Received: March 5, 2021. Revised: March 31, 2021.

International Journal of
Intelligent Engineering & Systems

http://www.inass.org/

A Modified ABC-PTS with Non-Uniform Phase Factor for OFDM Signal

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Abstract: Time-domain OFDM (Orthogonal Frequency Division Multiplexing) signal has various different levels from many subcarriers in one frame which are fatal effect in the non-linear OFDM channel. Because of the signal distortion occurring at the output of non-linear power amplifier, the performance of system has failure. This issue is called that Peak to Average Power Ratio or PAPR which is the main issue of concern for OFDM system. One of the effective PAPR reduction technique known as partial transmit sequence (PTS) with non-uniform phase factors investigating between 0 and 2π was proposed to solve this issue which can suppress the PAPR value competently by clustering their data subcarriers in frequency-domain and multiplying data subcarriers in each cluster by non-uniform phase factors in time-domain after *IFFT* (inverse fast Fourier transform). However the computational complexity is increased in proportion to the increasing of cluster numbers. By carefully reducing the PAPR of time-domain OFDM signal with small computational complexity, this paper proposes a modified ABC (Artificial Bee Colony) with PTS (ABC-PTS) scheme which can reduce the PAPR of time-domain OFDM signal by applying non-uniform phase factor in the weighting factor sequences with small computational complexity of PAPR reduction process by performing the modified ABC algorithm. The simulation results in this paper can demonstrate that the proposed scheme outperforms approximate 0.4dB and 0.8dB over the original PTS for adjacent and interleaved respectively and approximate 3.2dB over the conventional OFDM at CCDF=10^{-2} (Complementary Cumulative Distribution Function) with smaller computational complexity which is 19.14% approximately as compared with the original PTS. Moreover, the radix-2, radix-4 and split-radix *DIF-IFFT* (Decimation-in-Frequency *IFFT*) algorithms are employed to reduce the computational complexity which are approximate 50%, 62.5% and 66.67% for PAPR reduction process without affecting the optimum PAPR performance.

Keywords: OFDM, PAPR reduction, PTS, ABC, Radix, DIF-IFFT.

1. Introduction

An Orthogonal Frequency Division Multiplexing (OFDM) [1] is a popular wireless communication technique because the occupied bandwidth of transmission is efficiently used and transmission signal can be strongly distributed to the multipath fading channel etc. From these benefits, many wireless transmission standards take an OFDM technique such as the digital video broadcasting – second generation terrestrial (DVB-T2) [2], the wireless local area network (WLAN) [3], the long term evolution (LTE) [4, 5] and so on. However, its major limitation in time-domain non-linear channel is the higher peak to average power ratio (PAPR) [6, 7] due to the summation of amplitude of several data subcarriers. The time-domain OFDM signal has a lot of severe distortions at the output of non-linear power amplifier. From this problem, the system would be fatally degraded because of the more bit error rate (BER).

To relieve the problem due to the larger PAPR in the time-domain OFDM signal, the partial transmit sequence (PTS) schemes were proposed in [8, 9] to suppress the PAPR value by clustering their data subcarriers in frequency-domain and multiplying them in each cluster by uniform phase factors investigating within $[0, 2\pi)$ in time-domain after *IFFT*. By using PTS scheme, the PAPR of the time-domain OFDM signal is greatly reduced. However, the PTS with non-uniform phase factor distributed between 0 and 2π was proposed in [10] which can

Received: March 5, 2021. Revised: March 31, 2021.

reduce the PAPR beating the PTS with uniform phase factors.

From the effectiveness of using the PTS schemes as mentioned above, the PAPR problem can be solved. However, the more computational complexity of the optimized PAPR process in the PTS scheme is a significant issue. To fix this issue, this paper proposes a modified ABC-PTS scheme for time-domain OFDM signal. In the proposed scheme, the optimized PAPR values are founded by dividing data subcarriers in frequency-domain into V clusters and partitioning them in each cluster by two then multiply them in each cluster in time-domain by non-uniform phase factor in the weighting factor sequences so as to improve the PAPR issue. While the computational complexity of the optimized PAPR process can be reduced by performing the modified artificial bee colony (modified ABC) technique [11]. Furthermore, the radix DIF-*IFFT* techniques would be employed for the proposed scheme for reduction of the computational complexity required in the *IFFT* processing in the PAPR reduction.

This paper has ordered the information by the following as: Section 2 shows the OFDM system with PAPR reduction by using the original PTS scheme. The PAPR reduction with small complexity technique is proposed in Section 3. Section 4 presents the simulation and discussion. Finally, the summary is given in Section 5.

2. OFDM system with PAPR reduction by using the original PTS scheme

The M data subcarrier signals in frequency-domain as X_n for $0 \leq n \leq M-1$ with original PTS scheme is clustering M data subcarriers by V. Each cluster contains M/V data subcarriers with $(M-M/V)$ null subcarriers as $X_n^{(v)}$ for $1 \leq v \leq V$. The frequency-domain signal $X_n^{(v)}$ with zero-padding insertion (in case of $N>M$) is performed by N-points *IFFT* so we obtain the time-domain OFDM signal as $x_k^{(v)}$ for $0 \leq k \leq N-1$. The signal $x_k^{(v)}$ can be represented as

$$x_k^{(v)} = \frac{1}{\sqrt{N}} \sum_{n=0}^{M-1} X_n^{(v)} \cdot exp\left(-j\frac{2\pi nk}{N}\right). \quad (1)$$

In the original PTS, the optimization of PAPR value for the time-domain OFDM signal in Eq. (1) can be expressed as

$$\tilde{x}_k = \sum_{v=1}^{V} x_k^{(v)} \cdot exp\left(j\theta^{(v)}\right). \quad (2)$$

Considering the optimum PAPR value of Eq. (2), it can be chosen from the condition which can be defined as

$$\hat{v} = \underbrace{\arg\min}_{\theta^{(v)}} \left\{ \underbrace{\arg\max}_{0 \leq k \leq N-1} \left(\left| \tilde{x}_k \right| \right) \right\}. \quad (3)$$

In the calculation of PAPR for the time-domain OFDM signal in Eq. (2), it would be computed from the ratio of the maximum PAPR value and average PAPR value of $\tilde{x}_k$ which can be given by

$$PAPR = \frac{max|\tilde{x}_k|^2}{E[|\tilde{x}_k|]}, \quad (4)$$

where $|.|^2$ and $E[|.|]$ are the absolute operation for calculating the maximum PAPR value of $\tilde{x}_k$ and the expectation operation for finding the average PAPR value respectively.

The probability of the higher PAPR referred to the reference value as $PAPR_0$ is defined by the complementary cumulative distribution function (CCDF) which is given by

$$\begin{aligned} &CCDF\ of\ PAPR_0 \\ &= Prob.of\left(PAPR|_{inEq.(4)} > PAPR_0\right). \end{aligned} \quad (5)$$

3. Proposal of modified ABC-PTS scheme with non-uniform phase factor

This section presents the proposal of PAPR reduction scheme. In our work, we modify the original PTS by separating data subcarriers in each cluster by two determined partitions with non-uniform phase factor and apply the concept of original ABC technique for finding the desirable phases. The corresponding performance is gain in PAPR reduction with small reasonable computational complexity.

3.1 Two determined partitions-PTS

From the characteristic of time-domain OFDM signal as shown in [12], it can be observed that the possible PAPR values of time-domain OFDM signal after performing by N-point *IFFT* shows the mirror PAPR values between their first N/2-PAPR values and consecutive N/2-PAPR values. From this result, this paper proposes two determined partitions-PTS technique which separates the M/V data subcarriers of each cluster by two in frequency-domain. The procedure of two determined partitions-PTS

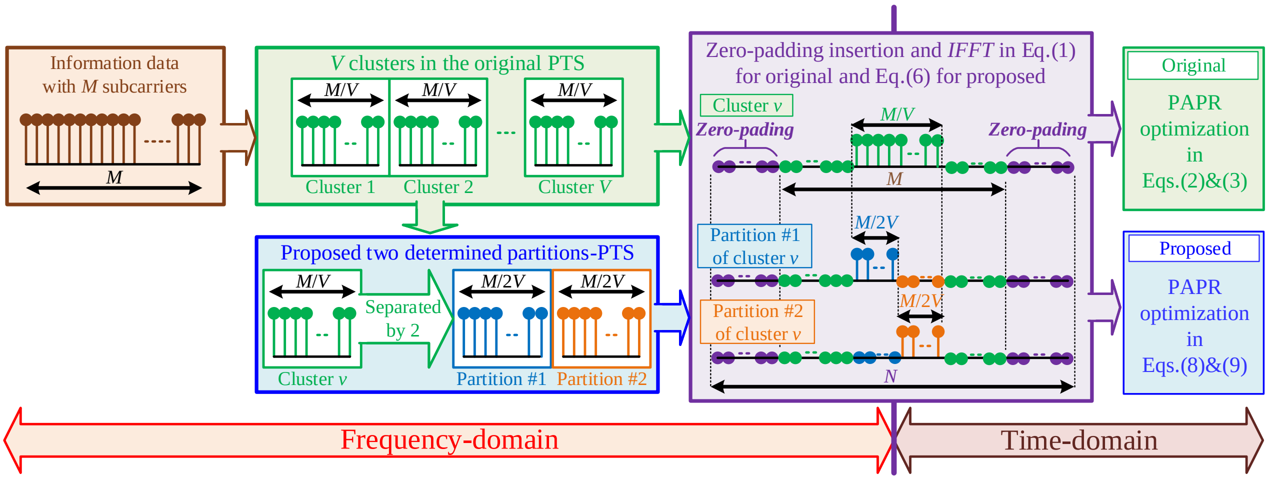

Figure. 1 Two-partitioned concept in the proposed PAPR reduction

technique would be explained step by step via the block diagram which is shown in Fig.1.

Fig. 1 shows the block diagram of proposed two determined partitions-PTS as compared with the original PTS which processes between in the frequency and time domains. The process of our work starts from inputting the information with M data subcarriers to the clustering section. Dividing M data subcarrier sequences into V clusters which are consecutive from cluster 1 to cluster V. Each cluster contains M/V data subcarriers. In the original PTS, M/V data subcarriers in each cluster with M-(M/V) null subcarriers are inserted by zero-padding at both ends of M data subcarriers then converted from frequency-domain into time-domain by N-points *IFFT* in Eq. (1). Finally, the PAPR optimization of time-domain OFDM signal by using the original PTS would be operated in Eqs.(2) and (3) respectively. In our work, before performing by N-points *IFFT* each cluster in the frequency-domain will be separated M/V data subcarriers by two as partition #1 and partition #2 which both of them carry the $M/2V$ data subcarriers instead of performing cluster with M/V data subcarriers directly in the original PTS.

In the frequency-domain, the $M/2V$ data subcarriers in partition #i with adding M-($M/2V$) null subcarriers as $X^{\#i(v)}$ for i=1 and 2 will be inserted by zero-padding at both ends of M data subcarriers then performed by N-points *IFFT* which can be given the time-domain OFDM signal in each partition by

$$x_k^{\#i(v)} = \frac{1}{\sqrt{N}} \sum_{n=0}^{M-1} X_n^{\#i(v)} \cdot exp\left(-j\frac{2\pi nk}{N}\right). \quad (6)$$

After that the time-domain OFDM signal $x_k^{\#i(v)}$ in Eq. (6) will find the optimum PAPR value from the multiplication between the $x_k^{\#i(v)}$ and phase factors which can be expressed by

$$\hat{x}_k = \sum_{v=1}^{V} \left\{ x_k^{\#1(v)} \cdot exp\left(j\theta^{\#1(v)}\right) + x_k^{\#2(v)} \cdot exp\left(j\theta^{\#2(v)}\right) \right\}. \quad (7)$$

From the relationship of phase factor between two partitions, it can be observed that $\theta^{\#2(v)}$ becomes zero when λ=0 [13]. Therefore, the optimized PAPR of time-domain OFDM signal in Eq. (7) can be rewritten by

$$\hat{x}_{prop.,k} = \sum_{v=1}^{V} \left\{ x_k^{\#1(v)} \cdot exp\left(j\theta^{\#1(v)}\right) + x_k^{\#2(v)} \right\}, \quad (8)$$

where $\hat{x}_{prop.,k}$ represents the proposed time-domain OFDM signal with PAPR optimization process.

From the proposed time-domain signal in Eq. (8), the optimum PAPR value of $\hat{x}_{prop.,k}$ will obtain from considering the condition which can be defined as

$$\hat{v}_{prop.} = \underset{\theta^{\#1(v)}}{\arg\min} \left\{ \underset{0 \le k \le N-1}{\arg\max} \left(\left| \tilde{x}_{prop.,k} \right| \right) \right\}. \quad (9)$$

In the observation on PAPR reduction process in Eq. (8), because there is no the multiplication for $x_k^{\#2(v)}$ in the partition #2 (operated only in the partition #1), the computational complexity technique of the optimum PAPR process requires in the proposed scheme would be decreased relatively.

From the reason in the previous paragraph, it can be expected that the small computational complexity in PAPR reduction can be performed by using the proposed scheme. Furthermore, the proposed signal in Eq. (9) will be optimized their PAPRs in Eq. (10) with small computational complexity by using the proposed phase factors generated by the modified ABC technique which will be thoroughly detailed in the next section.

3.2 Low computational complexity for proposed PAPR reduction by modified ABC with non-uniform phase factor

From the more complexity issue in the original PTS scheme, this paper modified the algorithm of artificial bee colony for finding the desired phase factors with phase factors distributed non-uniformly within 2π. From using this concept, it would give the low PAPR value with small reasonable computational complexity.

$$\theta_{conv.}^{(v)} \in \frac{2\pi\ell}{W}, \ell = 0,1,\ldots,W-1 \tag{10}$$

From Eq. (10), the discrete phase factors which are taken by four pre-determined phases (W=4) are 0, $\pi/2$, π and $3\pi/2$ respectively. From the results, it can be seen that the interval between consecutive phases is equal. By using these phase factors in original PTS, the low PAPR values would be given for the time-domain OFDM signal. However, in [10] the non-uniform phase factor was applied in the original PTS for PAPR reduction. The non-uniform phase factors for W=4 are expressed as

$$\theta|_{non-UFforW=4} = \{0,0.64\pi,\pi,1.36\pi\} \tag{11}$$

The PAPR performance of using the original PTS with non-uniform phase factor as given in Eq. (11) outperforms that with uniform phase factor for W=4 as given in Eq. (10). From this reason, the discrete phase factors used in the proposed PAPR reduction scheme in Eq. (8) and (9) are initially selected from the non-uniform phase factors as given in Eq.(11).

In the consideration of computational complexity (CC) of PAPR reduction for the original PTS computed in Eq. (2) and the proposed computed in Eq. (8), it can be defined as

$$CCofPTS|_{inEq.(2)} = (M/V)\cdot W^V \tag{12}$$

$$CCofProp.|_{inEq.(8)} = (M/2V)\cdot W^V \tag{13}$$

In comparison of computational complexity between the original PTS in Eq. (12) and the proposed in Eq. (13), it can be concluded that the half of computational complexity in PAPR reduction by using the original PTS would be reduced by using the proposed. From the conclusion, it can make a confirmation that the proposed two determined partitions-PTS can provide lower computational complexity in the PAPR reduction than the original PTS.

3.2.1. A modification of ABC technique

One of the main issues of using the original PTS scheme in the PAPR reduction is the more computational complexity in the optimization of PAPR. Because the PAPR value would be reduced by multiplying data subcarriers in each cluster by phase factor, the computational complexity due to the multiplication operated in PAPR reduction is increased in proportion to the increasing number of clusters. For the example, from Eq. (12) if W and V both are taken by 4, the number of phase factor patterns (W^V) is 256 patterns. When increasing V to 8, W^V is 65,536 patterns. From this result, it can be seen that its computational becomes so huge complexities. Even though the improvement of PAPR performance is performed by using the original PTS, its computational complexity is hugely increased. Many techniques have been proposed to solve this issue and one of these techniques is an ABC technique proposed in [11] which can reduce the computational complexity in the PAPR reduction process efficiently. In ABC technique, there are four main parameters in the consideration as follows: food source, employed, onlooker and scout bees. From the procedures of ABC technique proposed in [11], the desired phase factors will be generated by four sections.

Although the computational complexity issue can be fixed efficiently by applying the ABC technique, the complicated procedure is provided for operating. To realize this problem in this paper, the modification of ABC technique with non-uniform phase factor was proposed for generating phase factors considered in PAPR reduction which provide lower complicated process than the original technique.

Fig. 2 shows the block diagram of the modification of ABC technique. Firstly, the initial of pre-determined phase factors for W=4 as $\theta_{initial}^{\#1(v)}$ is set by the non-uniform phase factor in Eq. (11) as the food source. The population (P) of food source obtains from generating randomly phase factors with in the set of $\theta_{initial}^{\#1(v)}$. The employed and onlooker bees are employed for finding a new food source from the

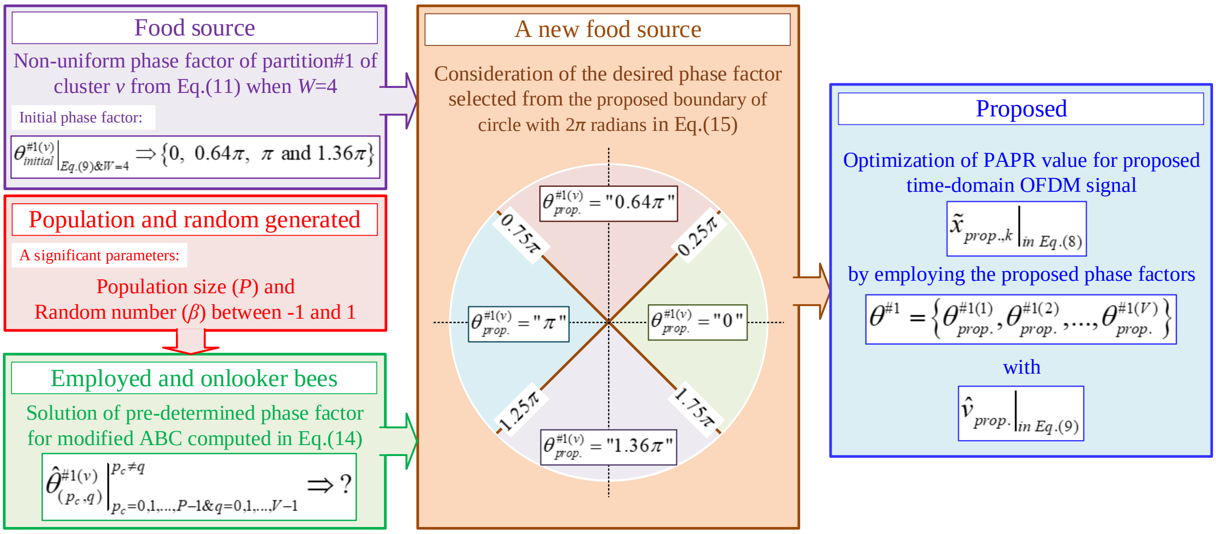

Figure. 2 The proposed phase factors generated by the modified ABC technique

comparison between the new food source and the honey in the the district of the prior food source.

The concept of the modified ABC technique can be defined parameters in equation form as follows

$$\hat{\theta}_{p_c,q}^{\#1(v)} = \hat{\theta}_{p_c,q}^{\#1(v)} + \beta_{p_c,q} \cdot \left[\hat{\theta}_{p_c,q}^{\#1(v)} - \hat{\theta}_{p_p,q}^{\#1(v)}\right] \quad (14)$$

where $\hat{\theta}_{p_c,q}^{\#1(v)}$ and $\hat{\theta}_{p_p,q}^{\#1(v)}$ are denoted by the current and previous food sources for p_c and $p_p = 0,2, \ldots, P-1$ and $q = 0,1,2, \ldots, V-1$ respectively. β is randomly generated within [-1, 1].

From Eq. (14), the proposed phase factors $\theta_{prop.}^{\#1(v)}$ which is employed in Eq. (8) would be chosen from the proposed boundary of circle with 2π radians which can be expressed as

$$\theta_{prop.}^{\#1(v)} = \begin{cases} 0.64\pi, & 0.25\pi \le \hat{\theta}_{p_c,q}^{\#1(v)} < 0.75\pi \\ \pi, & 0.75\pi \le \hat{\theta}_{p_c,q}^{\#1(v)} < 1.25\pi \\ 1.36\pi, & 1.25\pi \le \hat{\theta}_{p_c,q}^{\#1(v)} < 1.75\pi \\ 0, & 1.75\pi \le \hat{\theta}_{p_c,q}^{\#1(v)} < 2\pi \end{cases} \quad (15)$$

By employing the proposed phase factor in Eq. (15) generated from the population (phase factor pattern) P in the PAPR optimization of the proposed as given in Eq. (8), the computational complexity of the proposed scheme as given in Eq. (13) can be rewritten by

$$CCofProp. = \left(\frac{M}{2V}\right) \cdot P \quad (16)$$

From Eq. (16), it can be expected that the computational complexity in the PAPR reduction would be decreased by using the proposed scheme in proportional to the number of phase factor patterns P which is considered.

3.2.2. Proposed modified ABC-PTS based radix DIF-IFFT Techniques

From Eq. (8), it can be observed that the N-points *IFFT* is required to performing in all clusters. From this reason, the computational complexity due to *IFFT* would increase hugely when increasing the number of clusters. To solve this problem, the radix *DIF-IFFT* techniques [14] are employed for the proposed scheme for reducing the computational complexity obliged in the process of *IFFT*. The computational complexities of three different radix *DIF-IFFT* techniques have been compared with the conventional *IFFT* as shown in the Table 1.

In the Table 1, the computational complexities required in the process of radix-2, radix-4 and Split radix *DIF-IFFT* are approximate 50%, 62.5% and 66.7% respectively reduced from the conventional *IFFT*.

Table 1. Computational complexity for *IFFT* techniques

Types	Computational Complexity
N-point *IFFT*	$N \cdot \log_2(N)$
Radix-2 *DIF-IFFT*	$0.5N \cdot \log_2(N)$
Radix-4 *DIF-IFFT*	$0.375N \cdot \log_2(N)$
Split Radix *DIF-IFFT*	$0.333N \cdot \log_2(N)$

4. Simulation and discussion

The performances which are improved by using the proposed scheme are evaluated via the computer simulation and present in this section. The significant parameters based on the standard of wireless communication are listed in the Table 2.

One of the significant parameters for the proposed scheme is the population size P as number of random phase factor patterns which are considered for optimizing the PAPR. From this reason, the optimum P numbers need to make a decision for employing in the proposed PAPR reduction scheme. Fig. 3 shows the average of PAPR values when changing P phase factor pattern numbers. The adjacent and interleaved (I=1) partitions [15] are used for sorting the data subcarriers in each cluster. In our work, P phase factor pattern numbers would be selected from the average PAPR value of the original PTS as decision line which is 5.665dB approximately. From the observation in Fig.3, the average PAPR values from both line of adjacent and interleaved partitions in the period of P between 80 and 256 have a small change. When considering the optimum P number from the decision line, the optimum P number is taken by 98 which is employed in the proposed PAPR reduction scheme.

By applying the optimum P phase factor pattern number which is taken by 98 in our work, the percentage of computational complexity of the proposed scheme computed in Eq. (16) is 19.14 approximately as shown in Table 3. Table 3 shows the percentage of computational complexity for the original PTS computed in Eq. (12) and proposed with P=98 phase factor patterns computed in Eq. (16). From the results in Table 3, it can be seen that if the computational complexity of the original PTS is 100%, the improvement from the original PTS is approximate 80.86% by using the proposed scheme.

The probability of the larger PAPR value as compared with the reference PAPR value as $PAPR_0$ is defined by the *CCDF* in Eq. (5) for evaluating the PAPR performance shown in Figs.4 and 5. Fig. 4 shows the *CCDF* of PAPR for the PAPR reduction schemes with the adjacent partition. The proposed scheme with P=98 phase factor patterns was performed by radix-2, radix-4 and Split radix *DIF-IFFT* respectively. From the figure, it can be found that the PAPR performance at $CCDF$=10^{-1} of the conventional ODFM and original PTS with uniform phase factor [8, 9] are improved by the proposed scheme and similar to that of the original PTS with non-uniform [10]. While the evaluation of PAPR performance for the interleaved (I=1) partition is shows in the Fig.5. From the results in Fig.5, the *CCDF* of PAPR for the proposed modified ABC-PTS with non-uniform phase factor still shows better than that for the conventional OFDM and original PTS with uniform phase factor [15] and almost the same as that for the original PTS with non-uniform phase factor [10] at $CCDF$=10^{-1}. Here it is found that the BER performance of the time-domain OFDM signal degraded in the non-linear channel would be

Table 2. Simulation parameters

Information	Parameters
Modulation/Demodulation	16QAM/ Coherent
Bandwidth (MHz)	5
Number of *IFFT/FFT* points (N)	M+(M×O_v)
Number of zero-padding	N-M
Oversampling (O_v)	3
Data subcarriers (M)	64
Type of partition for arrangement the data subcarrier in each cluster	Adjacent and Interleaved (I=1)
Duration of symbol in one OFDM frame (t_s)	14.3μs
Duration of total frames with guard interval (t_t)	15.6μs

Table 3. Computational complexity for PAPR reduction schemes

Schemes	**Percentage of computational complexity (*W*=4,*V*=4)**
Original PTS$\|_{in\ Eq.(12)}$	100%
Proposed$\|_{in\ Eq.(16)}$ with P=98 phase factor patterns	19.14%

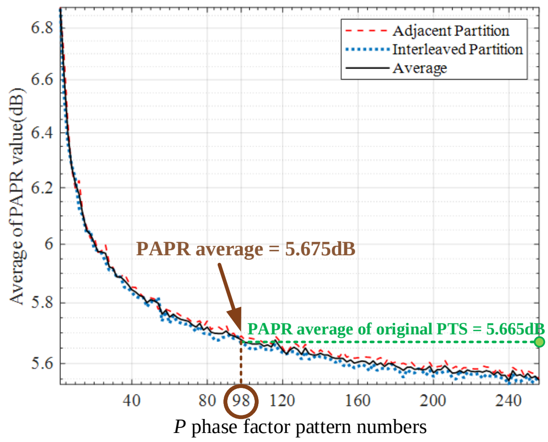

Figure. 3 Optimization of phase factor pattern numbers for proposed scheme with W=4 and V=4

Received: March 5, 2021. Revised: March 31, 2021.

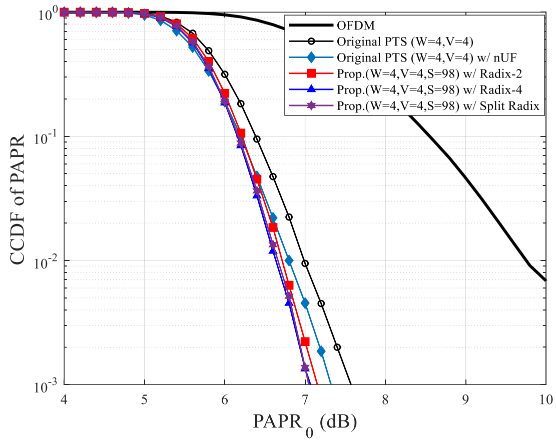

Figure. 4 CCDF of PAPR for adjacent

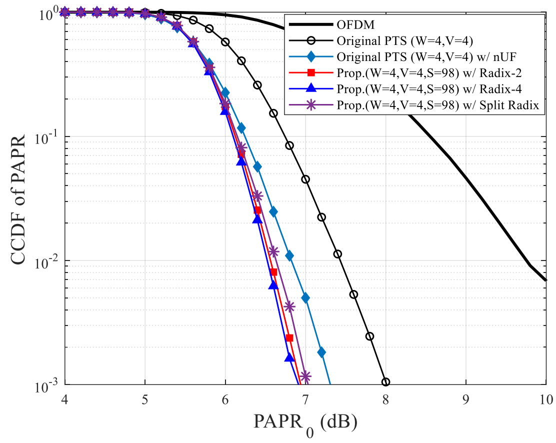

Figure. 5 CCDF of PAPR for interleaved

influenced by the *CCDF* of PAPR larger than 10^{-1}. Form this reason, it can be anticipated that the BER performance of the proposed modified ABC-PTS with non-uniform phase factor should be similar to that of the original PTS with non-uniform phase factor [10] and with keeping the same side information size.

From the results in Table 3, Figs.4 and 5, it can be confirmed that the improvement of PAPR performance can be provided with required small computational complexity in the process of PAPR reduction by using the proposed modified ABC-PTS scheme.

Furthermore, three *IFFT* techniques such as radix-2, radix-4 and Split radix *DIF-IFFT* are performed in our work with the adjacent and interleaved partitions. Their PAPR performances as shown in the Figs.4 and 5 show all the same. From these results, it can be found that the PAPR performance is not corresponded to the *IFFT* technique. It only has an effect on the computational complexity required in the *IFFT* process as shown in the Table 4.

5. Conclusions

In this paper, the two determined partitions-PTS by applying the modified ABC with non-uniform phase factors have been proposed for PAPR reduction in the time-domain OFDM signal. The adjacent and interleaved partitions both are employed for arranging the data subcarriers in the proposed scheme. The salient features of our work are to reduce the PAPR value of time-domain OFDM signal by applying the proposed two determined partition technique and to decrease the computational complexity in the PAPR optimization by modifying the ABC with non-uniform phase factor. Moreover, three different features of *IFFT* techniques are performed to the proposed PAPR reduction scheme

Table 4. Computational complexity of the various *IFFT* techniques for proposed scheme

Proposed modified ABC-PTS based	**Computational complexity computed in Table 1 (*N*=256)**	
N-point *IFFT*	2,048	100%
Radix-2 *DIF-IFFT*	1,024	50%
Radix-4 *DIF-IFFT*	768	37.50%
Split Radix *DIF-IFFT*	682.67	≈33.33%

for reducing the computational complexity required in *IFFT* process.

From the results by computer simulation, it can be concluded that the proposed modified ABC-PTS based radix *DIF-IFFT* technique with non-uniform phase factor can improve the performance of PAPR which is approximate 3.2dB over the conventional OFDM and 0.4dB for adjacent and 0.8dB for interleaved over the original PTS at *CCDF*=10^{-2} with smaller computational complexity which is 19.14% approximately. Furthermore, the side information of the proposed scheme required to inform to the receiver is similar to that of the original PTS scheme.

Conflicts of Interest

The authors declare no conflict of interest.

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