

## Modified Artificial Fish Swarm Algorithm for Peak to Average Power Ratio Reduction in OFDM Systems

By

**Tekanyi A. M. S., Abubilal K. A., Abbas A., and Salawudeen A. T.**

Department of Electrical and Computer Engineering,

Ahmadu Bello University, Zaria, Nigeria.

Email: [ahafiz2003@yahoo.com](mailto:ahafiz2003@yahoo.com)**ABSTRACT**

The multi-carrier Orthogonal Frequency Division Multiplexing (OFDM) technique suffers high Peak-to-Average Power Ratio (PAPR) that causes nonlinear signal distortion and reduction of power efficiency. But due to the non-linear optimization problem of the phase factor sequence selection, selecting its right sequence that gives minimal PAPR is the major challenge of Partial Transmit Sequence (PTS) technique widely used to reduce PAPR in the transmit data. PTS also suffers high complexity and inadequate memory when there is a large number of non-overlapping sub-blocks in one symbol. This research developed a modified Artificial Fish Swarm Algorithm (mAFSA) based PTS technique that generated the right optimum phase factor sequence for the least PAPR. The techniques were implemented in MATLAB R2015a and simulations were carried out using Complementary Cumulative Density Function (CCDF) metric to evaluate their performances. The mAFSA based PTS outperformed the standard AFSA (sAFSA) in PAPR reduction by 7.14%, 3.48% and 3.23% when the number of subcarriers were 32, 128, and 256 respectively. Furthermore when compared with the PTS only technique, mAFSA based PTS had an improved performance in PAPR reduction of 87.50%, 82.76% and 77.42% when the number of subcarriers were 32, 128, and 256 respectively.

**Keywords:** OFDM, PAPR, PTS, mAFSA, sAFSA, CCDF.

**INTRODUCTION**

OFDM is a special case of Multi-Carrier-Modulation (MCM) technique that divides the high data rate input data bit stream into several parallel large number of lower rate sub streams and each sub stream is transmitted over closely spaced orthogonal subcarriers (Venkatachalam & Manigandan, 2015). Each sub-carrier is modulated with a conventional modulation technique such as quadrature amplitude modulation or phase phase-shift keying at a very low symbol rate and maintains data rates similar to the conventional single carrier modulation schemes using the same bandwidth. The advantages of OFDM over other single carrier systems in wireless high speed data transmission (Jaya *et al.*, 2015) are:

- i. High Spectral Efficiency.
- ii. More resistant to frequency selection fading.
- iii. Simple channel equalization.

- iv. Robustness to channel fading.
- v. Immunity to impulse interference.
- vi. Flexibility of the system.

The large number of independently modulated subcarriers in OFDM can cause very high peak value when compared to the average of the whole system, which leads to the following drawbacks (Gangwar & Bhardwaj, 2012):

- i. OFDM signal exhibits very high Peak to Average Power Ratio (PAPR).
- ii. Very sensitive to frequency errors (transmitters and receivers offset)
- iii. Inter-Carrier-Interference (ICI) between the subcarriers.

In the recent past, there have been several researches on the PAPR problem resolution, resulting in several articles and papers such as the works of Mohanty & Ramavath, (2015); Sahoo & Patra, (2015); and Soliman *et al.*, (2015). Up to date, the PAPR

problem still prevents the adoption of OFDM in the uplink of mobile communication standards, as well as placing severe constraints on output power and coverage in the downlink (Wunder *et al.*, 2012). In addition, high PAPR brings about OFDM signal distortion in the nonlinear region of High Power Amplifier (HPA) and signal distortion induces the degradation of Bit Error Rate (BER) (Xiaowen *et al.*, 2011). Some of the popular methods for reducing PAPR include: Amplitude clipping (Wang & Luo, 2011), Coding (Naeiny *et al.*, 2010), Active Cancellation Extension (ACE) (Krongold & Jones, 2003), Selective Mapping (Li *et al.*, 2010), etc. Due to the complexity of these PAPR reduction methods, many researchers have used solutions based on Computational Intelligent (CI) techniques, which are relatively easy to implement and require less computational power. Reduction of PAPR using Artificial Bee Colony (ABC) optimization algorithm was proposed by Taspinar *et al.*, (2011) and Yu *et al.*, (2013). Bacterial Foraging Optimization (BFO) was used by Manjith & Suganthi, (2013) for PAPR reduction. An idea based on Particle Swarm Optimization (PSO) for PAPR reduction was employed by El Mouhib *et al.*, (2011) and Bi *et al.*, (2012). A modified Genetic Algorithm (GA) based Partial Transmit Sequence (PTS) with error correction for PAPR reduction was implemented by Liang *et al.*, (2010). The poor balance between exploration and exploitation in ABC and PSO bring about poor convergence, while the unnecessary oscillation in BFO and the inability of GA to provide near optimal solution because of their discrete nature is a draw back. Hence, there is a need for more researches on OFDM systems PAPR reduction techniques and this is the main focus of this work by experimenting a modified Artificial Fish Swarm Algorithm (mAFSA) based Partial Transmit Sequence (PTS) technique.

An optimization algorithm which is inspired by the intelligent swarming behaviours of the school of fish is called the standard AFSA (sAFSA). Generally, the primary behaviour of fish in water is to search for regions with more food either by its own swarming behaviours or by following the swarming behaviours of its neighbouring fish(es) (Mu'azu *et al.*, 2015). The individual behaviour of the artificial fish is to search for

local minima, which makes it difficult to move towards the global solution individually when dealing with multi-modal complex problems. This leads to some problems such as blindness of search and poor convergence (Mu'azu *et al.*, 2015). In this research, a mAFSA which works based on a feedback of the best individual result found to guide the evolution of the algorithms was used for PTS based PAPR reduction in the OFDM system and was able improve the computational complexity involved in phase factor selection which in turn reduced PAPR.

## OFDM SYSTEM

In OFDM, there exists a precise mathematical relationship between the frequencies of the carrier system and the processed signal is made digital in the frequency domain using the Inverse Fast Fourier Transform and Fast Fourier Transform (IFFT/FFT). The IFFT/FFT algorithms eliminate arrays of sinusoidal generators and coherent demodulation required in parallel data systems, which make the implementation of the technology cost effective. Therefore, both transmitter and receiver are implemented using the efficient FFT technique that reduce the number of operations from  $N^2$  in Discrete Fourier Transform (DFT) to  $N \log(N)$  in FFT (Cho *et al.*, 2010). OFDM does not use individual band-limited filters and oscillators for each sub-channel (Cho *et al.*, 2010) because of simultaneous transmission of sub-channels at frequencies that are orthogonal to each other. Furthermore, the spectra of subcarriers are overlapped for bandwidth efficiency, unlike the Filter Multi-Tone (FMT) scheme, where the wideband is fully divided into  $N$  orthogonal narrowband sub-channels. The major challenge for OFDM systems is that their signals exhibit a very high PAPR due to the high peak values of their transmit signals in the time domain. High PAPR decreases the Signal-to-Quantization Noise Ratio (SQNR) of Analogue-to-Digital Converter (ADC) and Digital-to-Analogue Converter (DAC) and also degrades the efficiency of the power amplifier in the transmitter (Taspinar *et al.*, 2011). The PAPR problem is more critical in the uplink since the efficiency of power

amplifier is limited by the battery power in the mobile terminal. Therefore, Radio Frequency (RF) power amplifiers need to be operate only in the linear region, otherwise, the signal peaks get into a non-linear region causing signal distortion. This signal distortion introduces intermodulation interference among the subcarriers and out of band radiation (Daoud & Alani, 2009). It is this reason why power amplifiers operate with large power back-offs and this in turn leads to very inefficient amplification and expensive transmitters. Hence, PAPR reduction is highly urgent and desirable if

the benefits of OFDM systems are to be achieved. Some of the popular and most used PAPR reduction techniques are (Taspinar *et al.*, 2011): Clipping, Coding, Selective Mapping (SLM), Tone Injection (TI), Tone Reservation (TR), Active Constellation Extension (ACE) and Partial Transmit Sequence (PTS). The block diagram of general system model of OFDM adopted by many researchers is shown in Figure 1.

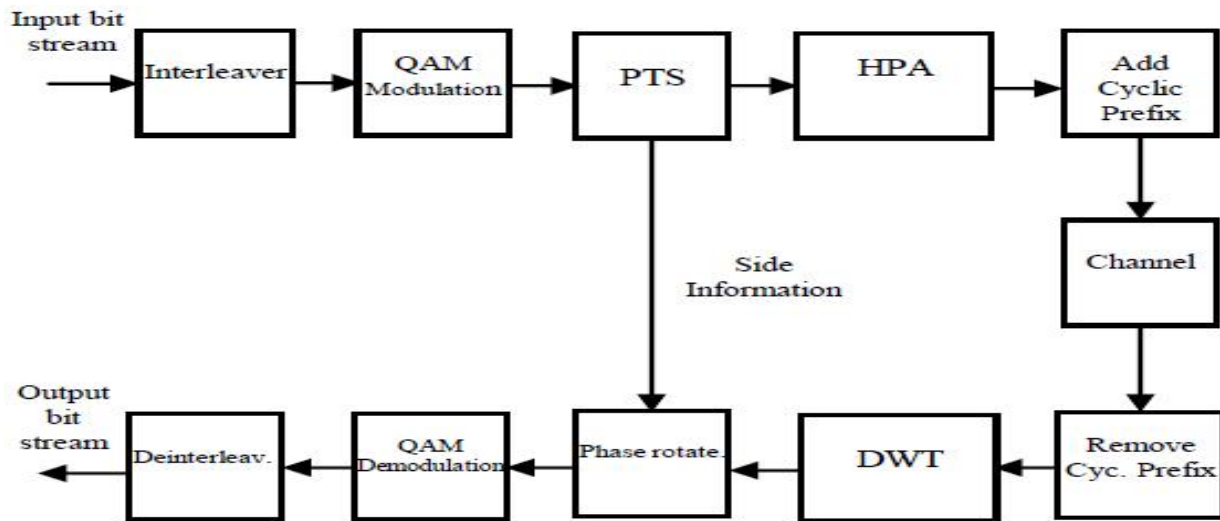


Figure 1: OFDM System Model (Taspinar *et al.*, 2011).

The user bits are interleaved to avoid burst errors in the communication channel and the signal is modulated with Quadrature Amplitude Modulation (QAM) scheme (Taspinar *et al.*, 2011). In this paper, the PTS is selected as the PAPR reduction technique.

**PARTIAL TRANSMIT SEQUENCE**

The Partial Transmit Sequence (PTS) technique partitions an input data block of *N* symbols into an *S* disjoint sub blocks (Cho *et al.*, 2010) as follows:

$$X_i = [X^0, X^1, X^2, \dots, X^{S-1}]^T \quad (1)$$

where  $X^i$  are consecutively located sub blocks of equal sizes. Each of this sub block is

partitioned with corresponding multiplication by a complex phase factor of:

$$b^s = e^{j\theta^s} \quad (2)$$

Taking the IFFT of product of *X* and *b* yields:

$$X = IFFT \left\{ \sum_{s=1}^S b^s X^s \right\} = \sum_{s=1}^S b^s IFFT \{ X^s \} = \sum_{s=1}^S b^s X^s \quad (3)$$

where  $\{ X^s \}$  is referred to as a PTS.

The phase factor is chosen as given in equation (2) such that PAPR is minimized.

$$[\tilde{b}^1, \dots, \tilde{b}^s] = \arg \min_{[b^1, \dots, b^s]} \left( \max_{n=0,1,\dots,N-1} \left| \sum_{s=1}^S b^s x^s [n] \right| \right) \quad (4)$$

The time domain signal with the lowest PAPR vector is expressed (Cho *et al.*, 2010) as follows:

$$X = \sum_{s=1}^S \tilde{b}^s X^s \tag{5}$$

In order to reduce the search complexity of the signal

$$\left\{ X = \sum_{s=1}^S \tilde{b}^s X^s \right\}$$

selection is limited to a set of certain elements as follows:

$$b = \left\{ e^{j2\pi i/W} \mid i = 0, 1, \dots, W - 1 \right\} \tag{6}$$

In the phase factor optimization, since the phase factor of the first sub blocks is usually taken as  $b_0 = 1$ , there are  $W^{S-1}$  alternate  $b$  combinations, where  $b = [b_0, b_1, b_2, \dots, b_{s-1}]$  and  $W$  is the number of phase factors. The  $b, b_s$  values are as follows (Taspinar *et al.*, 2011):

$$b_s = \begin{cases} \{\pm 1\} & , \text{ if } W = 2 \\ \{\pm 1, \pm j\} & , \text{ if } W = 4 \end{cases} \tag{7}$$

Several researchers have proposed a meta-heuristic algorithms such as BFO, PSO, ABC and AFSA based PTS technique for PAPR reduction in OFDM systems due their ease of implementation and robustness.

### MODIFIED AFSA BASED PTS SCHEME FOR PAPR REDUCTION

In order to implement the partial transmit scheme, the OFDM sequence is divided into multiple sub-sequence and each subsequence is multiplied by different weights using the mAFSA until an optimum value is obtained. Figure 2 shows the mAFSA based PTS for PAPR reduction.

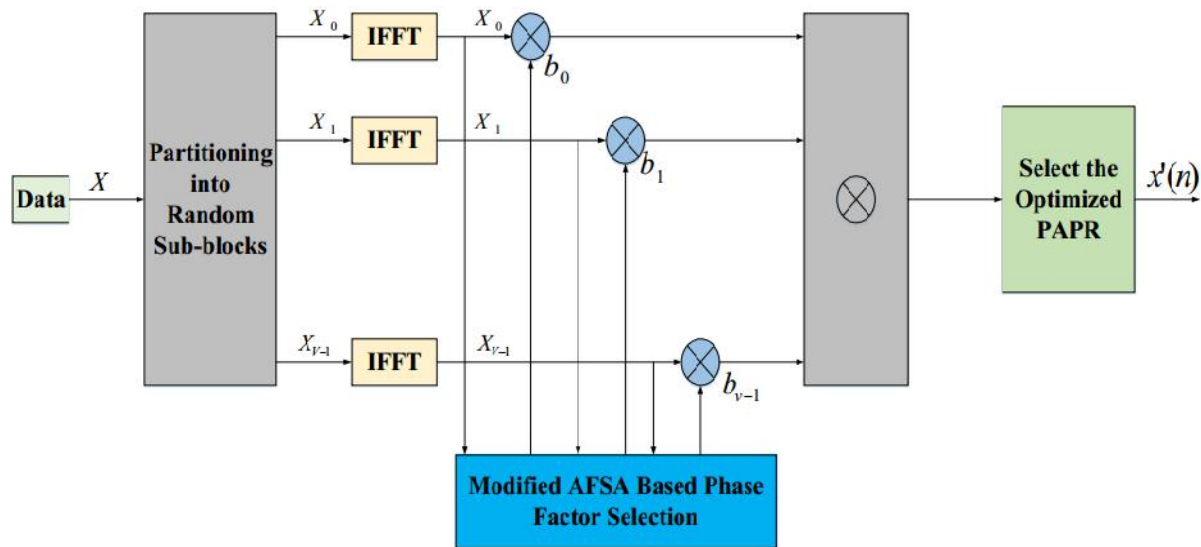


Figure 2: Modified AFSA Based PTS Model

From Figure 2, the data (information) stream in frequency domain  $X$  is separated into  $V$  non-overlapping sub-blocks and each sub-block vectors have the same size  $N$ . Therefore, every sub block contain  $NV$  nonzero elements and every other parts were set to zero. Different partitioning method have been proposed in literature, but for the purpose of this study, random partitioning method which provides an improved PAPR reduction and obeys the random principle of AFSA was

adopted. The sub-blocks were assumed to have the same size as (Taspinar *et al.*, 2011):

$$\hat{X} = \sum_{v=1}^V b_v X_v \tag{8}$$

where:

$$b_v = e^{j\ell_v} \left( \ell_v \in [0, 2\pi] \right) \{v = 1, 2, \dots, V\} \tag{9}$$

Equation (9) is the weighting factor used for phase rotation. The signal is converted into time domain by applying the IFFT operation on  $X_v$  by modifying equation (3) as follows:

$$\hat{x} = \sum_{v=1}^V b_v IFFT(X_v) = \sum_{v=1}^V b_v X_v \quad (10)$$

And:

$$b = [b_1, b_2, \dots, b_v] \quad (11)$$

In order to select a suitable optimum phase factor combination, the following objective function is employed for b in equation (11):

$$b = \operatorname{argmin}_{(b_1, b_2, \dots, b_v)} \left( \max_{1 \leq n \leq N} \left| \sum_{v=1}^V b_v x_v \right|^2 \right) \quad (12)$$

From equation (12)  $\operatorname{argmin}(\dots)$  is the judgment condition that output the minimum value of the objective function and the PAPR of the OFDM signal is determined. The transmitted signal of a continuous-time complex OFDM (Taspinar *et al.*, 2011) is given as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t}, 0 \leq t < NT \quad (13)$$

And:

$$X = [X_0, X_1, \dots, X_{N-1}] \quad (14)$$

The size of the input data vector corresponds to the size of the artificial fish swarm and the number of subcarriers  $N$  correspond to the population of fish. Each symbol is assigned to one subcarrier at a frequency of (Taspinar *et al.*, 2011):

$$f_v = v\Delta f, 0 \leq v \leq N - 1 \quad (15)$$

where subcarrier spacing is:

$$\Delta f = 1/NT \quad (16)$$

where,  $T$  is the symbol period of one OFDM signal. Since the PTS is required for discrete-time signals, Equation (13) is re-written as:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi f_n n/LN}, 0 \leq n < LN \quad (17)$$

where  $L$  is the oversampling factor.

The OFDM signal is oversampled when the value of  $L$  is 8. The PAPR of the discrete-time signal is expressed as (Taspinar *et al.*, 2011):

$$PAPR(x) = \frac{\max_{0 \leq n \leq LN-1} \{ |x(n)|^2 \}}{E \{ |x(n)|^2 \}} \quad (18)$$

where the function  $E\{\dots\}$  denotes the expected value of the OFDM signal.

It should be observed from Equation (12) that the PAPR reduction performance and computational complexity of the PTS algorithm are closely related to the sub-block partition and the searching nature of the weighting or phase factor selection. In this research, a suboptimum technique alongside the sAFSA were developed.

### MODIFIED AFSA IMPLEMENTATION

The sAFSA which simulate the foraging behaviour of school fish was employed for the optimum phase factor selection. Since in the sAFSA, the preying, swarming, and chasing behaviour are responsible for finding the optimum randomly deployed food sources. Therefore, the random partitioning method was adopted in this research. In the PAPR reduction problem, an artificial fish corresponds to a phase factor vector  $b_i = [b_{i1}, b_{i2}, \dots, b_{i(V-1)}]$  which is synonymous to the position of food in the solution search space. Assuming the current position of fish is  $b_i$ , the preying behaviour of sAFSA based on the phase factor determination is given as follows (Mu'azu *et al.*, 2015):

$$b_i^{(t+1)} = b_i + \operatorname{rand} \times \operatorname{step} \times \frac{b_j - b_i}{\|b_j - b_i\|} \quad (19)$$

Similarly, the swarming and chasing behaviour of sAFSA based on the phase factor notation are presented as follows:

$$b_i^{(t+1)} = b_i + W_i \times \operatorname{step} \times \frac{b_c - b_i}{\|b_c - b_i\|} \quad (20)$$

$$b_i^{(t+1)} = b_i + W_i \times \operatorname{step} \times \frac{b_{\min} - b_i}{\|b_{\min} - b_i\|} \quad (21)$$

where:  $b_i^{(t+1)}$  is the new phase (new food source)

$b_j$  is the current position

$b_i$  is the solution within the neighborhood of  $b_j$

$b_c$  is the center position of the food source (phase factor)

$b_{\min}$  is the best phase factor found so far within the visual distance.

In order to address some of the challenges of sAFSA, the best information obtained during the generation of sAFSA was used to increase the diversification of the search space. This is with the aim of addressing the imbalance between exploration and exploitation and improve the solution searching capability of the sAFSA. This is formulated as follows:

$$b_{new} = b_i + S \times | \times (b_{best} - \} ) \tag{22}$$

where:  $S$  is a random number generator with a mean of one and standard deviation of zero.

$|$  is the step size parameter

$b_{best}$  is the best individual found so far.

$\}$  is the weighted Euclidean position which depends on the behaviour evaluation. For example, if preying is the current behaviour under evaluation, then:

$$\} = \frac{b_j - b_i}{\|b_j - b_i\|} \tag{23}$$

if swarming is the behaviour under evaluation, then:

$$\} = \frac{b_c - b_i}{\|b_c - b_i\|} \tag{24}$$

if chasing is the behaviour under evaluation then

$$\} = \frac{b_{min} - b_i}{\|b_{min} - b_i\|} \tag{25}$$

The flowchart for the implementation of the developed modified artificial fish swarm algorithm-based partial transmit sequence is given in Figure 3.

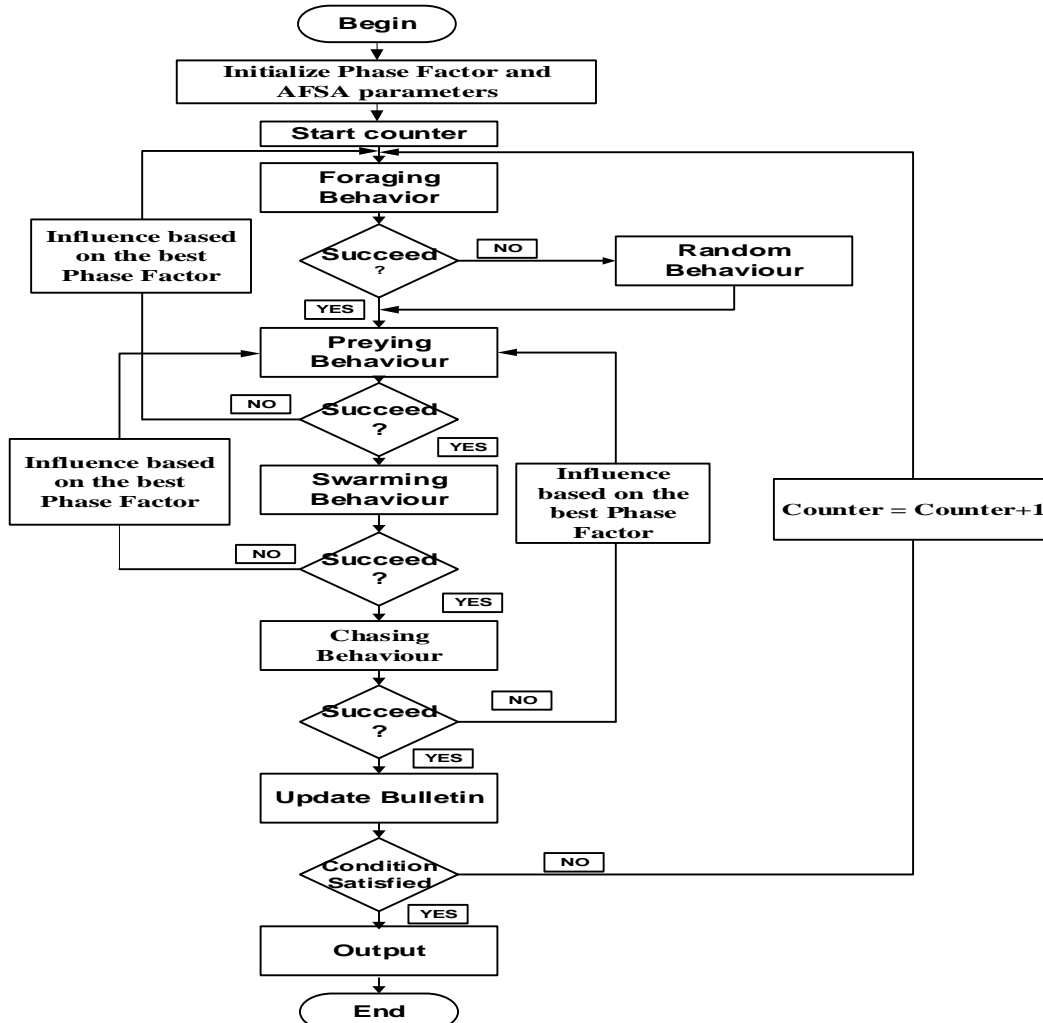
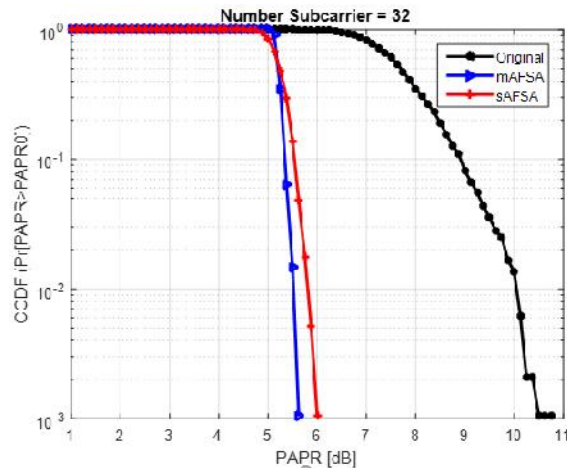


Figure 3: Implementation of the Developed mAFSA based PTS.

**RESULTS AND DISCUSSION**

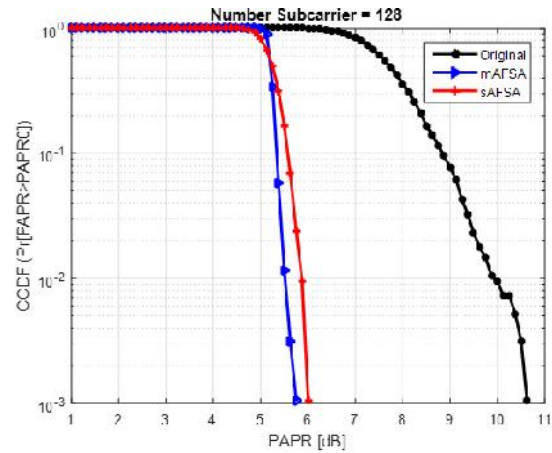
The performance evaluation of the developed mAFSA-PTS technique shown in Figure 3 was carried out by comparison of its results with those of both sAFSA-PTS and the PTS only techniques using the Complementary Cumulative Distribution Function (CCDF) metric.



**Figure 4:** CCDF against PAPR Plot for 32 Subscribers

Figure 4 shows the results for the mAFSA-PTS, sAFSA-PTS, and PTS only techniques used in the selection of the phase weighting factor needed for the least PAPR. The phase weighting sequence length of ( $L = 8$ ) was used and the number of subcarriers was set 32. From the results of Figure 4 the least PAPR for the mAFSA-PTS is at 5.6 dB, sAFSA-PTS is at 6.0 dB, and the PTS only is at 10.5 dB, respectively. This shows that the mAFSA-PTS yields better result than both the sAFSA-PTS and the PTS only techniques.

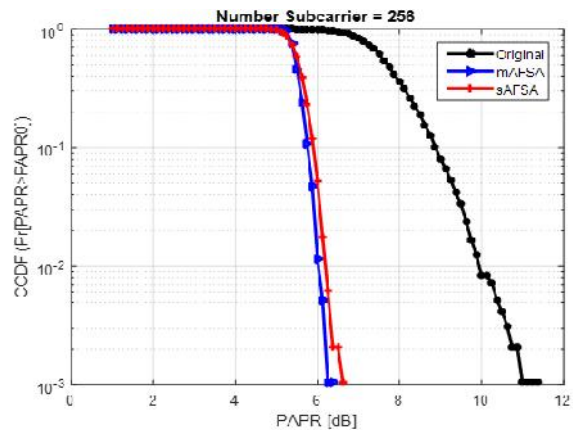
The number of subcarriers was increased to 128 as depicted in Figure 5 and the results for the mAFSA-PTS, sAFSA-PTS, and PTS only techniques used for the selection of the phase weighting factor needed for the least PAPR were obtained using the same phase weighting sequence length of ( $L = 8$ ).



**Figure 5:** CCDF against PAPR Plot for 128 Subscribers

Again, the mAFSA-PTS result has the least PAPR value at 5.8dB, followed by sAFSA-PTS at 6.0dB and then PTS only at 10.6dB.

Furthermore, when the number of subscribers was increased to 256 with the same phase weighting sequence length of ( $L = 8$ ) as indicated in Figure 6, the results of these techniques used for the selection of the phase weighting factor for the least PAPR were found to be 6.2 dB for mAFSA, 6.4 dB for sAFSA-PTS and 11.0 dB for PTS only technique. Again, mAFSA was the best.



**Figure 6:** CCDF against PAPR Plot for 256 Subscribers.

**CONCLUSION**

This research has presented the development of a modified artificial fish swarm algorithm-based partial transmit sequence technique for peak to average power ratio reduction in orthogonal frequency division multiplexing. Due to the ease at

which the sAFSA falls into local minima, this was resolved by modifying sAFSA to obtain mAFSA using the global best information obtained from the previous generation. The mAFSA was also able to reduce the high PAPR main drawbacks of OFDM, which causes signal distortion and Bit Error Rate (BER) performance degradation by eliminating nonlinear distortion effects (because of its low PAPR) and improved power efficiency of the high-power amplifier. Therefore, the developed mAFSA was used for phase factor selection in the partial transmit sequence based PAPR reduction for the OFDM system. The performance of the mAFSA technique was evaluated and result showed significant reduction in the peak to average power ratio.

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