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PAPR reduction performance of bat algorithm in OFDM systems

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ABSTRACT

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 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.

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

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

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi kn}{N}}, \qquad 0 \le n \le N-1 \tag{1}$$

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

$$PAPR(x_n) = 10log_{10} \frac{\max_{0 \le n \le N-1} \{|x_n|^2\}}{E\{|x_n|^2\}} dB \tag{2}$$

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

$$CCDF(N, PAPR_0) = Pr\{PAPR > PAPR_0\}$$
$$= 1 - (1 - e^{-PAPR_0})^N \tag{3}$$

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

$$X = \sum_{m=1}^{M} X_m \tag{4}$$

where X_m shows the mth 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

$$x' = \sum_{m=1}^{M} b_m . IFFT\{X_m\} = \sum_{m=1}^{M} b_m \, x_m \tag{5}$$

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.

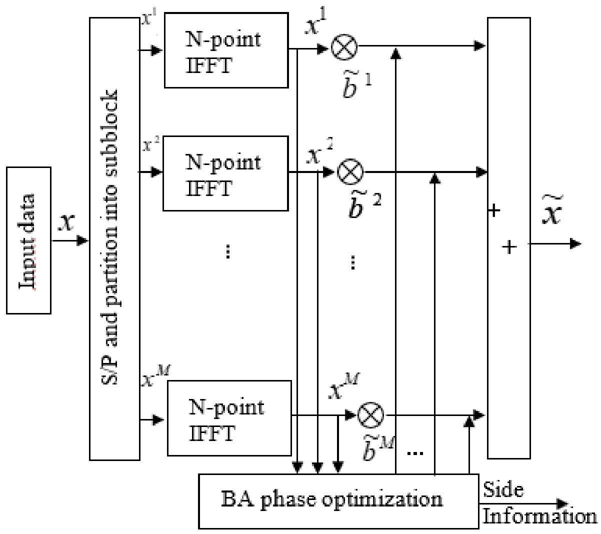

Figure 1. System model of the BA-PTS model

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_{min} with loudness A_0 and varying wavelength λ 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_{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

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (6)$$

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

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

where x* and β are the current global best location and random vector drawn from uniform distribution variable, respectively. The value of β 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/the 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 $P = 50$.

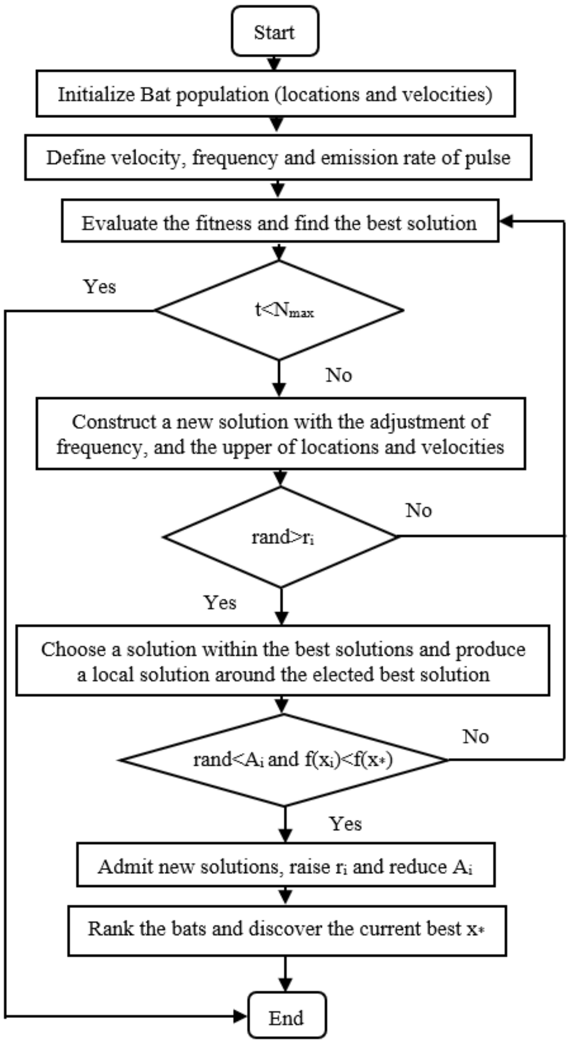

Figure 2. The flowchart of bat algorithm

Table 1. The fundamental parameters of the simulations

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	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.

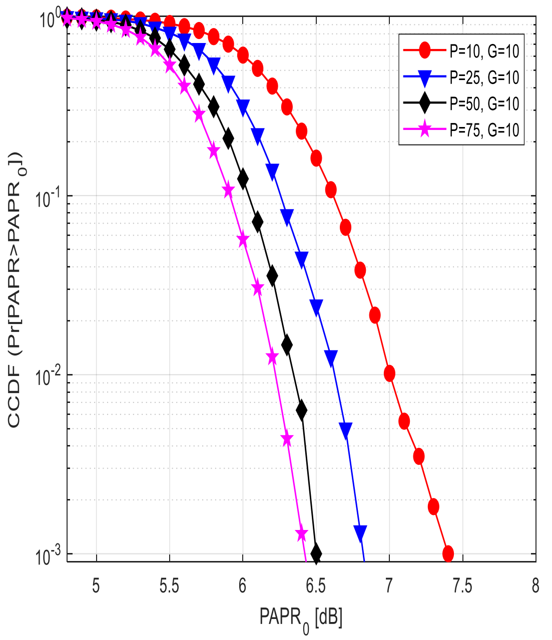

Figure 3. The CCDF versus PAPR₀ (dB) of BA-PTS with different values of P for G=10

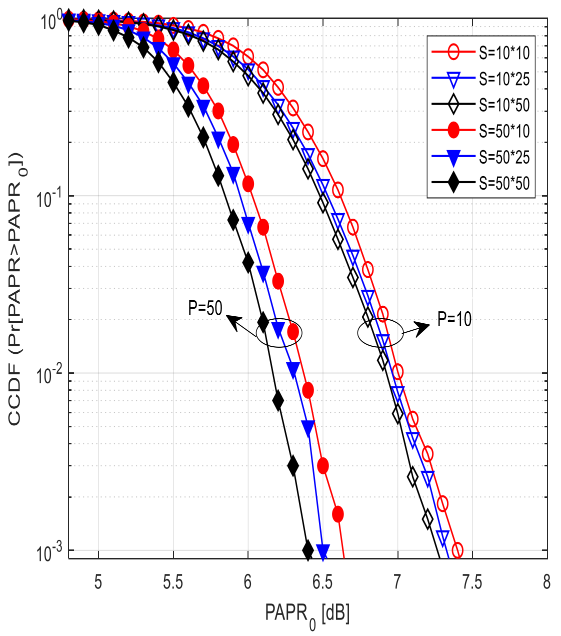

Figure 4. The CCDF versus PAPR0 (dB) of BA-PTS with different numbers of iteration for P=10 and P=50

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 7.42dB, 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, 7.27dB 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.

Table 2. Computational Complexity of the PTS Methods

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

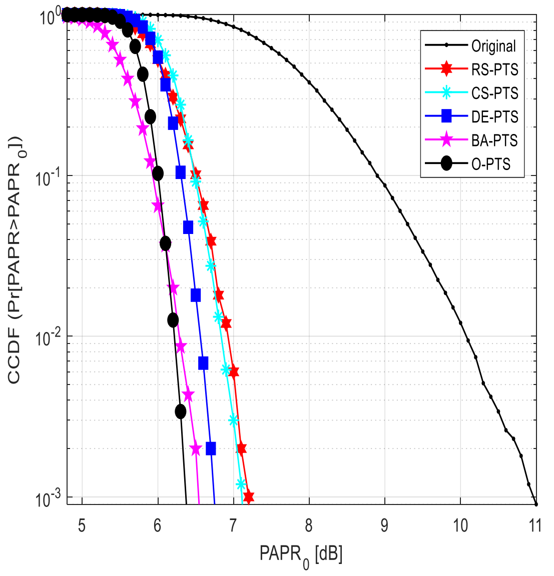

Figure 5. The CCDF versus $PAPR_0$ (dB) of optimum PTS, BA-PTS, DE-PTS, CS-PTS, RS-PTS and the original

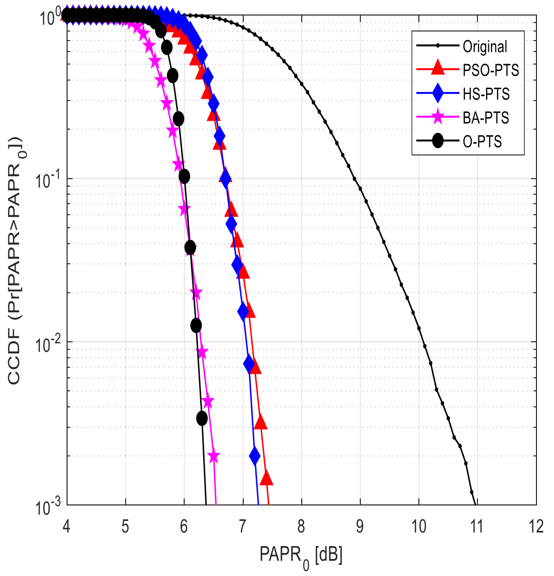

Figure 6. CCDF versus $PAPR_0$ (dB) comparison of optimum PTS, BA-PTS, HS-PTS, PSO-PTS and the original

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.

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