse unitary transform that applies to minimize PAPR in the NOMA system.

Xing et al. [15] applied clipping, flexible hybrid companding, and regularization optimization for PAPR reduction. The companding function of two parts is applied for the reduction of computation complexity. The amplitude of signal samples was measured over a given value of constant value for small power compensation and peak power reduction. A linear companding function is applied for signals with samples less than a given amplitude. The regularization optimization is applied to jointly optimize the continuity of the companding function and companding distortion to improve the BER performance and PSD. The developed model has higher efficiency than referenced companding method in terms of PAPR. This paper is formulated as follows: the explanation of the enhanced ABC method is given in Section 2. The results are illustrated in Section 3. The conclusion of this research work is given in Section 4.

II. MATERIAL AND METHOD

This research proposes an enhanced ABC method for phase optimization in the OFDM system to reduce PAPR. The enhanced ABC method increases the search process's exploitation, improving the model's efficiency. The block diagram of the enhanced ABC method is shown in Figure 1.

A. MIMO-OFDM and PAPR

Summing all N modulated subcarriers to generate OFDM sequence when applying IFFT operation and subcarriers are allowed to be orthogonally with one another [16]–[20]. To understand OFDM, consider $X = \{X_k\ ,\ k = 0,\ 1, \ldots\ldots, N-1\}$ is block symbols of input data complex representation after mapping operation. The number of subcarriers is denoted as N and k^{th} subcarrier block data is denoted as X_k. Equation (1) provides the OFDM signal of the complex baseband.

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi k\Delta f t}, 0 \le t \le T \tag{1}$$

Where $j = \sqrt{-1}$, the frequency space between sub-carriers is Δf, the total time is denoted as T, the k^{th} subcarrier twiddle factor is denoted as $e^{j2\pi\Delta ft}$. The symbol bandwidth is $B = N \times \Delta f$, $1/T$ is set for Δf to ensure orthogonal between symbol sub-carriers. Equation (2) denotes the baseband OFDM signal.

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T}, 0 \le t \le T \tag{2}$$

Nyquist rate $(t = T/N)$ is applied to sample the baseband OFDM signal. The time domain of the discrete OFDM signal is expressed in equation (3).

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}, 0 \le n \le N-1 \tag{3}$$

Where the discrete sampling index is denoted as n, and the vector of the discrete OFDM signal is given in equation (4).

$$x(n) = [x_0, x_1, \ldots, x_{N-1}]^T \tag{4}$$

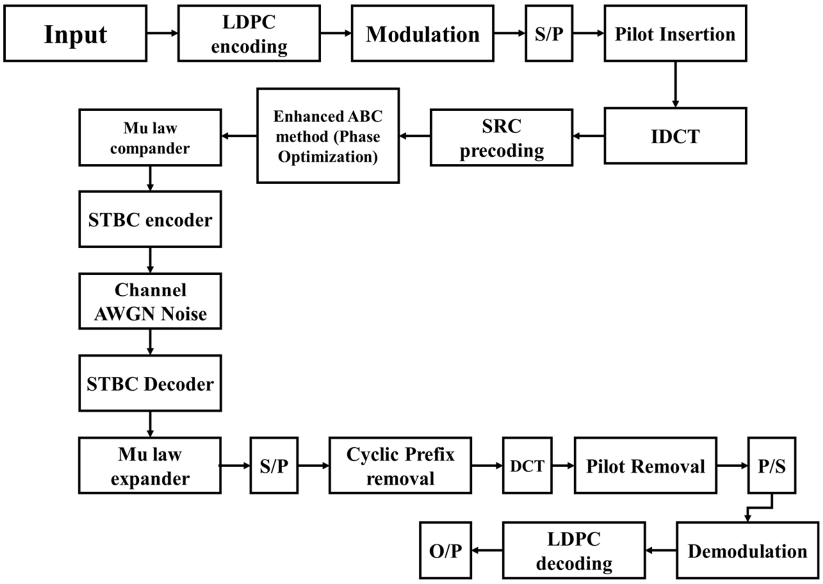

Fig. 1 The block diagram of the Enhanced ACO method of phase optimization in the OFDM system

B. Discrete Cosine Transform – Domain Conversion

Symbols are separately modulated for each user, and individual users of transmitting symbols are randomly generated [21]–[23]. Constellation symbols are applied for DCTM pre-coding. The autocorrelation relationship is reduced in the precoding method between transmitting symbols as shown in equations (5 & 6).

$$P_{jk} = \frac{1}{\sqrt{M}} j = 0,\ 0 \leq j \leq M-1 \tag{5}$$

$$\sqrt{\frac{\frac{2}{M}cos(\pi(2k+1)k)}{2M}} 1 \leq j \leq M-1, 0 \leq k \leq M-1 \tag{6}$$

C. PAPR Reduction

The PAPR reduction is carried out using three techniques: enhanced ABC method, Square root raised cosine precoding, and Mu law compander.

1) Precoding with Square root raised cosine: Precoding method has a large reduction gain of PAPR and small computational complexity. Transmitted signal distortion or side information is not required in the precoding technique. Most precoding matrices provide non-linear distortion than the original signal. The SRC matrix causes data loss and reduces distortion [24]. Equation (7) provides precoding matrix R.

$$R = \begin{bmatrix} R_{1,1} & R_{1,2} & \dots & R_{1,(N_T-N_R)} \\ R_{2,1} & R_{2,2} & \dots & R_{2,(N_T-N_R)} \\ \vdots & \vdots & \ddots & \vdots \\ R_{N_T,1} & R_{N_T,2} & \dots & R_{N_T,(N_T-N_R)} \end{bmatrix} \tag{7}$$

SRC precoding matrix of N_T subcarriers are spread with $(N_T - N_R)$, where subcarriers loss is denoted as $0 \leq N_R < N_T$. Subcarriers' losses become 0 if $N_R = 0$, which causes the SRC matrix to be a DFT matrix. The $R_{n,m}$ values are defined in equation (8).

$$R_{n,m} = R_{n,0} e^{j\left(\frac{2\pi nm}{N_T}\right)} \tag{8}$$

Where

$$R_{n,0} = \begin{cases} \frac{(-1)^n}{\sqrt{2}} sin\left(\frac{\pi n}{2N_R}\right), & 0 \leq n \leq N_R \\ \frac{(-1)^n}{\sqrt{2}}, & N_R \leq n \leq (N_T - N_R) \\ \frac{(-1)^n}{\sqrt{2}} cos\left(\frac{\pi(n-N_T)}{2N_R}\right), & (N_T - N_R) \leq n \leq N_T \end{cases}$$

The SRC precoding computational complexity is characterized based on number of real multiplications (RM_s) and real additions (RA_s), as given in equation (9 & 10).

$$RM_s = 4N_{DSC}(N_{DSC} - N_R) \tag{9}$$

$$RA_s = 2N_{DSC}(2(N_{DSC} - N_R) - 1) \tag{10}$$

Where number of data sub-carriers is denoted as N_{DSC}.

2) Mu-law Companding: Mu-law is a compression method that can be used to reduce PAPR [25], and PAPR reduction using the companding technique is discussed as follows.

Equation (11) expresses the transmitter of Mu-law compression of the signal.

$$S_u(t) = \frac{ln\left[1+\frac{u(|S(t)|)}{S_{max}(t)}\right]}{ln(1+u)} S_{max}(t).\ Sgn(S(t)) \tag{11}$$

Where Mu-law compand parameter is denoted as μ, sign function is denoted as Sgn, peak magnitude is denoted as $S_{max}(t)$, and input instantaneous magnitude is denoted as $S(t)$.

3) Selective Mapping: Data sequence of each input is denoted as $X = [X_1, X_2, \dots, X_N]$ and product by W phase sequence of randomly selected $\left(b^i = \left[b_1^i, b_2^i, \dots, b_N^i\right], i = 1,2,\dots,W\right)$ to generate W sequence of undergone phase scrambling $X_b^i, i = 1,2,\dots,W$ that consists of $\phi_s \in 0,2\pi)$ and $b_s^i = e^{j\phi s}, s = 1,\dots,N$. The W sequences are subsequently transforms into candidate signals by the Inverse Fast Fourier Transform (IFFT) and SLM technique [26 - 29], as shown in equation (12).

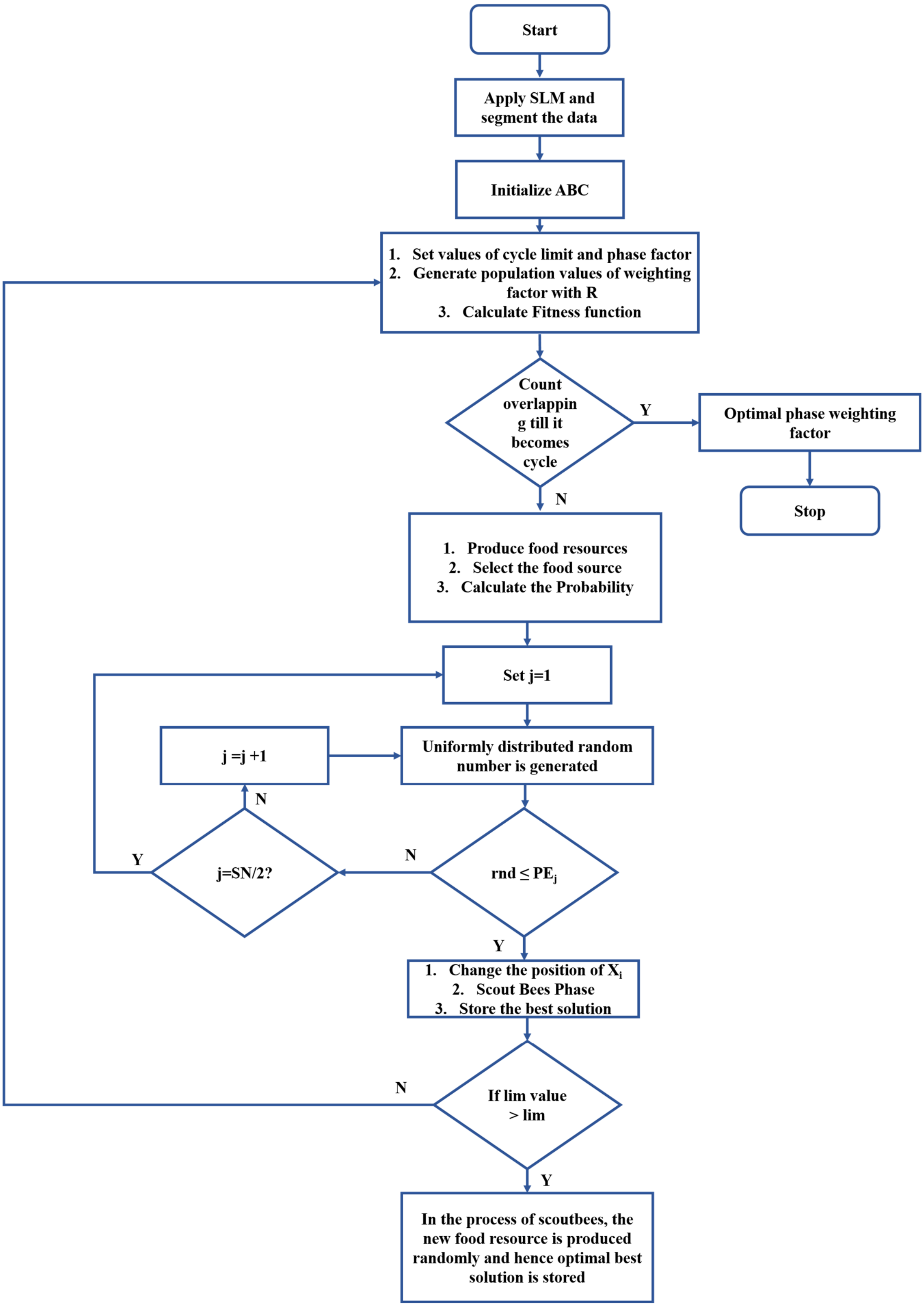

Fig. 2 The flow chart of Enhanced Artificial Bee Colony for PAPR reduction in MIMO-OFDM

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{k+1} b_k^i e^{\frac{j2\pi nk}{N}}, \; i = 1,2,\ldots,W \tag{12}$$

The transmission signal is the signal with the smallest PAPR by SLM technique (from W candidate signals) in the OFDM system, as in equation (13).

$$x_{selected}[n] = arg\,min(PAPR\{x^i[n]\}) \tag{13}$$

Where $i = 1, 2, \cdot\cdot\cdot, W$. The data sequence of the original input is restored based on the transmission system receiving end, and the transmission signal is signal information from receiving end. This process is described as

$log\ \ _2(W)$ bits and this is siding information. This process has a limitation on the phase-generation method and the SLM technique effectively decreases PAPR.

Due to randomly generated phase sequences, the systematic structure is not in phase generation. Phase sequence lacks a method to yield optimal PAPR with a candidate signal.

4) Enhanced ABC algorithm: Artificial Bee Colony Optimization method is inspired by bees gathering behavior nectar [30]. Each bee neighbourhood search optimization is measured by the global optimum and the ABC optimization are explained as follows:

Step 1: Food source initialization: Randomly generated number of feasible solutions (SN) are applied in the process. Food sources of the profit value are calculated using equation (14).

$$x_{i,j} = x_{min,j} + rand(0,1)\left(x_{max,j}, x_{min,j}\right) \qquad (14)$$

Where optimization problem of the number of parameters is denoted as D, and $x_i(i = 1, 2, \cdot \cdot \cdot, S_N)$ is D - dimensions vector.

Consider an arbitrary food source of x_i D dimensions vector. The food sources S_N centre point is x centroid of Ddimensional vector. The profit value is $fit(x_i)$ of food source x_i is given in equation (15).

$$fit(x) = \sqrt{\sum_{i=1}^{I}\left(x_i - x_{centroid}\right)^2} \qquad (15)$$

Step 2: Applied bees log itself as an optimum value and process the search in current food sources neighbourhood. The food sources search is given in equation (16):

$$v_{ij} = x_{ij} + \phi_{ij}\left(x_{ij} - x_{kj}\right) \qquad (16)$$

Step 3: Applied bees select food source based on the greedy method. Onlooker bee selects applied bee, as in equation (17).

$$p_i = \frac{fit(x_i)}{\sum_{n=1}^{SN} fit(x_n)} \qquad (17)$$

Where the number of feasible solutions is denoted as S_N.

Enhancement: Boltzmann selection technique is applied for selection of probability measure to choose one solution mutated, as given in equation (18).

$$PE_i = 1 - p_i = 1 - \frac{exp\left(\frac{fit_i}{T}\right)}{\sum_{n=1}^{\frac{SN}{2}} exp\left(\frac{fit_n}{t}\right)} \qquad (18)$$

Step 4: Food sources is selected by Onlookers based on p_i and applied bees search for new food sources and measure the profit value.

Step 5: After some iteration, no improvement is provided, it will give up and replace a new food source that is randomly generated.

Step 6: Measure the best result.

ABC method has many advantages compared with other heuristic methods such as easy to realize, fewer control parameters, and simpler structure. This has wide attention and research due to the wide range of searches and strong ability. The flow chart of the proposed method is given in Figure 2.

III. Result and Discussion

This research proposes an enhanced ABC method for PAPR reduction, BER, and SER in OFDM system. The DCT method is applied for domain conversion and precoder-compander is applied for PAPR reduction. Various FFT values and modulation orders were applied to test the efficiency of enhanced ABC method.

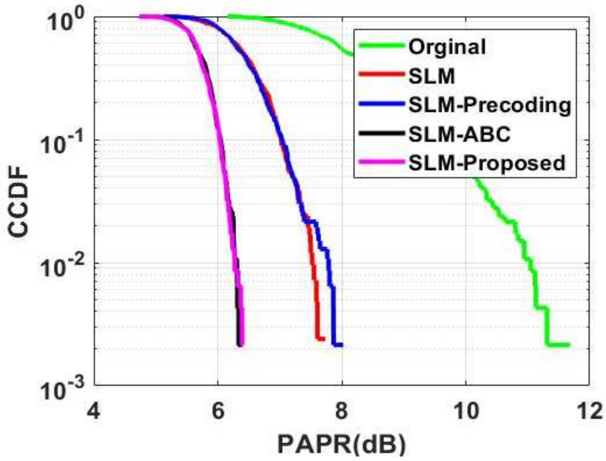

Fig. 3 Enhanced ABC method on PAPR reduction for FFT 64 M16

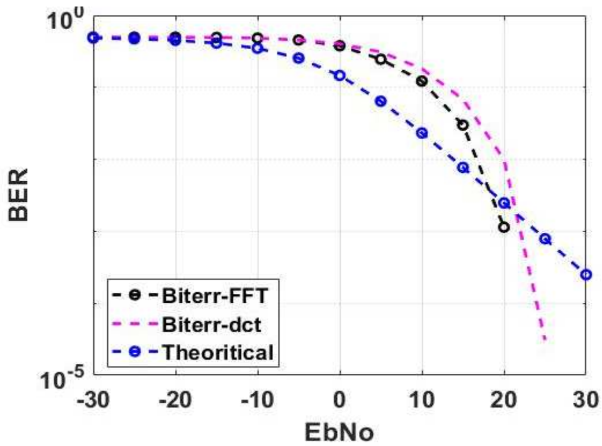

Fig. 4 BER of enhanced ABC in FFT 64 M256

Enhanced ABC method escapes from the local optima trap and increases the convergence due to increases in the exploitation process. The PAPR value of the enhanced ABC method with existing methods in FFT 64 of M16 and M256 modulation order are compared in Figures 3 and 4. The existing precoding affects the model's error rate and the ABC method has a limitation of lower convergence. The enhanced ABC has an average PAPR of 5.57, SLM-ABC has 5.68 PAPR, SLM-Precoding has 6.48 PAPR, SLM has 6.49 PAPR, and MIMO-OFDM has 8.39 PAPR.

PAPR value of enhanced ABC on FFT 128 on M8 modulation order and BER value of enhanced ABC method on FFT 128 M16 modulation is given in Figures 5 and 6. The enhanced ABC method has lower PAPR and BER values than the existing method due to increases in exploitation. The existing method of precoding and enhanced ABC method has limitations of higher error value and lower convergence.

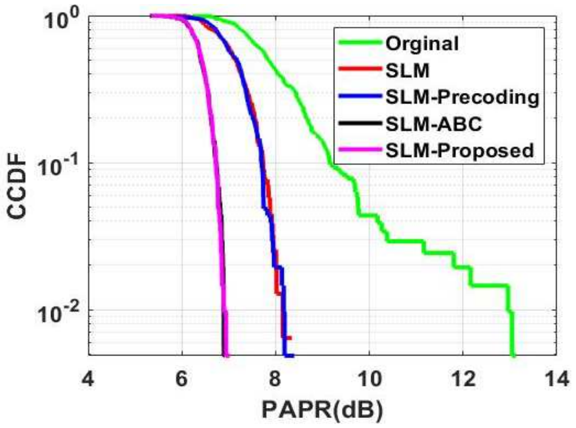

Fig. 5 PAPR of enhanced ABC in FFT 128 M8

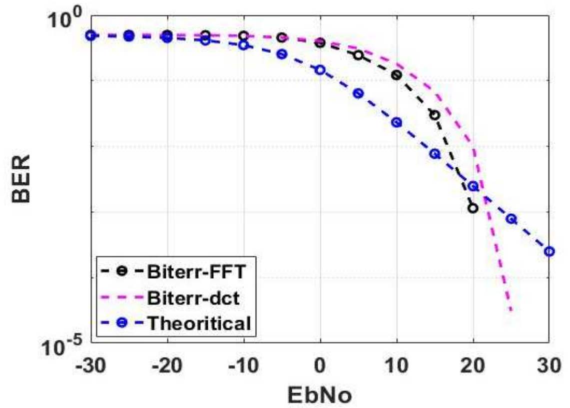

Fig. 6 BER of enhanced ABC method on FFT 128 M16

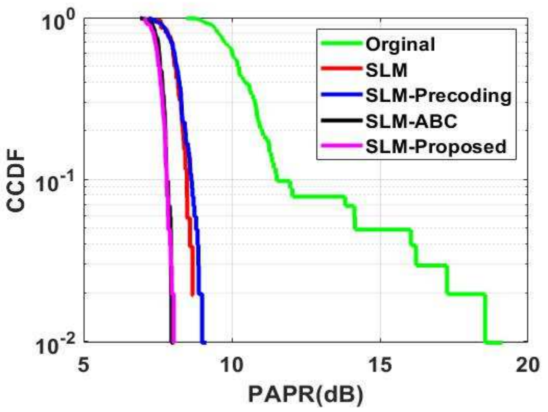

Fig. 7 PAPR of enhanced ABC method on FFT 512 M16

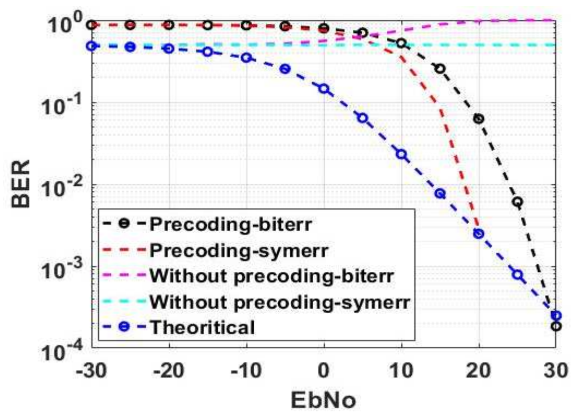

Fig. 8 BER of enhanced ABC method on FFT 512 M32

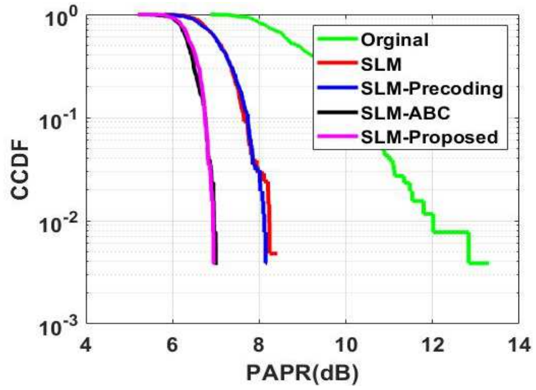

Fig. 9 PAPR of enhanced ABC method on FFT 512 M32

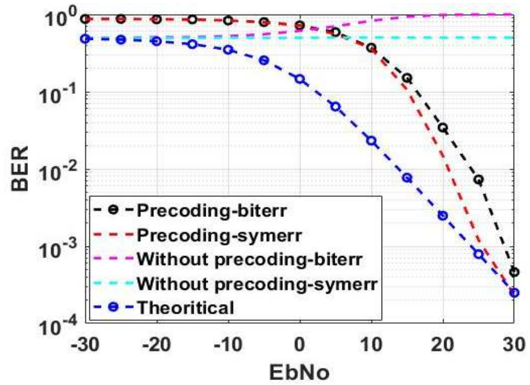

Fig. 10 BER of enhanced ABC method on FFT1024 M64

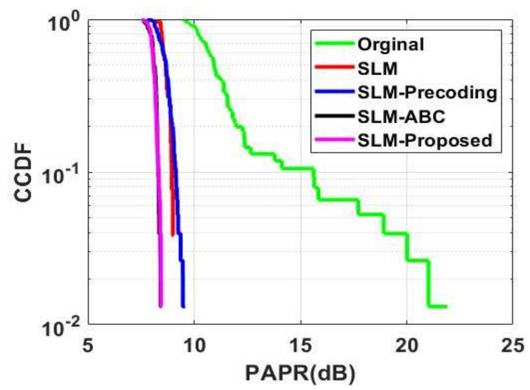

Fig. 11 PAPR of enhanced ABC method on FFT 1024 M64

PAPR of enhanced ABC method on FFT 512 M16, BER of enhanced ABC method on FFT 512 M32 modulation order, PAPR of enhanced ABC method on FFT 512 M32 modulation order are shown in Figures 7, 8 and 9, respectively. The enhanced ABC method has higher efficiency in various FFT values and modulation orders. The enhanced ABC method has the exploitation process of search that improves the convergence rate and escapes local optima trap.

Enhanced ABC method BER and PAPR value on FFT 1024 M64 modulation order are shown in Figure 10 and 11, respectively. The enhanced ABC method has the advantage of increases in exploitation and higher convergence. High error value, local optima and lower convergence are limitations in existing methods. The proposed method has a convergence rate 6.4069, and the existing one has a 6.4033 convergence rate.

IV. Conclusion

The existing research on the OFDM system applies various optimization methods, precoding, and compandor to improve the efficiency of the OFDM system. Higher BER and SER, lower convergence, and local optima trap in existing methods. This research proposes the enhanced ABC method with precoding and compandor techniques to improve the efficiency of the OFDM system. The enhanced ABC method has higher exploitation, improving the convergence rate and escaping the local optima trap. Square Root Raised Cosine precoding and Mu law compandor techniques were applied to reduce BER and SER. The enhanced ABC method with precoding-compandor technique improves the efficiency of the OFDM system. The enhanced ABC method achieves lower PAPR, BER, and SER than existing methods in the OFDM system.

Nomenclature

B	Symbol bandwidth
D	Number of parameters
$fit(x_i)$	Profit value
N	Number of subcarriers
n	Discrete sampling index
N_{DSC}	Number of data sub-carriers
R	Precoding matrix
RA_s	Number of real additions
RM_s	Number of real multiplications
$S(t)$	Input instantaneous magnitude
$S_{max}(t)$	Peak magnitude
S_N	Food sources
Sgn	Sign function
T	Total time
W	Phase sequence
X	Input data
$x(t)$	OFDM signal
Δf	Frequency space between sub-carriers
μ	Mu-law compand parameter

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