Research Article

PAPR reduction performance of bat algorithm in OFDM systems

YükSEL TOKUR BOZKURT a, b, * and NECMI TAŞPINAR a, b, *

a) Department of Electronics and Automation, Voc. Sch. of Technical Sciences, Gaziantep University, Gaziantep, 27310, Turkey
b) Department of Electrical and Electronics Engineering, Erciyes University, Kayseri, 38280, Turkey

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| Article history | ABSTRACT |
|-----------------|----------|
| Received 13 March 2018 | The progression in technology requires improved modulation techniques for wideband digital communication systems. Orthogonal frequency division multiplexing is efficacious systems to fulfill high-speed data transmissions needs. However, high peak-to-average power ratio (PAPR) is one of the significant limitations on the performance and power efficiency of OFDM systems. Due to industrial and scientific relevance, the assessment of the PAPR reduction has become a popular subject in the current decade. This study presents the combination of bat algorithm with partial transmit sequence scheme as an efficient PAPR reduction method with an alleviated computational load. A set of simulations with different partial transmit sequence schemes are performed to comparatively evaluate the PAPR reduction performance of the partial transmit sequence based on bat algorithm scheme in OFDM system. The simulation results elucidate that BA-PTS scheme can provides better PAPR reduction performance with less computational load. |
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1. Introduction

In past few decades, orthogonal frequency division multiplexing system has attracted considerable interest by offering distinctive features like high spectrum efficiency, robustness to interference, resistance to fading, sub-carrier rate adaptation, simple receiver, low cost transmitter [1]. With these outstanding capabilities, OFDM system has been adopted by several communication technologies like digital audio broadcast, digital video broadcast [2], asymmetric digital subscriber line services, IEEE 802.16a, IEEE 802.11a/g and it also becomes a promising candidate for the next-generation technologies in digital communication systems such as wireless local area networks (WLAN) [3], WiMAX, LTE/LTE-A, etc. to support high-speed wide band digital transmission and reception. Nevertheless, OFDM systems stricken high peak-to-average ratio (PAPR) which can induce signal distortions, reduction in efficiency of RF amplifier, complexity in digital-to-analog and analog-to-digital converters, thus reduction of PAPR has become a research hotspot in the field of digital communications [4-16].

In order to reduce the PAPR in OFDM systems, various methods such as; clipping technique [5], coding technique [6], pre-distortion technique [7], transform schemes [8], and probabilistic scrambling techniques [9-16], are found in the literature. The probabilistic scrambling techniques are based on scrambling of the input data and transmission of data sequence with lowest PAPR. Tone reservation, selective mapping, tone injection, and partial transmit sequence (PTS) techniques are the examples of probabilistic scrambling techniques. Among all the PAPR reduction techniques, PTS is the most promising distortionless technique and has been successfully used in numerous digital communication applications [9-11].

In PTS technique; firstly, the input data is partitioned into several closely spaced sub-blocks and sub-blocks are separately multiplied by a set of phase weighting factors to form multiple sequence, then the one with lowest PAPR is selected for the transmission. However, the search of all possible phase factors to find optimum phase factor set which produces lowest PAPR is an exhaustive search task. The complexity of search task enlarges exponentially with the increase in number of sub-blocks.

* Corresponding author. Tel.: +90-342-3171789; Fax: +90-342-3601171.
E-mail addresses: tokur@gantep.edu.tr (Y. Tokur Bozkurt), tasarinar@erciyes.edu.tr (N. Taspinar)
ORCID: 0000-0003-3195-132X (Y. Tokur Bozkurt), 0000-0003-4689-4487 (N. Taspinar)
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and eliminates the feasibility in practical implementations of high-speed data transmissions [11-16].

In recent years, suboptimal search strategies are applied to alleviate complexity of optimal phase factor search tasks. Some studies proposed the combination of PTS technique with certain suboptimal search strategies such as random search (RS) [11], cuckoo search (CS) [12], differential evolution (DE) [13], parallel tabu search [14], artificial bee colony [15], harmony search (HS) [16], and particle swarm optimization (PSO) [17]. Swarm intelligence is noted as a strong method appropriate for optimization problems. For example, as a stochastic global optimization technique Particle swarm optimization is based on social behavior of bird flocking or fish schooling. Bat algorithm has been inspired by bats behavior during their hunting and flight [18]. In the PSO, each particle in the swarm arranges its position in the search space based on the best position it has realized so far as well as the position of the familiar best-fit particle of the whole swarm. Finally approaches to the global best point of the entire search space. The bat algorithm is inspired from the echolocation behavior of microbats, with varying pulse rates of loudness and emission [19-20].

In this paper, a PTS technique combined with suboptimal bat algorithm is proposed to reduce to PAPR with a low computational load. Modified PTS combining the interleaved partitioning for reducing the PAPR of OFDM signals with QAM sub-blocks is proposed. In Section 2 the theoretical description of OFDM system is introduced. In Section 3 and 4 traditional PTS and the bat search optimization algorithm (BA) for PAPR reduction are explained, respectively. Simulation results of the proposed technique are presented in Section 5 and finally, Section 6 concludes the work.

2. System Model of OFDM

Suppose in an OFDM system \( X = [X_0, X_1, \ldots, X_{N-1}] \) indicates an input data sequence modulated by 16 quadrature amplitude modulation (QAM), where \( N \) shows the number of sub-carriers. Hence, in the discrete time domain an OFDM signal \( x = [x_0, x_1, \ldots, x_{N-1}] \) can be described by

\[
x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}, \quad \text{for} \quad 0 \leq n \leq N - 1
\]

where \( n \) is the discrete time index.

In the discrete time domain based on signal power the PAPR of OFDM signal can be represented by the ratio of the peak power to the average power, which can be showed by

\[
PAPR(x_n) = 10 \log_{10} \frac{\max_{0 \leq n \leq N-1} \{ |x_n|^2 \}}{E[|x_n|^2]} \quad dB
\]

where \( E \{ \} \) and \( \max \{ \} \) represent the expectation operation and the maximum operation, respectively.

Complementary cumulative distribution function (CCDF), which is also used to compare and evaluate PAPR reduction schemes’ performances, is be described by

\[
CCDF(N, PAPR_0) = Pr\{PAPR > PAPR_0\} = 1 - (1 - e^{-PAPR_0})^N
\]

where PAPR_0 shows a dedicated value of PAPR.

The PAPR characteristics of discrete-time OFDM signals and continuous-time OFDM signals are pretty much similar to each other. The proper PAPR performance can be accomplished through the implementation of LN-point IFFT of symbol sequence with \((L-1)N\) zero-padding [9-16]. In the discrete time domain, the oversampling factor, \( L \), is generally acknowledged as 4.

3. Traditional PTS

The functional block diagram of a distinctive partial transmit sequence combined bat algorithm optimization is shown in Figure 2. Proliferation of sub-blocks with optimized phase rotation vectors is the basic principle behind the PTS scheme as a distortionless PAPR reduction algorithm. In a representative PTS scheme, the input signal \( X \) is sectioned into \( M \) disjoint sub-blocks each with a set of sub-carriers equal size \( N \), such that

\[
X = \sum_{m=1}^{M} X_m
\]

where \( X_m \) shows the \( m \)th sub-block sequence. Each sub-block is weighted with an assigned phase weighting factor. The resulting sub-blocks are combined to diminish PAPR after being multiplied by phase rotation vectors. There wards, with the application of IFFT, the applicant sequence \( x' \) can be maintained given by

\[
x' = \sum_{m=1}^{M} b_m \cdot \text{IFFT}(X_m) = \sum_{m=1}^{M} b_m x_m
\]

Where \( x_m \) represents the \( m \)th sub-block sequence in the time domain and \( b_m \) is the phase factor for \( m \)th sub-block sequence. Finally, the one with the lowest PAPR between all the applicant sequences is picked for transmitted.

The side information is necessary to successfully acquire original data sequence at the receiver. Theorize there are \( W \) allowed phase weighting factors in conventional PTS. Hence, \( M \) shows the number of sub-block, we can obtain \( W^{M-1} \) applicant sequences. Thus, \( \log_2 W^{M-1} \) bits are required to express the side information.
4. Bat Search Optimization Algorithm

Bat algorithm (BA), suggested by Xin-She Yang [19] in 2010, is a nature-inspired stochastic search algorithm for both non-linear and linear global optimization problems. It mimics the echo-location characteristics of microbats with varying pulse rates of loudness and emission. The flow chart of a bat algorithm is given in Figure 2.

The bat algorithm is built on the following basic assumptions: all bats utilize echolocation to locate orientation of target and detect distance, fly from their own position $x_i$ to other randomly using velocity $v_i$, emit pulse using a constant frequency $f_{\text{min}}$ with loudness $A_0$ and varying wavelength $\lambda$ to detect forage, can also set the wavelength (or frequency) and the rate ($r \in [0,1]$) of emitted pulses with respect to proximity of target, and the loudness of emitted pulses alter from a large $A_0$ to a minimum constant value $A_{\text{min}}$.

In a d-dimensional search space there are some simple rules to update locations $x_i$ and velocities $v_i$ of bats during the search. At a time, instance $t$, a set of new positions $x_i^t$ and velocities $v_i^t$ can be given as

$$f_i = f_{\text{min}} + (f_{\text{max}} - f_{\text{min}}) \beta$$  \hspace{1cm} (6)

$$v_i^t = v_i^{t-1} + (x_i^t - x_*)f_i$$  \hspace{1cm} (7)

$$x_i^t = x_i^{t-1} + v_i^t$$  \hspace{1cm} (8)

where $x_*$ and $\beta$ are the current global best location and random vector drawn from uniform distribution variable, respectively. The value of $\beta$ must be between 0 and 1.

5. Simulations

The OFDM signals having $M = 16$ sub-blocks with 16-QAM modulation were randomly generated for computer simulations. Different number of the generation/iteration $G$, different number of the population/the particle $P$, number of the phase factor $W = 2$, the number of sub-carries $N = 256$, pulse rate $R = 0.5$ and loudness $A = 0.5$ were selected. The fundamental parameters of the simulations were listed in Table 1.

Figure 3 and Figure 4 show the CCDF versus PAPR plot of the proposed scheme with the variation of number of population and number of iteration, respectively. The examined values are 10, 25, and 75 for the number of population, 25, 50, and 75 for the number of iteration while $P = 10$ and $P = 50$.

| Quantity          | Symbol | Value   |
|-------------------|--------|---------|
| number of sub-blocks | $M$    | 16      |
| number of phase factor | $W$    | 2 (±1)  |
| number of the iteration | $G$    | 25,50,75 |
| number of sub-carriers | $N$    | 256     |
| number of the population | $P$    | 10,25,50 |
| loudness          | $A$    | 0.5     |
| pulse rate        | $R$    | 0.5     |
| modulation method | $\text{QAM}$ |         |
The CCDF versus PAPR plot for the proposed scheme with 256 subcarriers is shown in Figure 3. It is clearly seen that PAPR is significantly reduced as the numbers of population increases. The PAPR values at $CCDF = 10^{-3}$, are 7.4 dB, 6.82 dB, 6.51 dB and 6.42 dB for 10, 25, 50 and 75 number of population, respectively. Compared to the traditional PTS, the PAPR reduction of about 3.55 dB for 10 population 4.13 dB for 25 population, 4.44 dB for 50 population and 4.53 dB for 75 population were achieved.

In Figure 4, the simulation results are shown for the proposed scheme in which 10 and 50 numbers of population are employed with various iterations. The iterations are chosen as 10, 25 and 50. The number of sub-blocks and the number of sub-carriers are used as $M = 16$ and $N = 256$, respectively. It is observed that an increase in the number of iterations is resulted with a serious reduction in PAPR. When $P = 10$, the PAPR values are 7.42 dB, 7.3 dB, and 7.28 dB at same time when $P = 50$, the PAPR values are 6.62 dB, 6.5 dB, and 6.42 dB for 10, 25 and 50 iterations, respectively. The PAPR reductions for $P = 50$, in accordance with for the PAPR reductions $P = 10$, are approximately 0.8 dB for 10 iteration, 0.8 dB for 25 iteration, 0.86 dB for 50 iteration.

Table 2 shows comparison of computational complexity amongst different methods for $M = 16$, $N = 256$ and $W = 2$.

In Figure 5, the performance comparison of the proposed scheme with other PTS based PAPR reduction schemes (optimum, random search, differential evolution and cuckoo search) are presented. When $CCDF=10^{-3}$, the PAPR of the original is 10.95 dB, the random search (RS) is 7.2 dB, the PAPR values for and the suboptimal methods are 7.1 dB for the cuckoo search (CS), 6.75 dB for the differential evolution (DE), 6.37 dB for the Optimum-PTS (O-PTS) and 6.54 dB for the proposed system. For same search complexity, the PAPR of the BA-PTS is smaller 0.21 dB, 0.56 dB, 0.66 dB than that of DE-PTS, CS-PTS and RS-PTS, respectively. The comparison shows that the BA-PTS gives better PAPR reduction compared with RS-PTS, CS-PTS and DE-PTS in OFDM system.

In Figure 6, the performance comparison of the proposed scheme with other PTS based PAPR reduction schemes such as harmony search, particle swarm optimization and optimum are presented. When $CCDF = 10^{-3}$, the PAPR of the original is 10.95 dB, the PAPR values for and the suboptimal methods are 7.45 dB for the PSO-PTS, 7.27 dB for the HS-PTS, and 6.54 dB for the proposed system. For same search complexity, the PAPR of the BA-PTS is smaller 0.91 dB, 0.73 dB, than that of PSO-PTS and HS-PTS, respectively.

| Method  | Search | PAPR  |
|---------|--------|-------|
| Original| 0      | 10.95 |
| PSO-PTS | 1000   | 7.45  |
| HS-PTS  | 1000   | 7.27  |
| RS-PTS  | 1000   | 7.2   |
| CS-PTS  | 1000   | 7.1   |
| DE-PTS  | 1000   | 6.75  |
| BA-PTS  | 1000   | 6.54  |
| O-PTS   | 32768  | 6.37  |
The comparison shows that the BA-PTS gives better PAPR reduction compared with HS-PTS and PSO-PTS in OFDM system.

6. Conclusion

In this paper, we present PTS based on bat algorithm in OFDM system to deal with the PAPR problem to reduce the complexity. The CCDF simulations are performed to evaluate the PAPR reduction performance of the proposed BA-PTS scheme. The PAPR reduction performance and computational load are compared with those of original PTS, Optimum-PTS, RS-PTS, CS-PTS, DE-PTS, PSO-PTS and HS-PTS. It is shown that compared to RS-PTS, CS-PTS, DE-PTS, HS-PTS and PSO-PTS, BA-PTS scheme provides better PAPR reduction performance with less computational load.

References

1. Yang, S., Yang, W., Cai, Y., and Wei L., An energy efficient PTS scheme for PAPR reduction in OFDM relay systems. in ChinaCom 2015: Shanghai, China. p.858-863.
2. Patidar, M.K., Mishra, A., and Saxena, R., Partial approximate gradient constellation for PAPR reduction in OFDM signals. International Journal of Systems, Control and Communications, 2016. 7(1): p.83-96.
3. Joshi, A., and Saini, D.S., Peak-to-average power ratio reduction of OFDM signals using improved PTS scheme with low computational complexity. WSEAS Transactions on Communications, 2013. 12(12): p. 630-640.
4. Huang, X., Diversity performance of precoded OFDM with MMSE equalization. in ISCTE’07: Sydney, Australia. p.802-807.
5. Wang, J., Guo, Y., and Zhou, X., PTS-clipping method to reduce the PAPR in ROF-OFDM system. IEEE Transactions Consumer Electronics, 2009. 55(2): p. 356-359.
6. Jones, A.E., Wilkinson, T.A., and Barton, S.K., Block coding scheme for reduction of peak to mean envelope power ratio of multicarrier transmission scheme. Electron Lett, 1994. 30(25): p. 2098–2099.
7. Sharma, C., Tomar, S.K., and Gupta, A.K., PAPR reduction in OFDM system using adaptive coding technique with pre distortion method. WSEAS Transactions Communications, 2011. 10(9): p. 255-262.
8. Huang, X., Lu, J., Zheng, J., and Letaief, K.B., Comanding transform for reduction in peak-to-average power ratio of OFDM signals. IEEE Transactions on Wireless Communications, 2004, 3(6): p. 2030-2039.
9. Jie, Y., Lei, C., Quan, L., and De, C., A modified selected mapping technique to reduce the peak-to-average power ratio of OFDM signal. IEEE Transactions on Consumer Electronics, 2007. 53(3): p. 846-851.
10. Chen, J.C., and Li, C.P., Tone reservation using near-optimal peak reduction tone set selection algorithm for PAPR reduction in OFDM systems. IEEE Signal Processing Letters, 2010. 17(11): p. 933-936.
11. Cimini, L.J., and Sollenberger, N.R., Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences. IEEE Commun Lett, 2000. 4(3): p. 86-88.
12. Tokur Bozkurt, Y., and Taspınar, N., PAPR reduction in OFDM systems using partial transmit sequence with Cuckoo search optimization algorithm. International Journal of Intelligent Systems and Applications in Engineering, 2016. 4(1): p. 260-263, 2016.
13. Hung, H.L., and Huang, Y.F., Peak-to-average power ratio reduction in orthogonal frequency division multiplexing system using differential evolution-based partial transmit sequences scheme. Commun IET, 2012. 6(11): p. 1483-1488.
14. Taspınar, N., Kalinli, A., and Yıldırım, M., Partial transmit sequences for PAPR reduction using parallel tabu search algorithm in OFDM systems. IEEE Commun Lett, 2011. 15(9): p. 974-976.
15. Taspınar, N., Karaboga, D., Yıldırım, M., and Akay, B.,
16. Kermani, E.M., Salehinejad, H., and Talebi, S., *PAPR reduction of OFDM signals using harmony search algorithm*, in ICT2011: Ayia Napa, Cyprus. p. 90-94.

17. Gao, J., Wang, J., and Wang, B., *Improved particle swarm optimization for PAPR reduction of OFDM systems*, International Conference on Networking, Sensing and Control, in ICNSC2010: Chicago, IL, USA. p.621-624.

18. Chaieb, H., and Sakly, A., *Review and comparison BAT and PSO MPPT’s based algorithms for photovoltaic system*, WSEAS Trans on Power Systems, 2018. 13: p.108-117.

19. Yang, X.S., *A new metaheuristic bat-inspired algorithm-Inspired Algorithm, Nature Inspired Cooperative Strategies for Optimization*, Springer, 2010. 284: p. 65-74.

20. Mishra, S., Shaw, K., and Mishra D., *A new meta-heuristic bat inspired classification approach for microarray data*, Procedia Technology, 2012. 4: p. 802-806.