



Novel algorithm to minimize peak-to-average power ratio of orthogonal frequency division multiplexing system with less intricate partial transmit sequence using various modulation schemes

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Peak-to-Average Power Ratio (PAPR);
Partial Transmit Sequence (PTS);
Quadrature Amplitude Modulation (QAM).

Abstract

At present time, mobile communication is essential for the daily life of human beings, and for that, modulation schemes are very important for the quality and speed of transmission. Orthogonal Frequency Division Multiplexing (OFDM) is one of the best schemes for mobile communication. In this study, we focused on reducing the Peak-to-Average Power Ratio (PAPR) using a novel algorithm in the OFDM system. To reduce the PAPR, the modified Low Complexity-Partial Transmit Sequence (LC-PTS) has been proposed in this study and simulated with different modulation techniques. The main parameter for OFDM is PAPR, and reduction of PAPR is desirable for an efficient transmission system. This parameter has been further minimized in LC conditions in Partial Transmit Sequence (PTS) that include the Binary Phase-Shift Keying (BPSK), Quadrature Phase-Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM) modulation schemes. The obtained simulated results show clearly that among various modulation techniques, BPSK is the optimum technique for the proposed algorithm to reduce the PAPR.

1. Introduction

In the modern world, everyone wants to become fast or advance in technology [1-5]. To fulfill the demands, they need a high data-rate wireless communication system [6-10]. Therefore, the different types of modulation schemes are developed. In multicarrier modulation schemes, Orthogonal Frequency Division Multiplexing (OFDM) can play an important role for high-speed data rate wireless communication system and also it is capable to restrained multipath fading as well as Inter-Symbol Interference (ISI) [11-15]. OFDM has a large number of practical applications in wireless communication in a modern world such as Asymmetric Digital Subscriber Line (ADSL), Institute of Electrical and Electronics Engineering (IEEE) 802.11, IEEE 802.15.3a, Digital Audio Broadcasting (DAB), Digital Video

Broadcasting (DVB), High Performance Radio Local Area Network (HIPERLAN) and IEEE 802.16 Broadband Wireless Access System (BWAS). OFDM can be used from 2 to 66 GHz with multiple frequency allocation. In OFDM, phase of the output signal is the summation of the different input carrier signals which increases Peak-to-Average Power Ratio (PAPR) effectively [16]. When there is large PAPR, it creates many problems, therefore, to overcome this problem, it is necessary to use a highly expensive power amplifier, which is not economically feasible to overcome the effect of in-band out band radiation [17,18].

To decrease PAPR, several methods are used such as clipping; coding, Tone Reservation (TR), tone injection, Selected Mapping (SLM), Differential Evolution Algorithm

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(DEA) and Partial Transmit Sequence (PTS) [19]. The conventional Differential Evaluation (DE) algorithm is developed depending on the scale factor and recombination rates which are based on the Cauchy distribution instead of the Gaussian distribution for achieving faster convergence. A pivot-based population is adopted to maintain a balance between the population size and the number of generations. A novel DE algorithm is incorporated in the TR scheme and it proved mathematically that the Differential Evaluation-Tone Reservation (DE-TR) algorithm searched an optimal Peak Reduction Tone (PRT) set with an LC of computation. The proposed technique offered faster convergence rate as the local search is more attractive in comparison with the other techniques. The premature convergence can also be avoided by adopting this algorithm. The significant PAPR minimization and the Bit Error Rate (BER) efficiency are achieved by employing the Optimized Iterative Clipping and Filtering (OICF) technique in the DE-TR algorithm. Both the Error Vector Magnitude (EVM) performance and the Power Spectral Density (PSD) performance are analyzed. A comparative analysis of the suggested DE-TR technique with other relevant schemes is performed [20]. PTS is a less distortion and efficient phase optimization scheme in which input data or multiple candidate signals (effective input signals) are split into several disjoint sub-blocks and after applying a set of phase rotation vector to each sub-block, reduce PAPR in an OFDM system without effective disturbance [21,22]. PTS [22,23] is a very popular PAPR reduction scheme which is frequently utilized in many applications due to its efficient and distortion less PAPR reduction capability. In the PTS technique, the information data sequence modulated by any type of Quadrature Amplitude Modulation (QAM) is partitioned into a number of sub-blocks. After that, the related sub-blocks are multiplied by randomly generated phase factor combinations and eventually re-collected to obtain the signal with minimized PAPR. The aim of conventional PTS method is to find the optimum phase sequence through which the signal with minimum PAPR is achieved from the PTS output. The search for the optimal phase sequence is performed by generating the random combinations of the phase rotation factors. In the PTS technique the random search approach is used, hence it is difficult to influence a judicious solution without accomplishing a significant number of searches. In the PTS scheme, when the number of disjoint sub-blocks increases then complexity also increases in PAPR reduction [23]. To decrease the complexity, optimization is needed. Therefore, several optimization methods are available for PTS [24-29]. The different techniques are described [30-33] which emphasis on reduction in the number of candidate signals [34-37]. The Binary Phase-Shift Keying (BPSK) digital modulation scheme described as by altering two dissimilar phases of carrier signals while the Quadrature Phase Shift Keying (QPSK) technique essentially transmits two bits per symbol and another technique, QAM, is capable of giving double its effective bandwidth. The number of samples may be decreased for peak power calculation [38]. When we compare these methods with the conventional PTS Scheme, it is noted that the same PAPR reduction performance has been obtained. In contrast, the PAPR reduction method [33-38] have an average performance in PAPR reduction. The

differential Evolution optimization method reduces the computational complexity using different steps; setting the parameters, generating the initial population, selection, mutation, and crossover, output the best result while in the proposed Low Complexity-Partial Transmit Sequence (LC-PTS) algorithm includes the BPSK, QPSK, and QAM modulation scheme have been used to reduce the PAPR.

In this paper a novel algorithm for PAPR reduction has been developed under the specific condition of less complex environment. The modified PTS algorithm that includes BPSK, QPSK, and QAM modulation schemes has been employed to investigate the OFDM with reduced PAPR. In this study the different modulation technique with low PTS has been simulated and the comparison among BPSK, QPSK, 16 QAM, 128 QAM, and 256 QAM has been investigated to find the optimum technique for reducing the PAPR. For a fixed subcarrier different curves of Complementary Cumulative Distribution Function (CCDF) for varying PAPR have been obtained for different subblocks.

2. PAPR

If the number of input symbol is X_k , the total number of sub carriers is N , f_k is equal to $k\Delta f$ and k is from 0 to $N-1$ then the OFDM system output can be represented as shown in Eq. (1) [39]:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}, \quad 0 \leq t \leq T. \quad (1)$$

The value of Δf can be represented in terms of time period T as $\Delta f = 1/(NT)$.

The generated output for OFDM system can be represented as $x(n)$ shown in Eq. (2):

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi \frac{nk}{N}}, \quad 0 \leq n \leq N-1. \quad (2)$$

The PAPR can be calculated in continuous domain as shown in Eq. (3):

$$PAPR = \frac{\max_{0 \leq t \leq NT} [|x(t)|^2]}{E(|x(t)|^2)}, \quad \text{for } 0 \leq t \leq NT. \quad (3)$$

Here the operator $E\{\cdot\}$ shows the expectation operator and the average power of $x(t)$ which can be represented as $E(|x(t)|^2)$. The PAPR can be calculated in discrete form as shown in Eq. (4). PAPR is typically represented as CCDF which demonstrates the possibility that PAPR of OFDM frame is greater than the threshold value can be represented as $PAPR_0$ ($CCDF = Pr(PAPR > PAPR_0)$), and it can be calculated by Monte Carlo simulation [40].

$$PAPR = \frac{\max_{0 \leq n \leq N-1} [|x(n)|^2]}{E(|x(n)|^2)}, \quad \text{for } 0 \leq n \leq N-1. \quad (4)$$

The number of subcarriers (N) and type of modulation are important factor which can alter the PAPR in OFDM [41]. If the number of subcarriers N increases results the PAPR increment and vice versa. PAPR depends on N , as shown in Eq. (4). If N is large the value of PAPR is also high and vice versa. The value of N also effects the code rate proportionally. Constellation is important factor in modulation

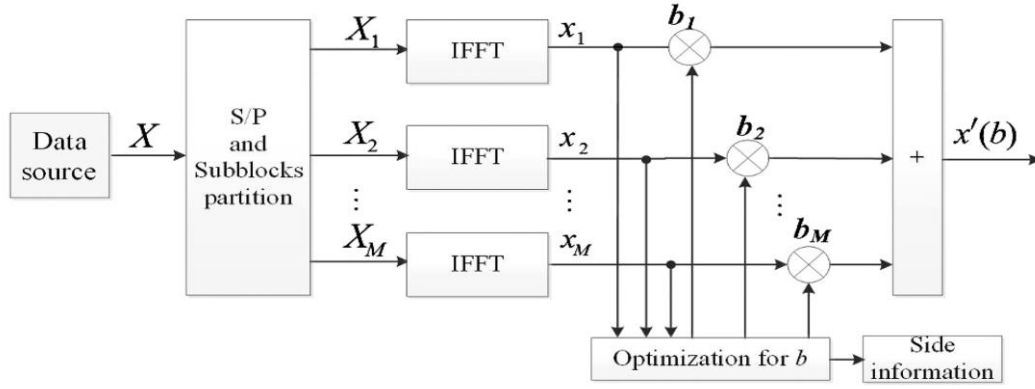


Figure 1. Block of PTS scheme.

scheme and it is more for M-ary Quadrature Amplitude Modulation (M-QAM) while it is less in M-ary Phase Shift Keying (M-PSK), and PAPR depends linearly on it.

3. PTS and proposed algorithm

The PTS scheme is demonstrated with blocks in Figure 1. If the input block contains N input signals which can be divided into subblocks of V disjoint and expressed as in Eq. (5) [41]:

$$X = [X^0, X^1, X^3 \dots X^{V-1}]^T. \quad (5)$$

Here X' represents the subblocks which are equal in size and located consecutively. In SLM technique, scrambling is used for all subcarriers while in PTS, scrambling is used for each subblock i.e., its phase is rotated separately [42]. After scrambling each partitioned subblock will be multiplied with analogous complex phase factor b^v which is equal to $e^{j\theta^v}$ and v is equal to $1, 2, \dots, V$, eventually doing its Inverse Fast Fourier Transform (IFFT) and represented in Eq. (6):

$$x = IIFT \left\{ \sum_{v=1}^V b^v X^v \right\} = \sum_{v=1}^V b^v \cdot IIFT \{X^v\} = \sum_{v=1}^V b^v X^v. \quad (6)$$

Here PTS is shown as $\{X^v\}$ and the phase vector is an important and can be used to reduce the PAPR [43] and can be represented in Eq. (7):

$$b = \arg \min_{(b_1, b_2, \dots, b_V)} \left(\max_{1 \leq n \leq N} \left| \sum_{v=1}^V b^v X^v \right|^2 \right). \quad (7)$$

The corresponding signal in time-domain can be represented containing lowest PAPR vector as shown in Eq. (8):

$$X = \sum_{v=1}^V b^v X^v. \quad (8)$$

Normally selection of phase factors b^v is restricted due to increase the search complexity. If sets of phase factor are W^{V-1} which can be searched from the allowed sets of phase factors b to get the best set of phase vectors, and this process increases the search complexity exponentially as the number of subblocks increases. To handle such complex situation the proposed algorithm has been presented. Table 1 represents the notions used in proposed algorithm and Table 2 represents the parameters used in the proposed algorithm assisted PTS scheme.

Table 1. Notations and its significance used in proposed algorithm assisted PTS scheme.

Notations	Significance
X_k	Number of input symbol
N	Number of total subcarriers
T	Time period
$x(t)$	Time domain signal
$x(n)$	Discrete time signal
b^v	Phase factor
W^{V-1}	Sets of phase factor
V	Number of sub blocks

Table 2. Parameters used in the proposed algorithm assisted PTS scheme.

Parameters	Value
Number of total subcarriers (N)	512 and 1024
Oversampling factor (L)	4
Number of OFDM blocks (N_{blk})	5000
Number of subblocks (V)	1, 2, 4, 8, and 16
Number of bits per symbol (b)	1 for BPSK and 2 for QPSK

3.1. Steps for proposed algorithm assisted PTS scheme

In a proposed algorithm, parallel direct search and merge sorting is used to calculate the optimal phase factors, and it is used with the PTS method for PAPR reduction.

- First, it defines the limits for each OFDM symbol as lower and upper limits, $0 \leq x^i \leq x_N$;
- Select the initial parameters randomly from a uniform interval $[0, x_N]$;
- For a given OFDM symbol x^i , select three random phase rotation factors x^a, x^b, x^c such that $a \neq b \neq c$;
- First, calculate the weighted difference of above two-phase rotation factors then add to the third factor to produce a trial phase factor, $y^{i+1} = x^a + F(x^b - x^c)$, where F is constant from $[0, 1]$;
- The complex phase factor b^i is calculated from OFDM symbol x^i and trial phase factor y^{i+1} ;
- With the help of complex phase factor b^i calculate PAPR for each OFDM symbols and stored in the form of array $A [1 \dots N]$, where $i = 1, 2, \dots, V$;
- Now divide-and-conquer paradigm is used to find minimum value of PAPR. Breaking into smaller sub problem, recursively solving the problem, appropriately combining the answers;

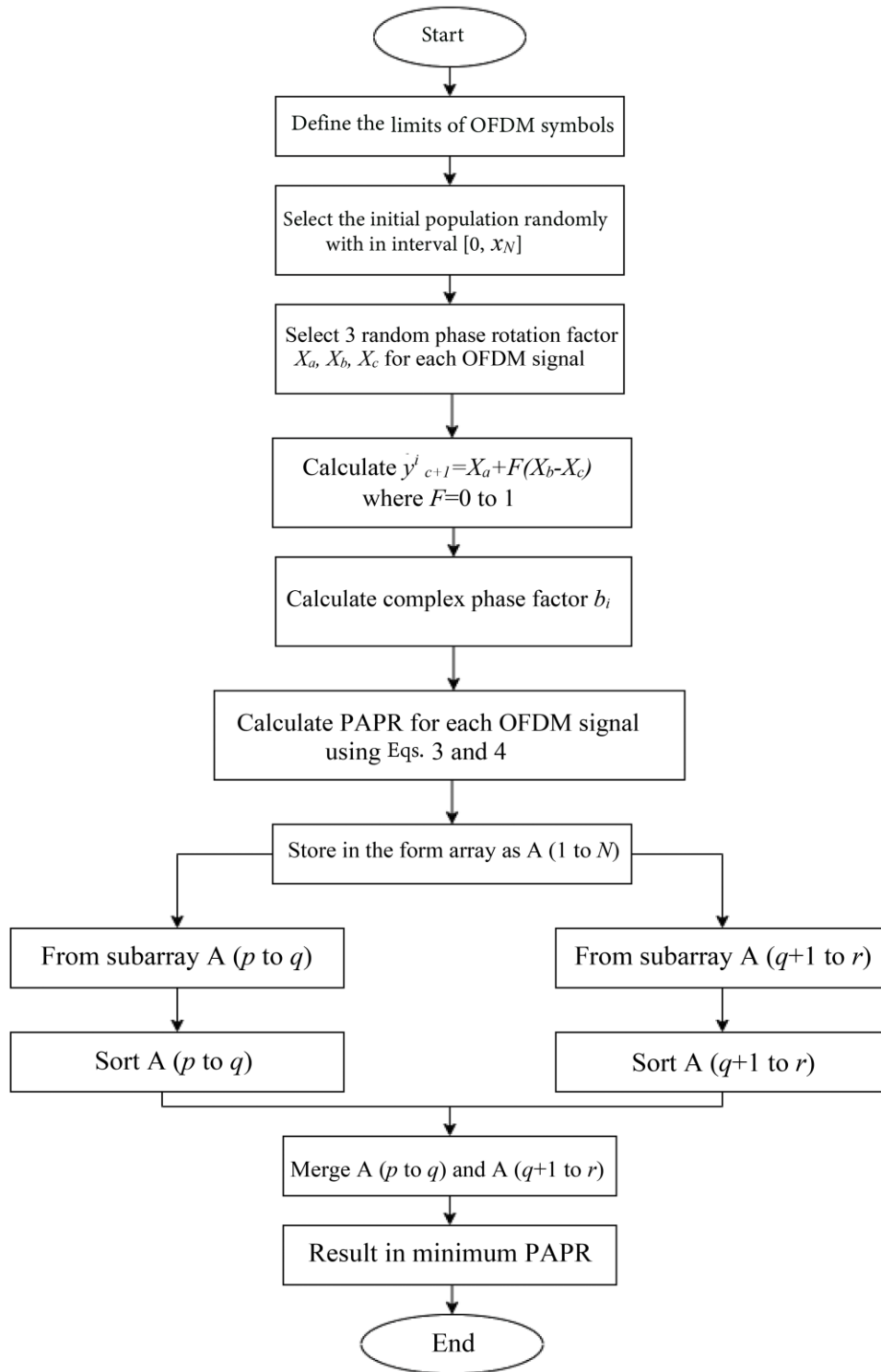


Figure 2. Flowchart for proposed algorithm assisted PTS scheme.

- For a given array A and $A[p \dots r]$ can be split into two sub-arrays which are $A[p \dots q]$ and $A[q + 1 \dots r]$, where q is the halfway point of $A[p \dots r]$. p is equal to unity and r is equal to N ;
- Pacify by sorting iteratively of these two sub arrays $A[p \dots q]$ and $A[q + 1 \dots r]$;
- $A[p \dots q]$ and $A[q + 1 \dots r]$ are the sorted subarrays can be combined again in $A[p \dots r]$ and decide the new procedure which is known as merge (A, p, q, r).

3.2. Flowchart for proposed algorithm assisted PTS scheme

The sorting arrays on different machines are done with the help of recursive algorithm therefore time complexity is also important and can be defined with the help of recurrence relation as $T(N) = 2T(N/2) + \Theta(N)$. The flowchart for proposed algorithm is shown in Figure 2.

4. Results and discussion

In this article, the process of reducing the PAPR in Orthogonal

Frequency Division Multiplexing (OFDM) system has been done with the help of some important parameters of PTS scheme. These parameters are defined under the condition of LC-PTS which include the BPSK, QPSK, and QAM modulation scheme. In QAM the modulation order is considered here significantly as 16, 64, 128 and 256, respectively. The parameters are as follows:

N (number of total subcarriers) = 512 and 1024;

L (oversampling factor) = 4;

N_{blk} (number of OFDM blocks) = 5000;

V (number of subblocks) = 1, 2, 4, 8 and 16;

b = number of bits per symbol.

4.1. BPSK scheme

The simulation results with BPSK modulation scheme for $N=512$ and $N=1024$ have been shown in Figure 3(a) and (b). The simulation result of LC-PTS at both $N=512$ and 1024 subcarriers with the BPSK modulation scheme with different subblocks as $V=1, 2, 4, 8$, and 16. When number of

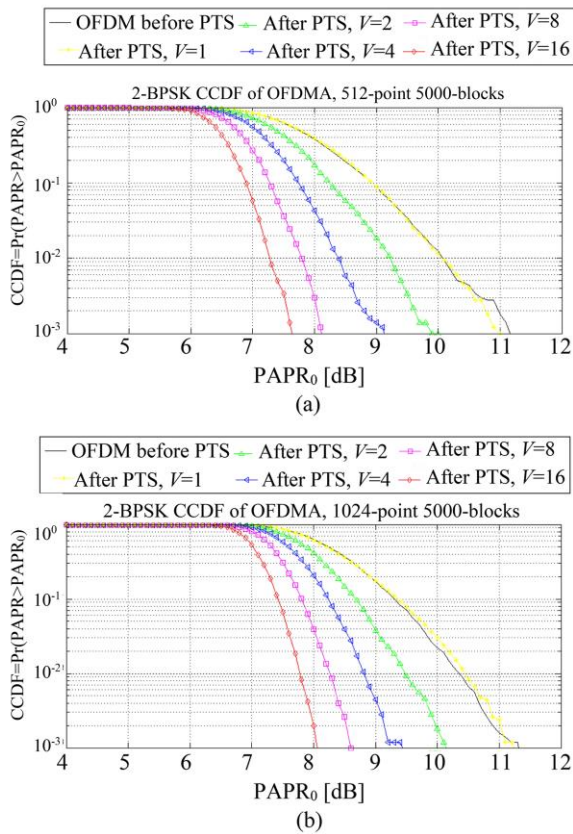


Figure 3. CCDF performance of the LC-PTS method with BPSK modulation scheme for (a): $N=512$ and (b): $N=1024$ sub-carriers with different subblocks (V).

Table 3. The PAPR value in dB for before PTS and after PTS at each subblocks such as $V=1, 2, 4, 8, 16$ at different modulation schemes for $N=512$.

Modulation scheme	$N=512$ at $CCDF=10^{-3}$					
	OFDM/PAPR (dB)	$V=1$ /PAPR (dB)	$V=2$ /PAPR (dB)	$V=4$ /PAPR (dB)	$V=8$ /PAPR (dB)	$V=16$ /PAPR (dB)
BPSK	11.15	11.00	10.00	9.125	8.115	7.639
QPSK	11.09	11.09	10.29	9.222	8.499	8.00
16 QAM	11.19	11.00	10.16	9.234	8.644	8.046
64 QAM	11.16	11.39	10.10	9.196	8.574	7.966
128 QAM	11.22	11.14	10.49	9.299	8.479	8.015
256 QAM	11.28	11.07	10.36	9.152	8.637	8.070

subblocks increases PAPR is reduced significantly as shown in Figure 3(a) and (b). At $N=512$ subcarriers as shown in Figure 3(a) represents more PAPR reduction than $N=1024$ which is shown Figure 3(b). The PAPR reduction in BPSK at $N=512$ and $N=1024$ for $V=16$ is found as 7.639 dB and 8.056 dB, respectively. The simulated value for BPSK at each subblock at $CCDF=10^{-3}$ is represented in Table 3 and Table 4, respectively. The PAPR reduction is observed more at $N=512$ than $N=1024$ may be due to increase in complexity of each conferred modulation schemes [23] which can also be verified from Table 3 and Table 4.

4.2. Quadrature phase shift keying scheme

The simulation result of LC-PTS at $N=512$ and $N=1024$ with QPSK modulation scheme with different subblocks such as $V=1, 2, 4, 8$, and 16 is shown in Figure 4(a) and (b). It can be inferred again that when number of subblocks increases the PAPR reduction is more. Although it is also seen that PAPR reduction is more at $N=512$ subcarriers as shown in Figure 4(a) as compared to at $N=1024$ which is shown Figure 4(b). The PAPR reduction in QPSK at $N=512$ and $N=1024$ for $V=16$ is found as 8.00 dB and 8.491 dB, respectively. The actual data of QPSK simulation at each subblock at $CCDF=10^{-3}$ is tabulated in Table 3 and Table 4, respectively.

4.3. 16 QAM scheme

The obtained simulation Results using 16 QAM modulation scheme for $N=512$ and $N=1024$ have been shown in Figure 5(a) and (b). The simulation result of LC-PTS at both $N=512$ and 1024 subcarriers with the 16 QAM modulation scheme is again evaluated with different subblocks as $V=1, 2, 4, 8$, and 16. The similar observation as BPSK and QPSK is found that as the number of subblocks increases, PAPR is reduced significantly, as shown in Figure 5(a) and (b). At $N=512$ subcarriers as shown in Figure 5(a) represents more PAPR reduction than $N=1024$ which is shown in Figure 5(b). The PAPR reduction in 16 QAM at $N=512$ and $N=1024$ for $V=16$ is found as 8.046 dB and 8.498 dB, respectively. The obtained simulated data for 16 QAM at each subblock at $CCDF=10^{-3}$ is presented in Table 3 and Table 4, respectively.

4.4. 64 QAM scheme

The curves of simulated results using 64 QAM modulation scheme for $N=512$ and $N=1024$ have been shown in Figures 6(a) and (b). The simulation result of LC-PTS at both $N=512$ and 1024 subcarriers with the 64 QAM modulation scheme is again evaluated with different subblocks as $V=1$,

2,4,8,16. The similar observation as BPSK, QPSK, and 16 QAM is found that as the number of subblocks increases, PAPR is reduced significantly, as shown in Figure 6(a) and (b). At $N=512$ subcarriers as shown in Figure 6(a) represents more PAPR reduction than $N=1024$ which is shown Figure 6(b). The PAPR reduction in 64 QAM at $N=512$ and $N=1024$ for $V=16$ is found as 7.966 dB and 8.436 dB, respectively. The obtained simulated data for 64 QAM modulation scheme at each subblock at $CCDF=10^{-3}$ is mentioned in Table 3 and Table 4, respectively.

4.5. 128 QAM scheme

The simulation Results with 128 QAM modulation scheme for $N=512$ and $N=1024$ have been shown in Figure 7(a) and (b). The simulation result of LC-PTS at both $N=512$ and 1024 subcarriers with the 128 QAM modulation scheme with different subblocks as $V=1,2,4,8,16$. The similar observation as BPSK, QPSK, 16 QAM, and 64 QAM is found as the number of subblocks increases PAPR is reduced

significantly as shown in Figure 7 (a) and (b). At $N=512$ subcarriers as shown in Figure 7(a) represents more PAPR reduction than $N=1024$ which is shown in Figure 7(b). The PAPR reduction in 128 QAM at $N=512$ and $N=1024$ for $V=16$ is found as 8.015 dB and 8.436 dB, respectively. The obtained simulated data for 128 QAM modulation scheme at each subblock at $CCDF=10^{-3}$ is given in Table 3 and Table 4, respectively.

Efficiency calculation of different modulation schemes at subblock $V=16$:

$$Efficiency = \left(1 - \frac{PAPR_{dB_{V=16}}}{PAPR_{dB_0}} \right) \times 100.$$

4.6. 256 QAM scheme

The simulation results with 256 QAM modulation scheme for $N=512$ and $N=1024$ have been shown in Figure 8 (a)

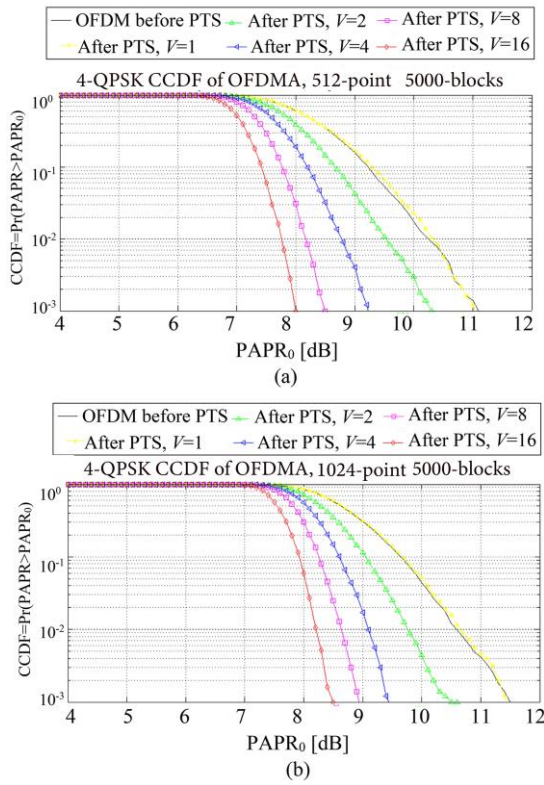


Figure 4: CCDF performance of the LC-PTS method with QPSK modulation scheme for $N=512$ sub-carriers with different subblocks (V).

Table 4. The PAPR value in dB for before PTS and after PTS at each subblocks such as $V = 1,2,4,8,16$ at different modulation schemes for $N = 1024$.

$N=1024$ at $CCDF=10^{-3}$						
Modulation scheme	OFDM/PAPR (dB)	$V=1$ /PAPR (dB)	$V=2$ /PAPR (dB)	$V=4$ /PAPR (dB)	$V=8$ /PAPR (dB)	$V=16$ /PAPR (dB)
BPSK	11.32	11.24	10.14	9.437	8.957	8.056
QPSK	11.50	11.50	10.49	9.437	8.939	8.491
16 QAM	11.56	11.45	10.39	9.377	8.999	8.498
64 QAM	11.60	11.54	10.48	9.508	8.954	8.436
128 QAM	11.44	11.44	10.54	9.695	8.899	8.436
256 QAM	11.44	11.44	10.40	9.545	8.897	8.483

Note: CCDF: Complementary Cumulative Distribution Function; PAPR: Peak-to-Average Power Ratio; BPSK: Binary Phase-Shift Keying; QAM: Quadrature Amplitude Modulation.

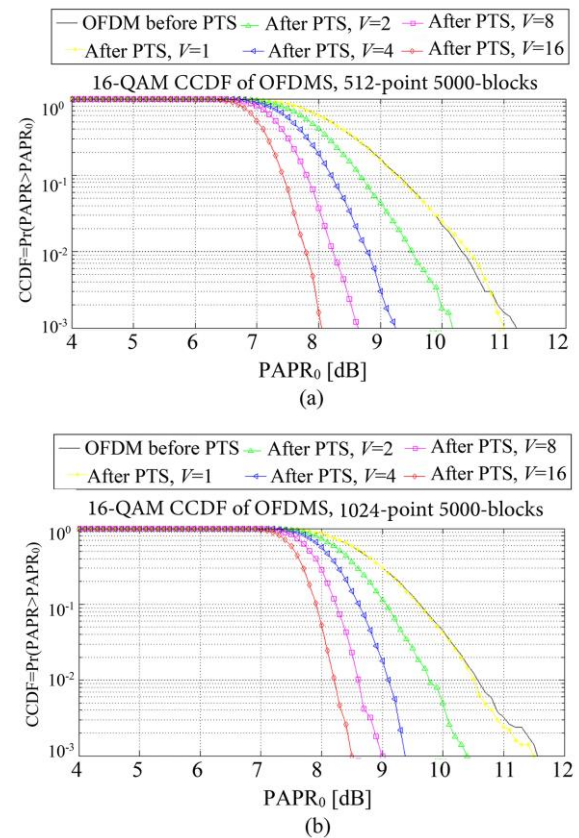


Figure 5: CCDF performance of the LC-PTS method with 16 QAM scheme for $N=512$ and 1024 sub-carriers with different subblocks (V).

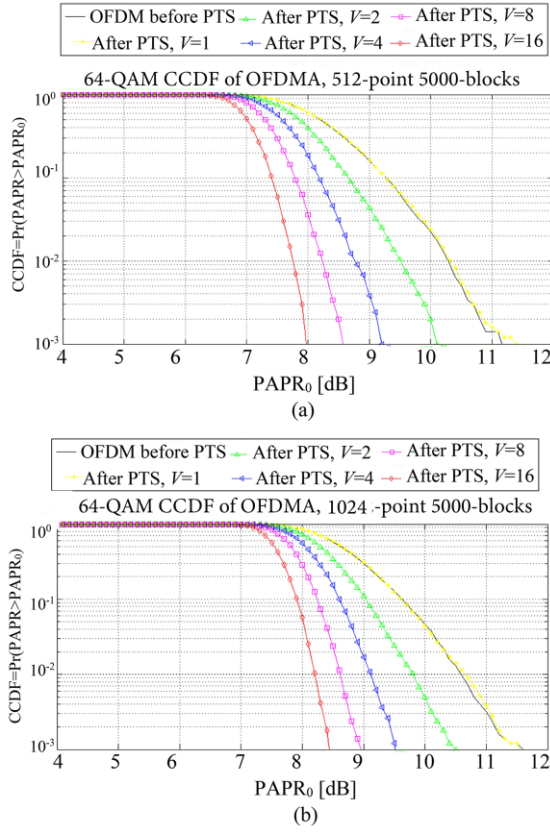


Figure 6. CCDF performance of the LC-PTS method with 64 QAM scheme for $N=512$ and 1024 sub-carriers with different subblocks (V).

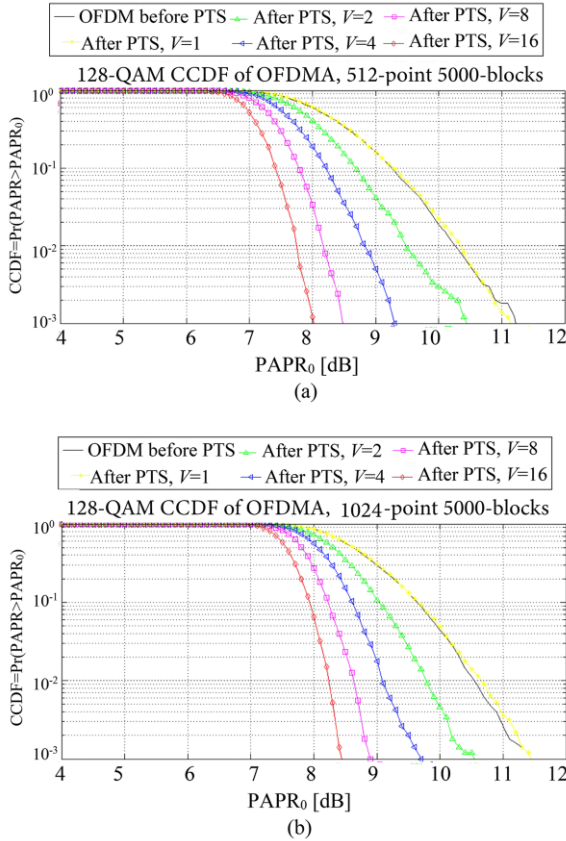


Figure 7. CCDF performance of the Lc-PTS method with 128 QAM scheme for $N=512$ and 1024 sub-carriers with different subblocks (V).

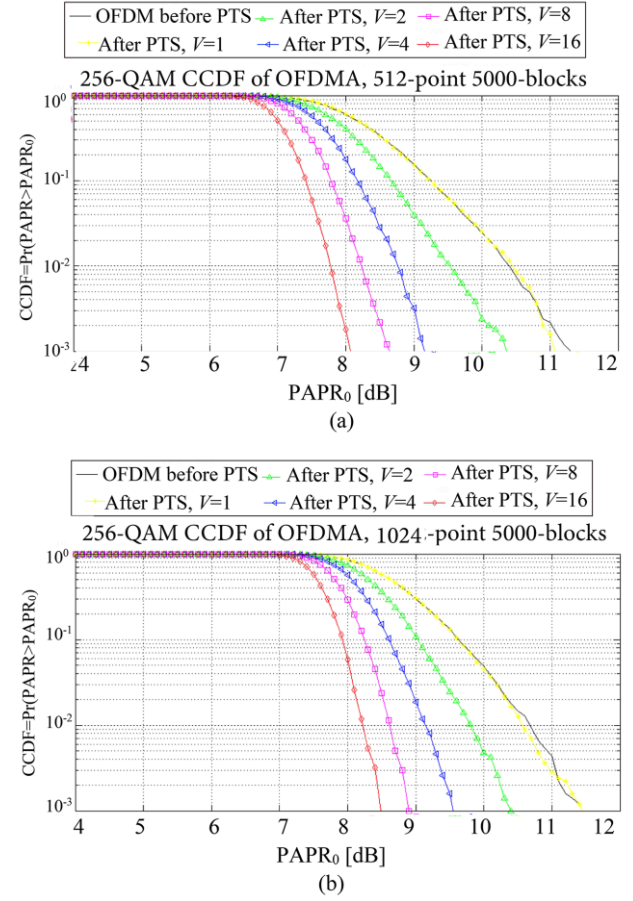


Figure 8. CCDF performance of the LC-PTS method with 256 QAM scheme for $N=512$ and 1024 sub-carriers with different subblocks (V).

and (b). The simulation results of LC-PTS at both $N=512$ and 1024 subcarriers with the 256 QAM modulation scheme with different subblocks as $V=1,2,4,8,16$. A similar observation as BPSK, QPSK, 16 QAM, 64 QAM, and 128 QAM is found as the number of subblocks increases, PAPR is reduced significantly, as shown in Figure 8(a) and (b).

At $N=512$ subcarriers, as shown in Figure 8(a), there is more PAPR reduction than $N=1024$ which is shown in Figure 8(b). The PAPR reduction in 256 QAM at $N=512$ and $N=1024$ for $V=16$ is found to be 8.070 dB and 8.483 dB, respectively. The obtained simulated data for 256 QAM modulation scheme at $CCDF=10^{-3}$ are arranged in Table 3 and Table 4, respectively.

In the present study, we have significantly reduced PAPR by using the modified low PTS technique. This method gives the better result as 7.639 dB PAPR in comparison to recent research as tabulated in Table 5 as original Asymmetrically Clipped Optical-Orthogonal Frequency Division Multiplexing (ACO-OFDM)-16.3 dB, Genetic Algorithm-Partial Transmit Sequence (GA-PTS)-13.7 dB, Particle Swarm Optimization (PSO-PTS)-12.8 dB, Harmony Search (HS-PTS)-12.2 dB, Firefly-based (FP-PTS)-11.8 dB, Improved Firefly-based (IFP-PTS)-11.4 dB, Optimized Partial Transmit Sequence (OPTS)-10.5 [41].

5. Conclusion

The different modulation techniques with low Partial Transmit Sequence (PTS) have been simulated and the results reveal that among Binary Phase-Shift Keying (BPSK),

Table 5. The PAPR comparison of different methods to the proposed method at $CCDF = 10^{-3}$.

Methods	Complexity	$P=10, G=20$ PAPR (dB)
Original ACO-OFDM	-	16.3
GA-PTS	$P \times G$	13.7
PSO-PTS	$P \times G$	12.8
HS-PTS	$P \times G$	12.2
FP-PTS	$P \times G$	11.8
IFP-PTS	$P \times G$	11.4
OPTS	$w^{v-1}=2^{15}$	10.5
Low PTS (proposed algorithm)	-	7.639

Note: CCDF: Complementary Cumulative Distribution Function; PAPR: Peak-to-Average Power Ratio; BPSK: Binary Phase-Shift Keying; QAM: Quadrature Amplitude Modulation.

Quadrature Phase-Shift Keyin (QPSK), 16 Quadrature Amplitude Modulation (QAM), 128 QAM, and 256 QAM, the BPSK modulation technique is found optimum for reducing the Peak-to-Average Power Ratio (PAPR). The divide-and-conquer algorithm is applied in Low Complexity-Partial Transmit Sequence (LC-PTS) to find optimum phase vector b . To get the optimum modulation scheme for reducing the PAPR in Orthogonal Frequency Division Multiplexing (OFDM) system, the BPSK, QPSK and QAM modulation have been considered and opted LC-PTS method. The reduction of PAPR is analyzed for the number of subcarrier $N=512$, and 1024 and different number of subblocks which include $V=1,2,4,8$, and 16. We have analyzed that the results for PAPR reduction of OFDM system using LC-PTS under different modulation schemes such as QAM with higher order of modulation namely, BPSK, QPSK, 16-QAM, 64-QAM, 128-QAM and 256-QAM. PAPR reduction Performance is calculated for Number of subcarrier $N=128, 256, 512$ and 1024 for different number of subblocks is $V=1, 2, 4, 8$ and 16 and from the simulation result we see that BPSK provides good amount of PAPR reduction, but its drawback is that it uses only two symbols and information that can be transmitted reduces considerably. Thus, from the above result we concluded that we can adopt BPSK modulation for better PAPR reduction. Hence the bandwidth requirement for BPSK is more as compare to other schemes of low PTS.

The significant PAPR reduction has been achieved in case of BPSK at $V=16$ for $N=512$ at $CCDF=10^{-3}$. The simulation result shows that CCDF of the PAPR of QPSK OFDM symbols for 64,128,256,512 and 1024 sub-carriers. The most obvious trend in the graph is that PAPR is increasing as number of sub-carriers increases. The theoretical value of CCDF is almost same as simulated value of CCDF.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors contribution statement

First author: Data curation; Formal analysis; Investigation; Visualization; Writing-original draft

Second author: Conceptualization; Methodology; Resources; Software Supervision; Validation; Project Administration; Data curation; Formal analysis; Writing-review & editing

Third author: Formal analysis; Investigation; Methodology; Validation; Visualization; Writing-review & editing

References

- Wei, Z., Yuan, W., Li, S., et al. "Orthogonal time frequency space modulation: A promising next generation waveform", *IEEE Wireless Communication*, **28**(4), pp. 136-144 (2021). <https://doi.org/10.1109/MWC.001.2000408>
- Huang, C., Hu, S., Alexandropoulos, G., et al. "Holographic MIMO surfaces for 6G wireless networks: Opportunities, challenges, and trends", *IEEE Wireless Communication*, **27**(5), pp. 118-125 (2020). <https://doi.org/10.1109/MWC.001.1900534>
- Zhang, S. "An overview of network slicing for 5G", *IEEE Wireless Communication*, **26**(3), pp. 111-117 (2019). <https://doi.org/10.1109/MWC.2019.1800234>
- Wu, W., Zhou, C., Li, M., et al. "AI-native network slicing for 6G networks", *IEEE Wireless Communication*, **29**(1), pp. 96-103 (2022). <https://doi.org/10.1109/MWC.001.2100338>
- Kang, J., Xiong, Z., Niyato, D., et al. "Reliable federated learning for mobile networks", *IEEE Wireless Communication*, **27**(2), pp. 72-80 (2020). <https://doi.org/10.1109/MWC.001.1900119>
- Yuan, X., Zhang, Y., Shi, Y., et al. "Reconfigurable-intelligent-surface empowered wireless communications: Challenges and opportunities", *IEEE Wireless Communication*, **28**(2), pp. 136-143 (2021). <https://doi.org/10.1109/MWC.001.2000256>
- Wan, C. and Rahman, A. "Quantum-enabled 6G wireless networks: Opportunities and challenges", *IEEE Wireless Communication*, **29**(1), pp. 58-69 (2022). <https://doi.org/10.1109/MWC.006.00340>
- Chen, S., Liang, Y., Sun, S., et al. "Vision, requirements, and technology trend of 6G: How to

- tackle the challenges of system coverage, capacity, user data-rate and movement speed”, *IEEE Wireless Communication*, **27**(2), pp. 218-228 (2020).
<https://doi.org/10.1109/MWC.001.1900333>
9. Song, F., Li, L., You, I., et al. “Optimizing high-speed mobile networks with smart collaborative theory”, *IEEE Wireless Communication*, **29**(3), pp. 48-54 (2022).
<https://doi.org/10.1109/MWC.001.2100579>
 10. Tang, F., Chen, X., Zhao, M., et al. “The roadmap of communication and networking in 6G for the metaverse”, *IEEE Wireless Communication*, **30**(4) pp. 72-81 (2023).
<https://doi.org/10.1109/MWC.019.2100721>
 11. Cho, Y., Kim, K., Woo, J., et al. “Low-complexity PTS schemes using dominant time-domain samples in OFDM systems”, *IEEE Transactions on Broadcasting*, **63**(2), pp. 440-445 (2017).
<https://doi.org/10.1109/TBC.2017.2662228>
 12. Ye, C., Li, Z., Ziang, T., et al. “PAPR reduction of OQAM-OFDM signals using segmental PTS scheme with low complexity”, *IEEE Transactions on Broadcasting*, **60**(1), pp. 141-147 (2014).
<https://doi.org/10.1109/TBC.2013.2282732>
 13. Yang, L., Soo, K., Li, S., et al. “PAPR reduction using low complexity PTS to construct of OFDM signals without side information”, *IEEE Transactions on Broadcasting*, **57**(2), pp. 284-290 (2011).
<https://doi.org/10.1109/TBC.2011.2122870>
 14. Li, Y., Qiu, H., Chen, X., et al. “A novel PAPR reduction algorithm for DCO-OFDM/OQAM system in underwater VLC”, *Optics Communications*, **463**, 125449 (2020).
<https://doi.org/10.1016/j.optcom.2020.125449>
 15. Carcangiu, S., Fanni, A., and Montisci, A. “A closed form selected mapping algorithm for PAPR reduction in OFDM multicarrier transmission”, *Energies*, **15**(5), 1938 (2022).
<https://doi.org/10.3390/en15051938>
 16. Qin, L., Li, H., Chen, D., et al. “Peak shrinking and interpolating for PAPR reduction in M-IFoF-based mobile fronthaul”, *Digital Communications and Networks*, **8**(1), pp. 51-57 (2022).
<https://doi.org/10.1016/j.dcan.2021.06.003>
 17. Şimşir, Ş. and Taşpınar, N. “A novel discrete elephant herding optimization-based PTS scheme to reduce the PAPR of universal filtered multicarrier signal”, *Engineering Science and Technology, an International Journal*, **24**(6), pp. 1428-1441 (2021).
<https://doi.org/10.1016/j.jestch.2021.03.001>
 18. Fang, Z., Qian, H., Kang, K., et al. “Distortion-less PAPR reduction algorithm for multi-user MIMO system with linear precoding”, *Digital Signal Processing*, **95**, 102575 (2019).
<https://doi.org/10.1016/j.dsp.2019.102575>
 19. Lahcen, A., Kamal, A., Mustapha, H., et al. “Peak-to-average power ratio reduction using new swarm intelligence algorithm in OFDM systems”, *Procedia Manufacturing*, **32**, pp. 831-839 (2019).
<https://doi.org/10.1016/j.promfg.2019.02.291>
 20. Rakshit, M., Bhattacharjee, S., Garai, G., et al. “A novel differential evolution algorithm for tone reservation-based peak to average power ratio reduction technique in orthogonal frequency division multiplexing systems”, *Swarm and Evolutionary Computation*, **72**, 101086 (2022).
<https://doi.org/10.1016/j.swevo.2022.101086>
 21. Taşpınar, N. and Şimşir, S. “An efficient SLM technique based on migrating bird’s optimization algorithm with cyclic bit flipping mechanism for PAPR reduction in UFMC waveform”, *Physical Communication*, **43**, 101225 (2020).
<https://doi.org/10.1016/j.phycom.2020.101225>
 22. Kumar, A., Rajagopal, K., Gugapriya G., et al. “Reducing PAPR with low complexity filtered NOMA using novel algorithm”, *Sustainability*, **14**(15), 9631 (2022).
<https://doi.org/10.3390/su14159631>
 23. Miriyala, G. and Mani, V. “A new PAPR reduction technique in DCO-OFDM for visible light communication systems”, *Optics Communications*, **474**, 126064 (2020).
<https://doi.org/10.1016/j.optcom.2020.126064>
 24. Bello, P. “Selective fading limitations of the Kathryn modem and some system design considerations”, *IEEE Transactions on Communication*, **13**, pp. 320-333 (1965).
<https://doi.org/10.1109/TCOM.1965.1089134>
 25. Zimmerman, M. and Kirsch, A. “The AN/GSC-10 (Kathryn) variable rate data modem for HF radio”, *IEEE Transactions on Communication Systems*, **15**, pp. 197-204 (1967).
<https://doi.org/10.1109/TCOM.1967.1089577>
 26. Powers, E. and Zimmermann, M. “A digital implementation of a multichannel data modem”, In *Proc. IEEE Int. Conf. Communication Philadelphia*, PA (1968).
 27. Saltzberg, B. “Performance of an efficient parallel data transmission system”, *IEEE Transactions on Communication Technology*, **15**, pp. 805-811 (1967).
<https://doi.org/10.1109/TCOM.1967.1089674>
 28. Harmuth, H., *Transmission of Information by Orthogonal Functions*, Springer Berlin, Heidelberg, **79** (1972).
<https://doi.org/10.1007/978-3-642-61974-8>

29. Weinstein, S. and Ebert, P. "Data transmission by frequency-division multiplexing using the discrete Fourier transform", *IEEE Transactions on Communication Tech.*, **19**, pp. 628-634 (1971).
<https://doi.org/10.1109/TCOM.1971.1090705>
30. Cimini, L. "Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing", *IEEE Transactions Communication*, **33**, pp. 665-675 (1985).
<https://doi.org/10.1109/TCOM.1985.1096357>
31. Mino, O., Fujiwara, T., Nishizawa, H., et al. "Development of north America terrestrial digital audio broadcasting receiver (HD Radio)", *Fujitsu Ten Tech*, **25**, pp. 42-53 (2005).
<https://doi.org/10.2991/emle-16.2017.81>
32. Chow, P., Tu, J., and Cioffi, J. "Performance evaluation of a multichannel system for ADSL and VHDLSL", *IEEE Journal on Selected Areas in Communications*, **9**(6), pp. 909-911 (1991).
<https://doi.org/10.1109/49.93101>
33. Cimini, L. and Sollenberger, N. "Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequence", *IEEE Communication Lett.*, **4**(3), pp. 86-88 (2000).
<https://doi.org/10.1109/4234.831033>
34. Jayalath, D. and Tellambura, C. "Adaptive PTS approach for reduction of peak-to-average power ratio of OFDM signal", *Electron Lett.*, **36**(14), pp. 1226-1228 (2000).
<https://doi.org/10.1049/el.20000881>
35. Alavi, A., Tellambura, C., and Fair, I. "PAPR reduction of OFDM signals using partial transmit sequence: An optimal approach using sphere decoding", *IEEE Communication Lett.*, **9**(11), pp. 982-984 (2005).
<https://doi.org/10.1109/LCOMM.2005.11015>
36. Jiang, T., Xiang, W., Rechardson, P., et al "PAPR reduction of OFDM signals using partial transmit sequences with low computational complexity", *IEEE Trans. Broadcast*, **53**(3), pp. 719-724 (2007).
<https://doi.org/10.1109/TBC.2007.899345>
37. Nguyen, T. and Lampe, L. "On partial transmit sequences for PAR reduction in OFDM systems", *IEEE Trans. Wireless Communication*, **7**(2), pp. 746-755 (2008).
<https://doi.org/10.1109/TWC.2008.060664>
38. Wang, L. and Cao, Y. "Sub-optimum PTS for PAPR reduction of OFDM signals", *Electron Lett.*, **44**(15), pp. 921-922 (2008).
<https://doi.org/10.1049/el:20080764>
39. Aghdam Hosseinzadeh, M. and Sharifi A.A. "PAPR reduction in OFDM systems: An efficient PTS approach based on particle swarm optimization", *ICT Express*, **5**(3), pp. 178-181 (2019).
<https://doi.org/10.1016/j.icte.2018.10.003>
40. Sharifi A.A. and Emami, H. "PAPR reduction of asymmetrically clipped optical OFDM signals: Optimizing PTS technique using improved flower pollination algorithm", *Optics Communications*, **474**, 126057 (2020).
<https://doi.org/10.1016/j.optcom.2020.126057>
41. Goel, A. and Gupta S. "Side information embedding scheme for PTS based PAPR reduction in OFDM systems", *Alexandria Engineering Journal*, **61**(12), pp. 11765-11777 (2022).
<https://doi.org/10.1016/j.aej.2022.05.021>
42. Sayyari, R., Pourrostan, J., and Ahmadi H. "Efficient PAPR reduction scheme for OFDM-NOMA systems based on DSI & pre coding methods", *Physical Communication*, **47**, 101372 (2021).
<https://doi.org/10.1016/j.phycom.2021.101372>
43. Tran, V.-N., Vu V.-K., Nguyen T.-C., et al. "Optimization of partial transmit sequences scheme for PAPR reduction of OFDM signals", *International Conference Engineering and Telecommunication*, pp. 1-5 (2020).
<https://doi.org/10.1109/EnT50437.2020.9431307>

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