Novel Algorithm to minimize PAPR of OFDM system with Less Intricacy PTS using Various Modulation Schemes

Deo Chandra Jaiswal[1], *S.K. Sriwas[2], Abhishek Nigam[1], Siddharth Srivastava[1], Mahendra Kumar[2]

[1]Electronics and Communication Department, Institute of Engineering and Technology, Lucknow-226021, India

[2]Department of Electronics and Communication, Bundelkhand Institute of Engineering and Technology, Jhansi-284128, India

*Corresponding Author: - Email: surendrasriwas@bietjhs.ac.in, Mobile Number: +91-9956835338

***Abstract*: -** In the 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 to reduce the peak-to-average power ratio (PAPR) using a novel algorithm using 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 efficient transmission system. This parameter has been further minimized in low complexity 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 scheme. The obtained simulated results show clearly that among various modulation techniques, the BPSK is the optimum technique for proposed algorithm to reduce the PAPR.

Keywords: Algorithm, BPSK, OFDM, PAPR, PTS, QAM

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 ADSL (Asymmetric Digital Subscriber Line), IEEE 802.11, IEEE 802.15.3a, digital audio broadcasting (DAB), digital video broadcasting (DVB), 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, tone injection, SLM, differential evolution algorithm (DEA) and Partial transmit Sequence (PTS) [19]. The conventional 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 DE-TR algorithm searched an optimal PRT set with a low Complexity 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 BER efficiency are achieved by employing the OICF technique in the DE-TR algorithm. Both the EVM performance and the 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 to reduce PAPR in 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 quadrate 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 accomplishment 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 to give double of 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 parameter, generating the initial population, selection, mutation, crossover, output the best result while in the proposed low complexity partial transmit sequence (LC-PTS) algorithm that 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 CCDF for varying PAPR have been obtained for different subblocks.

2. Peak-to-Average Power Ratio

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

$$x(t) = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} X_K e^{j2\pi fkt} \, , \; 0 \le t \le T$$

(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 Equation (2)

$$x(n) = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} X_K e^{\frac{j2\pi kn}{N}} \; , \; 0 \le n \le \mathrm{N}-1$$

(2)

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

$$PAPR = \frac{\max_{0 \le t \le \mathrm{N}T}\left[| x(t) |^2 \right]}{E(| x(t) |^2)}, \;\; for\, 0 \le t \le \mathrm{N}T$$

(3)

Here the operator E {.} 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 Equation (4). PAPR is typically represented as complementary cumulative distribution function (CCDF) which demonstrates the possibility that PAPR of OFDM frame is greater than the threshold value can be represented as PAPR0 (*CCDF=Pr (PAPR > PAPR0)*), and it can be calculated by Monte Carlo simulation [40].

$$PAPR = \frac{\max_{0 \le n \le N-1}\left[| x(n) |^2 \right]}{E(| x(n) |^2)}, \quad for\, 0 \le n \le NL - 1$$

(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 Equation (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 scheme and it is more for M-QAM while it is less in M-PSK and PAPR is linearly depend on it.

3. PTS (partial transmit sequence) 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 Equation (5) [41].

$$X = [X^0, X^1, X^3 ....X^{V-1}]^T \tag{5}$$

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.... V, eventually doing it's IFFT and represented in Equation (6).

$$x = IIFT\left\{ \sum_{v=1}^{V} b^v X^v \right\} = \sum_{v=1}^{V} b^v . IIFT\left\{ X^v \right\} = \sum_{v=1}^{V} b^v X^v \tag{6}$$

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 Equation (7).

$$b = \underset{(b_1, b_2, ...b_V)}{arg\, min}\left(\underset{1 \le n \le N}{max} | \sum_{v=1}^{V} b^v X^v |^2 \right)$$

(7)

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

$$X = \sum_{v=1}^{V} b^v X^v \tag{8}$$

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 allowed sets of phase factors b to get the best set of phase vector and this process increases the search complexity exponentially as the number of subblocks increase. 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.

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.

1. First, it defines the limits for each OFDM symbol as lower and upper limits, $0 \leq x^i \leq x_N$.
2. Select the initial parameters randomly from a uniform interval [0, x_N].
3. For a given OFDM symbol xi, select three random phase rotation factors x_a, x_b, x_c such that a≠b≠c.
4. First, calculate the weighted difference of above two-phase rotation factors then add to the third factor to produce a trial phase factor ${y^i}_{c+1} = x_a + F(x_b - x_c)$ where F is constant from [0,1].
5. The complex phase factor bi is calculated from OFDM symbol xi and trial phase factor ${y^i}_{c+1}$.
6. With the help of complex phase factor bi calculate PAPR for each OFDM symbols and stored in the form of array A [1…. N]. Where i= 1,2…. V.
7. Now divide-and-conquer paradigm is used to find minimum value of PAPR. Breaking into smaller subproblem, recursively solving the problem, appropriately combining the answers.
8. For a given array A and A [p ... r] can be split into two sub-arrays which are A[p .. q] and A[q + 1 .. r]. Where q is the halfway point of A[p .. r]. p is equal to unity and r is equal to N.
9. Pacify by sorting iteratively of these two subarrays A [p .. q] and A[q + 1 .. r].
10. A[p .. q] and A[q + 1 .. r] are the sorted subarrays can be combined again in A[p .. 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) + Θ (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 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; Nblk (Number of OFDM blocks) = 5000

V (Number of Subblocks) = 1, 2, 4, 8 and 16; b = Number of bits per symbol

4.1 Binary Phase-Shift Keying Scheme

The simulation Results with BPSK modulation scheme for N = 512 and N = 1024 have been shown in Figures 3(a &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 subblocks increases PAPR is reduced significantly as shown in Figure 3(a & 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 Fig. 4(a &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 Quadrature Amplitude Modulation Scheme

The obtained simulation Results using 16 QAM modulation scheme for N = 512 and N = 1024 have been shown in Figures 5(a &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 & b). At N=512 subcarriers as shown in Figure 5(a) represents more PAPR reduction than N =

1024 which is shown 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 Quadrature Amplitude Modulation Scheme

The curves of simulated results using 64 QAM modulation scheme for N = 512 and N = 1024 have been shown in Figures 6(a &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 & 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 Quadrature Amplitude Modulation Scheme

The simulation Results with 128 QAM modulation scheme for N = 512 and N = 1024 have been shown in Figures 7(a &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 & b). At N=512 subcarriers as shown in Figure 7(a) represents more PAPR reduction than N = 1024 which is shown 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

$$Efficiency = \left(1 - \frac{PAPRdB_{V=16}}{PAPRdB_0}\right) * 100$$

4.6 256 Quadrature Amplitude Modulation Scheme

The simulation Results with 256 QAM modulation scheme for N = 512 and N = 1024 have been shown in Figures 8 (a &b). The simulation result 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. The 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 & b).

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

In the present study we have got significantly reduced PAPR by using 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 ACO-OFDM-16.3 dB, GA–PTS-13.7 dB, PSO–PTS-12.8 dB, HS-PTS -12.2 dB, FP–PTS-11.8 dB, IFP–PTS-11.4 dB, OPTS-10.5 [41].

5. Conclusion

The different modulation technique with low PTS has been simulated and the results reveal that among BPSK, QPSK, 16 QAM, 128 QAM, and 256 QAM, the BPSK modulation technique is found optimum for reducing the PAPR. The divide-and-conquer algorithm is applied in LC PTS to find optimum phase vector b. To get the optimum modulation scheme for reducing the PAPR in 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- Q AM, 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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Deo Chandra Jaiswal received his B. Tech. degree in Electronics Engineering, M. Tech degree in Electronics and Communication Engineering and Ph.D in Electronics Engineering from Harcourt Butler Technical University (formerly HBTI) Kanpur, in 2010, 2012 and 2020 respectively. Presently, he is teaching as Assistant Professor in Electronics and Communication Engineering Department, Institute of Engineering and Technology, Lucknow (IET, Lucknow). His research interest focuses on survivability, traffic routing, optimization of power and bandwidth squeezed restoration in new optical networking paradigm.

Surendra Kumar Sriwas is presently working as Assistant Professor in Electronics & Communication Engineering department, Bundelkhand Institute of Engineering and Technology (BIET), Jhansi (UP), India. He has completed his Bachelor of Engineering in Electronics and communication engineering from Hindustan College of Science and Technology, Mathura in 2001. He has completed his M.Tech in Microwave Engineering from Madhav Institute of Technology and Science (MITS) Gwalior in 2007. He received his PhD degree in Design and analysis of Optical IDMA from AKTU Lucknow in 2017. He has 13 years of Teaching and research experience and published numbers of referred journal papers.

Abhishek Nigam is currently teaching at IET LUCKNOW as Assistant Professor in Electronics and Communication Department. He has done his M. TECH AND PhD both from MNNIT ALLAHABAD. He has completed his B.Tech in Electronics and Instrumentation from GBTU Lucknow.

Siddharth Srivastava is currently pursuing PhD from IET Lucknow, He has good experience in the field of wireless communication. His PhD area also is massive MIMO and Beam Forming in wireless communication.

Mahendra Kumar is presently working as Associate Professor in Electronics & Communication Engineering department, Bundelkhand Institute of Engineering and Technology (BIET), Jhansi (UP), India. His interests are in Multiple Access Schemes for area of research interest design of Microstrip Antennas for various applications. He has published many research papers in different international journals and conference.

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Figure 8. Complementary cumulative distribution function performance of the low complexity partial transmit sequence method with 256 quadrature amplitude modulation scheme for N =512 and 1024 sub-carriers with different subblocks (V).

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Figure 1.

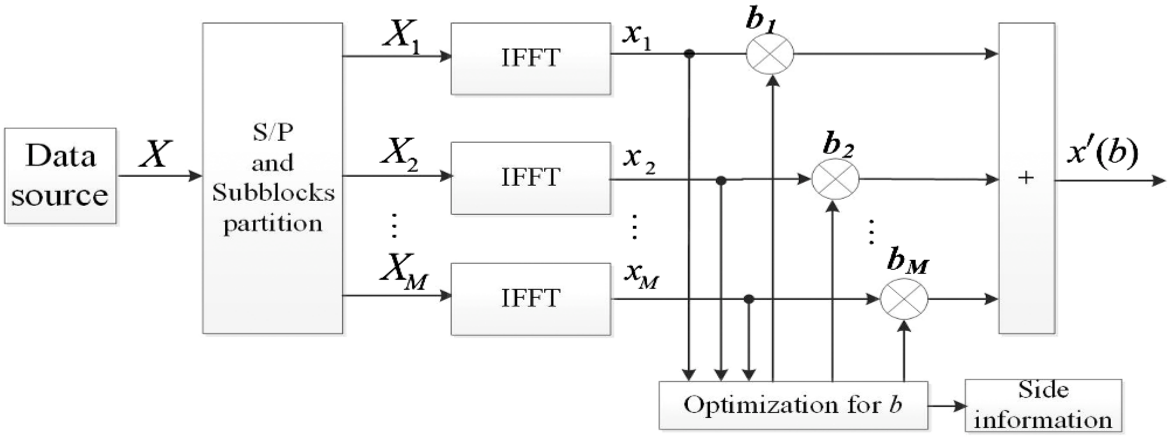


Figure 2.

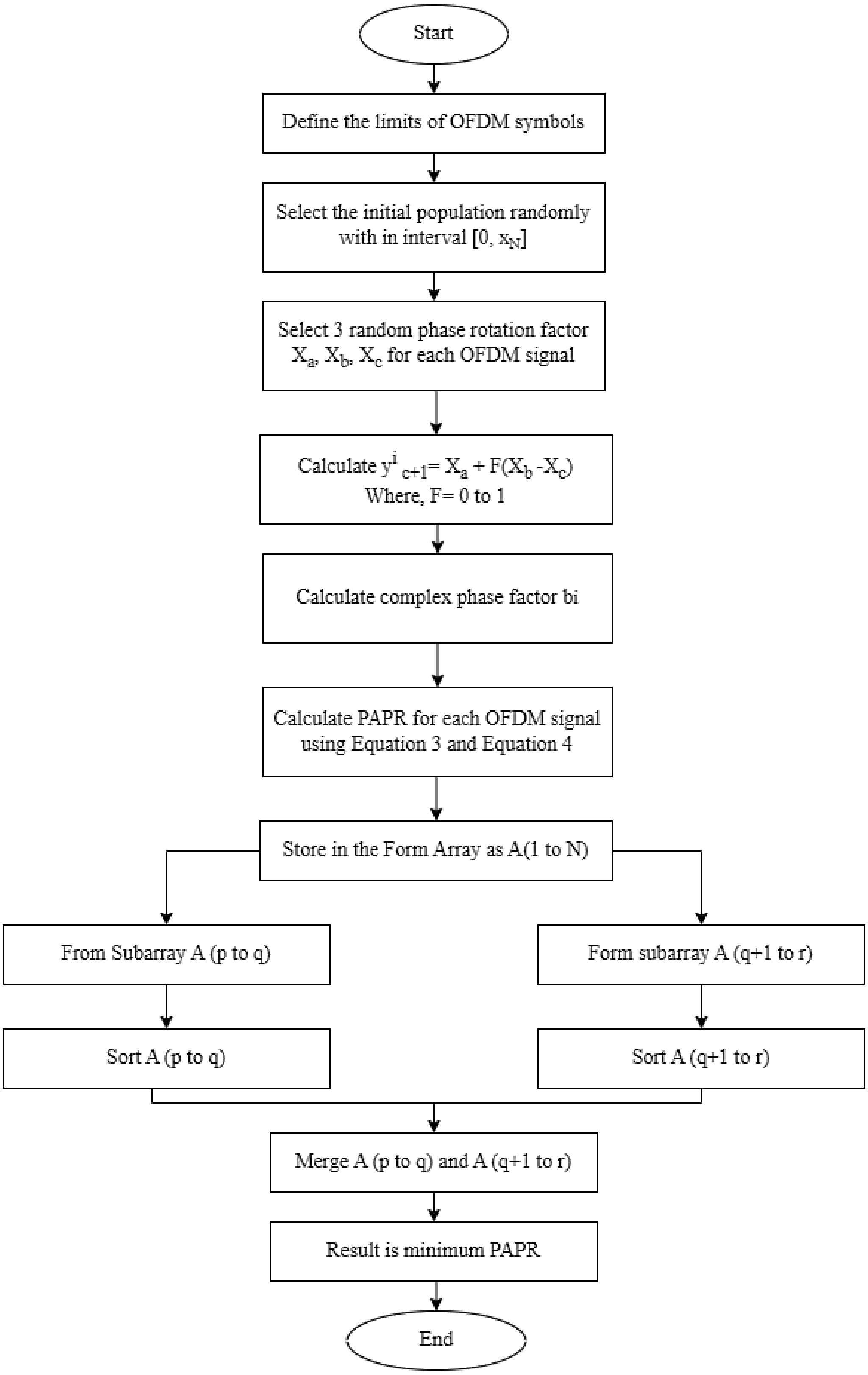

Start
Define the limits of OFDM symbols
Select the initial population randomly with in interval [0, x_N]
Select 3 random phase rotation factor X_a, X_b, X_c for each OFDM signal
Calculate y^i_{c+1} = X_a + F(X_b - X_c)
Where, F= 0 to 1
Calculate complex phase factor bi
Calculate PAPR for each OFDM signal using Equation 3 and Equation 4
Store in the Form Array as A(1 to N)
From Subarray A (p to q)
Form subarray A (q+1 to r)
Sort A (p to q)
Sort A (q+1 to r)
Merge A (p to q) and A (q+1 to r)
Result is minimum PAPR
End

Figure 3.

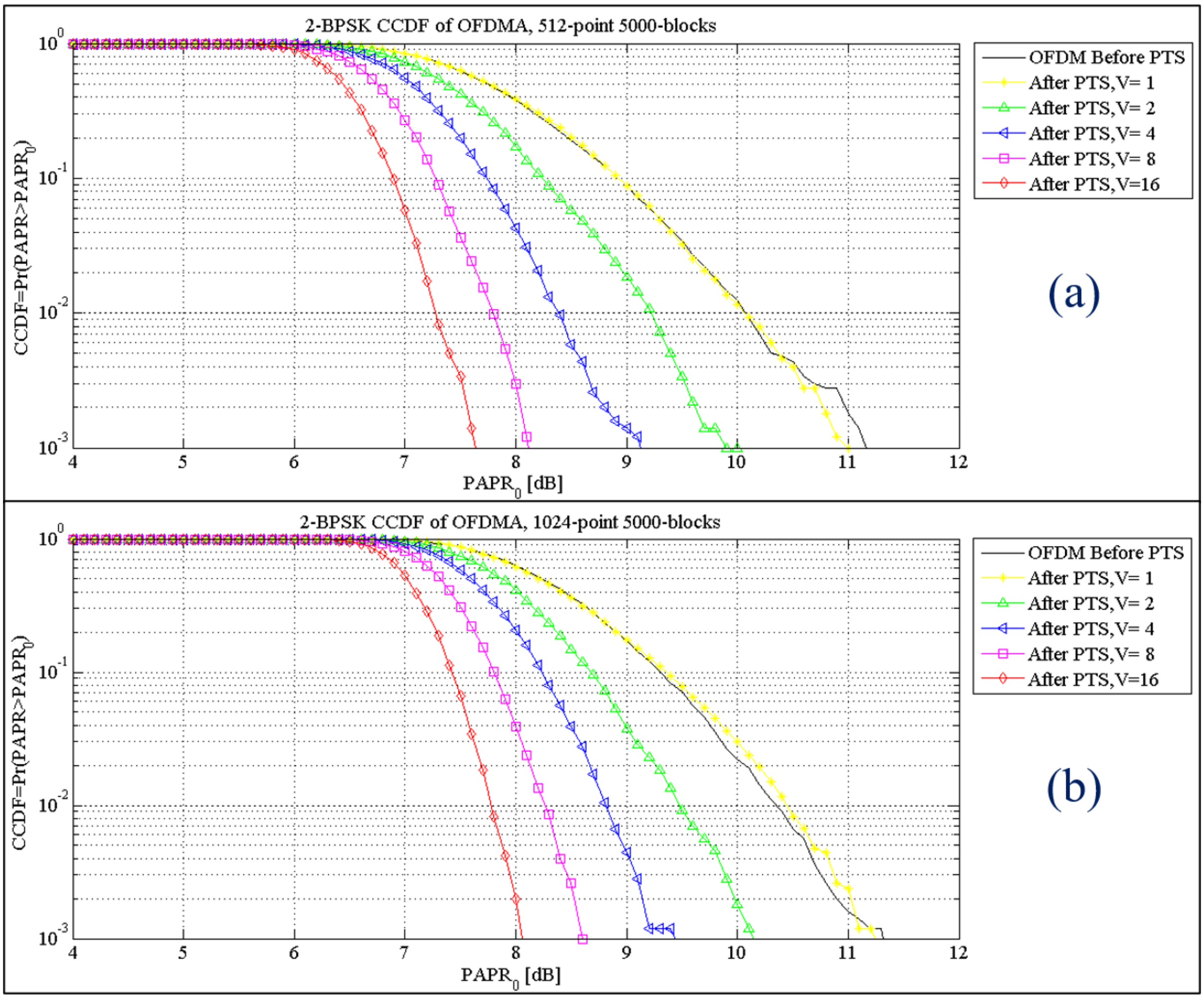

2-BPSK CCDF of OFDMA, 512-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(a)
2-BPSK CCDF of OFDMA, 1024-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(b)

Figure 4.

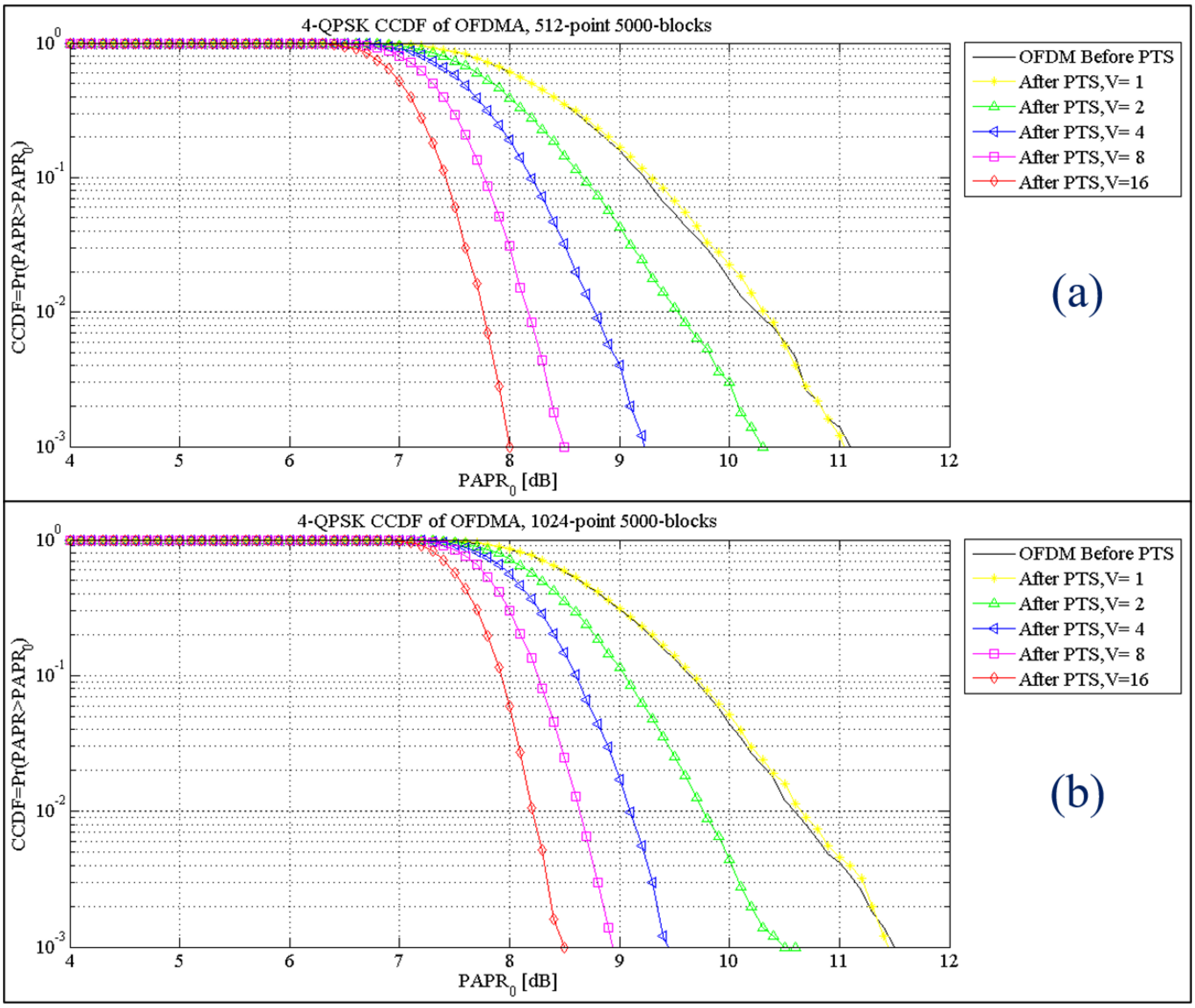
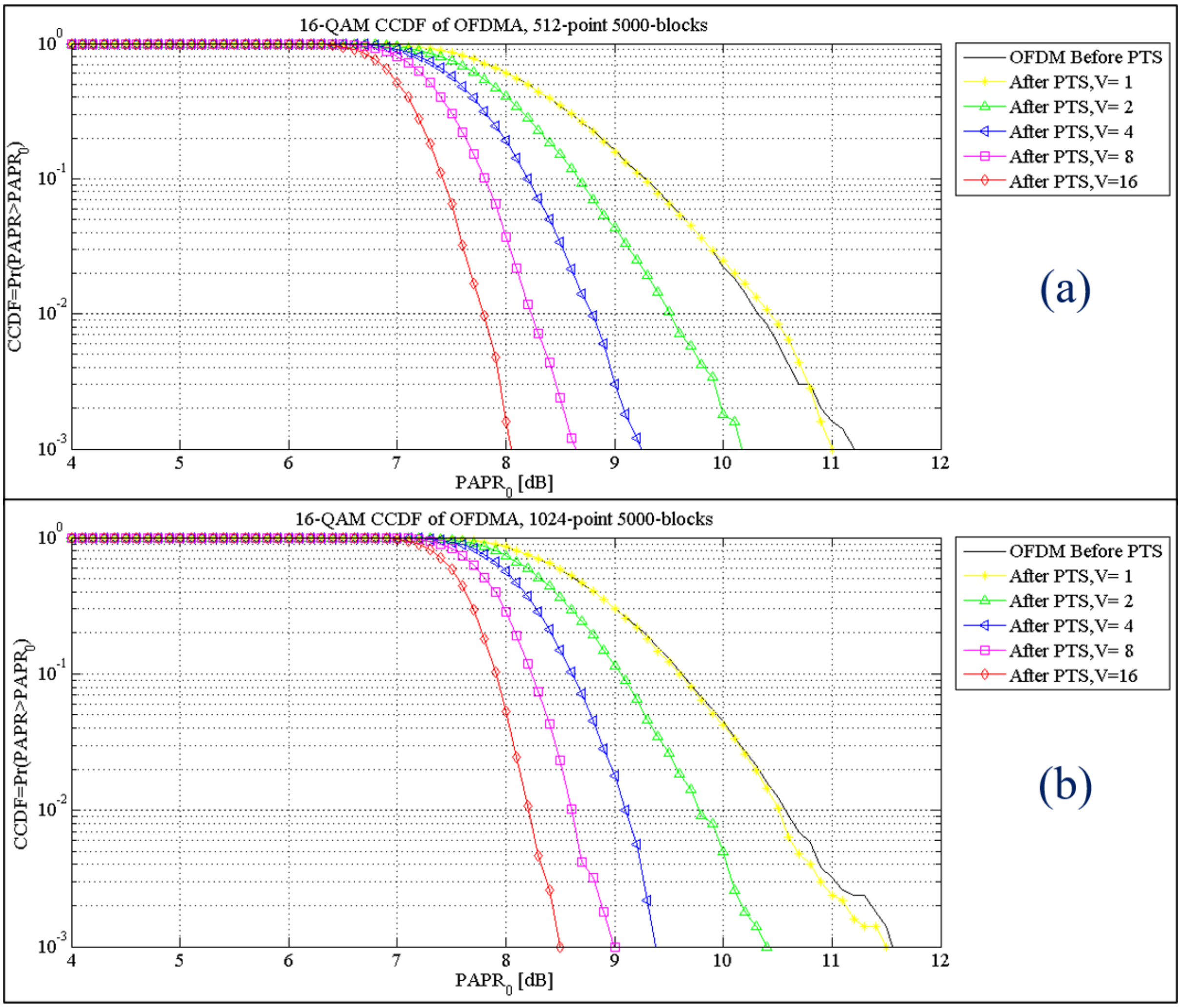
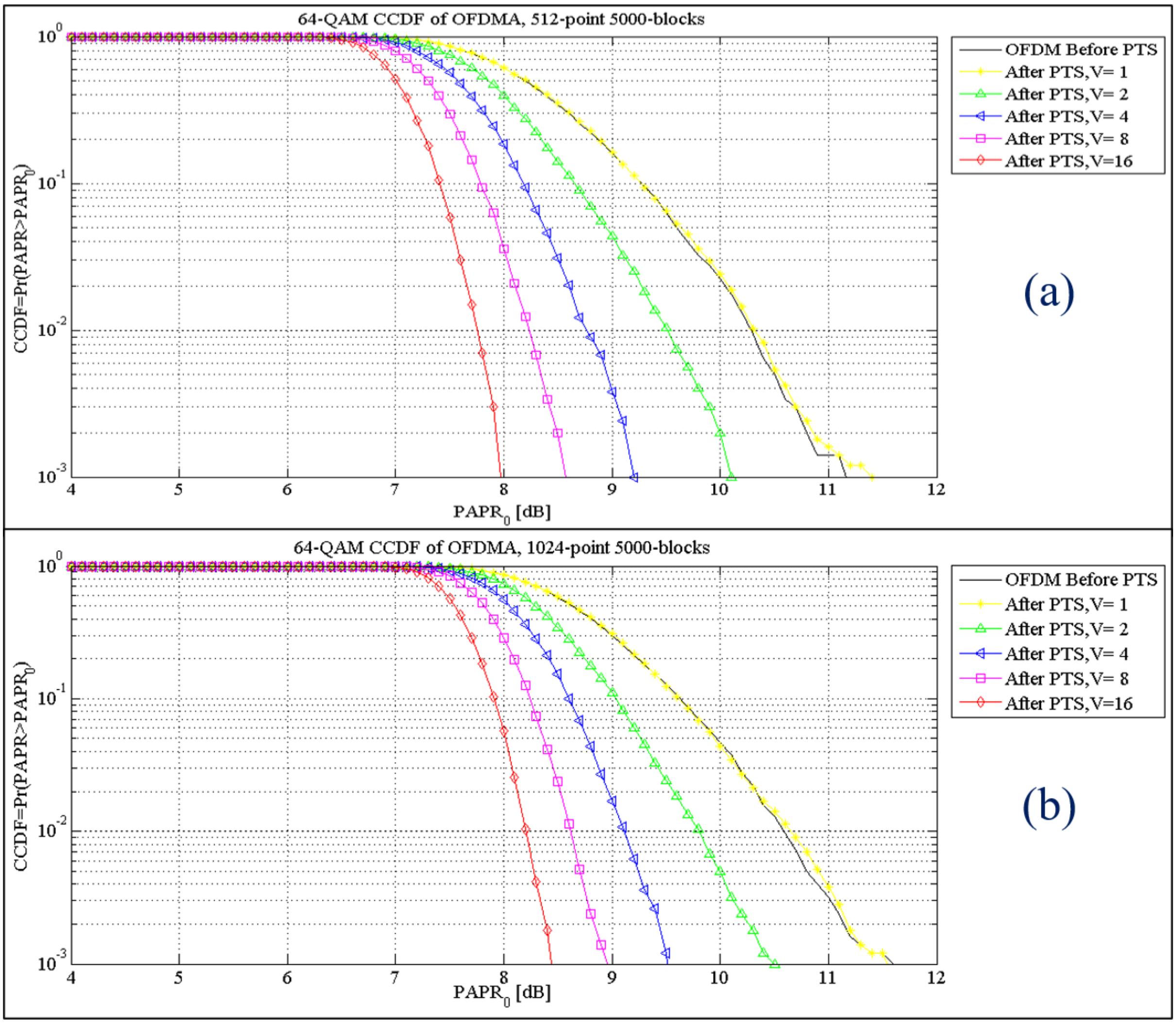

4-QPSK CCDF of OFDMA, 512-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(a)
4-QPSK CCDF of OFDMA, 1024-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(b)

Figure 5.



16-QAM CCDF of OFDMA, 512-point 5000-blocks
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
(a)
16-QAM CCDF of OFDMA, 1024-point 5000-blocks
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
(b)

Figure 6.



64-QAM CCDF of OFDMA, 512-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(a)
64-QAM CCDF of OFDMA, 1024-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(b)

Figure 7.

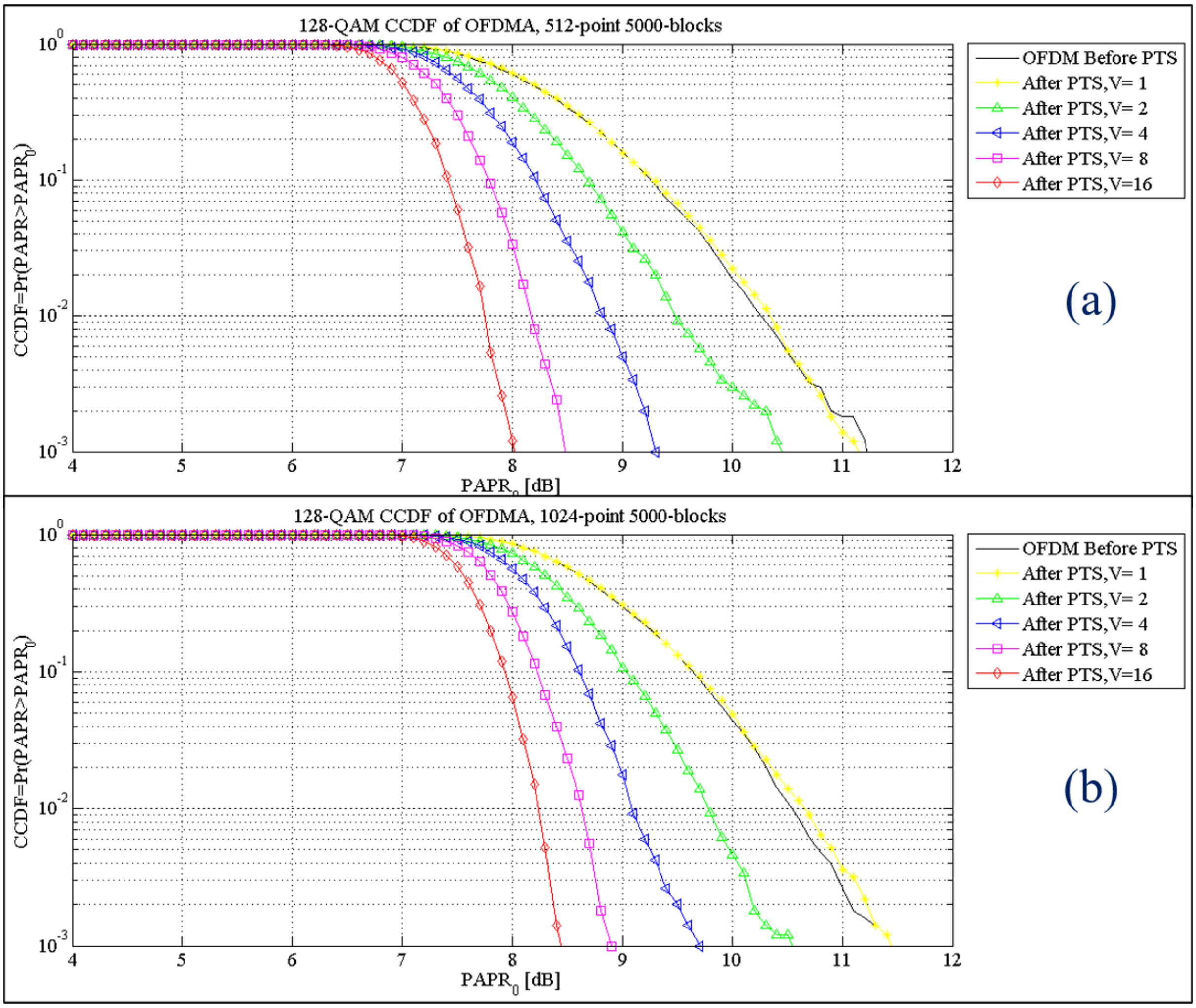
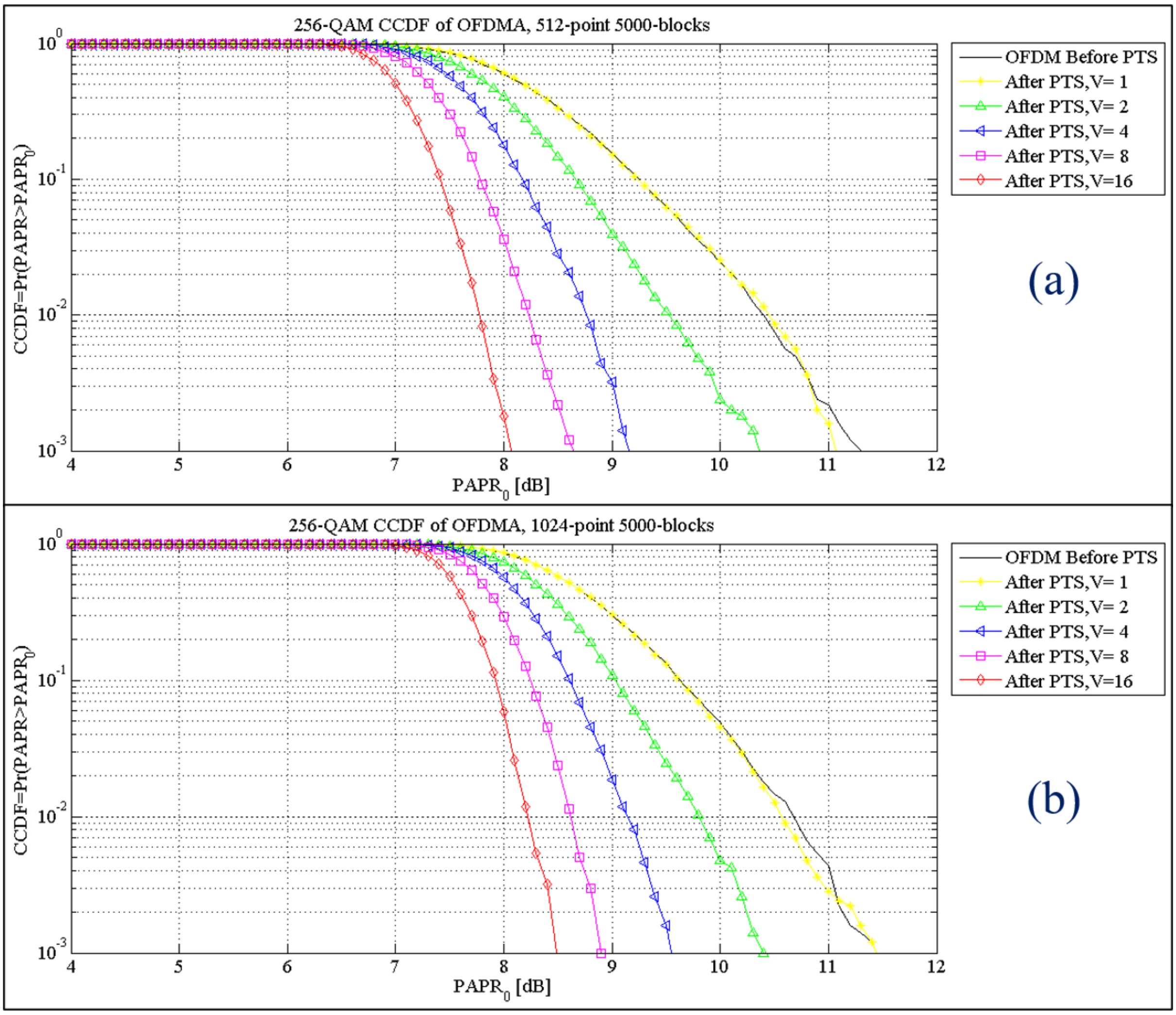

128-QAM CCDF of OFDMA, 512-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(a)
128-QAM CCDF of OFDMA, 1024-point 5000-blocks
CCDF=Pr(PAPR>PAPR0)
PAPR0 [dB]
OFDM Before PTS
After PTS,V= 1
After PTS,V= 2
After PTS,V= 4
After PTS,V= 8
After PTS,V=16
(b)

Figure 8.



Tables

Table 1.

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	Value
Number of total Subcarriers (N)	512 and 1024
Oversampling factor (L)	4
Number of OFDM blocks (Nblk)	5000
Number of Subblocks (V)	1, 2, 4, 8 and 16
Number of bits per symbol (b)	1 for BPSK and 2 for QPSK

Table 3.

N=512 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	11.15	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

Note: - CCDF - complementary cumulative distribution function, (PAPR - peak-to-average power ratio, BPSK - Binary Phase-Shift Keying, BPSK - Quadrature Amplitude Modulation, QAM - Quadrature Amplitude Modulation

Table 4.

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, BPSK - Quadrature Amplitude Modulation, QAM - Quadrature Amplitude Modulation

Table 5.

Methods	Complexity	P=10, G =20 PAPR (dB)
Original ACO-OFDM	-	16.3
GA–PTS	P×G	13.7
PSO–PTS	P×G	12.8
HS-PTS	P×G	12.2
FP–PTS	P×G	11.8
IFP–PTS	P×G	11.4
OPTS	$\boldsymbol{\omega^{V-1} = 2^{15}}$	10.5
Low PTS (Proposed Algorithm)	-	**7.639**

Note: - ACO-OFDM - asymmetrically clipped optical OFDM, GA - Genetic algorithms, PTS - partial transmit sequence, PSO - particle swarm optimization, HS - harmony search, FP - Flower pollination, IFP - Improved flower pollination, OPTS-optimal PTS.