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PAPR Reduction in OFDM Systems using Partial Transmit Sequence combined with Cuckoo Search Optimization Algorithm

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Abstract:Partial transmit sequence (PTS) scheme is one of theefficacious toolfor lessening peak-to-average power ratio (PAPR) inorthogonal frequency division multiplexing (OFDM) system. However, computational cost for the optimum phase factors searches of PTS scheme entails huge computational requirements and limits its applicability to practical applications especially for high-speed data transmissions. This study proposes a PAPR reduction method with a low computational complexity based on a combination of cuckoo search optimization algorithm with PTS scheme in OFDM system. In terms of PAPR and computational cost reductions, the performance of the cuckoo-PTS scheme is comparatively investigated by performing a set of simulations with different PTS schemes.

Keywords:*Cuckoo search, OFDM,PAPR, partial transmit sequence.*

1. Introduction

Over the past few decades, due to key features as, high bandwidthefficiency, narrowband interference, efficient implementation and robustness to frequency selective fading[1–4],the OFDM systems have receivedincreasing attention and become one of the promising techniques for high data rate transmissions in digital communication. However, OFDM systems are susceptible to high peak-to-average power ratio (PAPR) [2] which causes significant reductions in radio frequency power amplifiers and yields high complexity in digital-to-analog and analog-to-digital converters. High PAPR also leads to implementation problems for the systems with large numbers of subcarriers. The PAPR can be reduced with the applications of constitutional arrangements and restrictions which in turn adversely affect the operation of the power amplifier and the spectral efficiency of OFDM systems.

Numerous methods with different advantages and drawbacks have been appeared in the literature for the reduction of PAPR in OFDM systems such as clipping [3], selected mapping [4],clipping and filtering [5],partial transmit sequence (PTS) [6-7], coding [14],tone injection [9],tone reservation [10],peak windowing [17], interleaving [12] and active constellation extension [13] have been appeared. Among these methods, the PTS is one of the popular distortionless techniques and provides remarkable PAPR reduction performance. However, the search and combination of phase factors which requires an exhaustive search procedure is the primary drawback of PTS technique. The replacement of optimum phase factor search steps of PTS scheme with a suboptimal search technique offers reduction in computational complexity of PTS scheme. Many suboptimal PTS schemes, including the harmony search (HS) [14], parallel tabu search (parallel-TS) [15],artificial bee colony (ABC) [16],differential evolution (DE) [17],particle swarm optimization (PSO) [18] and random search [7], have been presented in the literature and it is reported that PAPR reductions with less computational costs are successfully obtained.

In this paper, a suboptimal PTS scheme based on Cuckoo Search Optimization Algorithm is proposed for the PAPR reduction in OFDM systems. The Cuckoo Search Optimization Algorithm, proposed by Xin-She Yang and Suash Deb [19], is a relatively new optimization method that mimics breeding behaviour of some cuckoo species.

2. System Model of OFDM

The system model of OFDM is given in Fig. 1. First, the incoming bit sequences are interleaved to transform burst errors into random errors. The interleaved signal is modulated with 16-QAM modulation. To recover the original signal at the receiver, side information is transferred. In order to combat with inter-symbol interference (ISI) induced by communication channel, a cycle prefix (CP) is applied to the signal after passing through a high-power amplifier. The CP is extracted from the signal at the receiver. The phase of original signal is acquired with the use of phase rotation and side information following the realization of fast Fourier transform (FFT). The symbols are demodulated with 16-QAM and conveyed to their original place in the bit sequence with the application of the de-interleaver [16].

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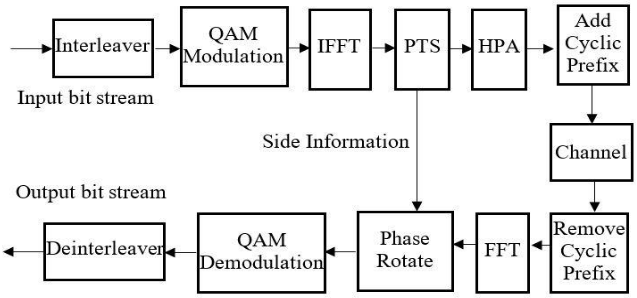

Figure 1. Block diagram of the system model.

3. Conventional PTS

The PTS is a promising distortionless PAPR reduction algorithm based on multiplication of subblocks with optimized phase rotation vectors. In a typical PTS scheme, the input signal is partitioned into M disjoint subblocks each of which have a set of sub-carriers with equal size, N, such that

$$\mathrm{X} = \sum_{m=0}^{M-1} \mathrm{X}^{(m)} \quad (1)$$

Oversampling is implemented to subblocks by padding $L(N-1)$ zeros to original OFDM blocks. Oversampled subblocks are transformed into time domain and mathematically expressed by

$$x = IFFT\left\{\sum_{m=0}^{M-1} \mathrm{X}^{(m)}\right\} = \sum_{m=0}^{M-1} x^{(m)} \quad (2)$$

The goal of PTS scheme is to obtain a combination of x signal with a rotational phase vector $\mathbf{b} = [b_1 \quad b_2 \quad \cdots \quad b_{M-1}]^T$ to offer the lowest PAPR that is represented by

$$\tilde{x} = \sum_{m=0}^{M-1} b_m x^{(m)} \quad (3)$$

The individuals of rotational phase vector is $b_m = e^{j\theta_m}$, where θ_m is selected freely between 0 and 2π. The allowed rotational phase vector combinations is W^M, where W is the number of allowed phase factor. However, the phase factor for the first subblocks is taken as $b_0 = 1$, then there are W^{M-1} alternative rotational phase vector combinations. The values of b_m are selected as follows:

$$b_m = \pm 1 \text{ for } W = 2 \quad (4)$$

The block diagram of a typical partial transmit sequence is shown in Fig. 2.

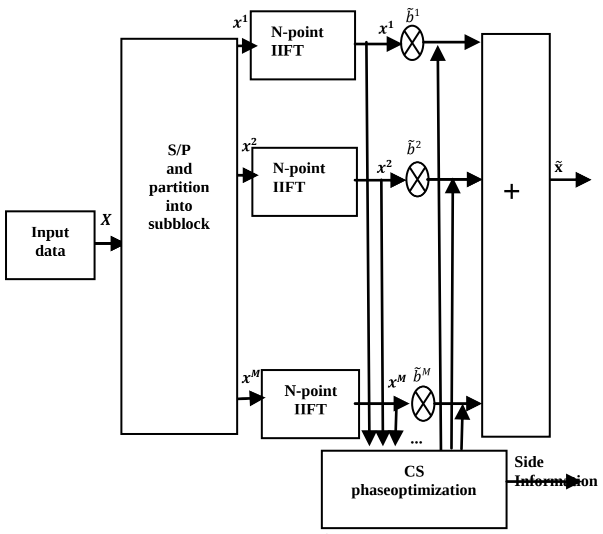

Figure 2. Blocks diagram of the CS-PTS model.

4. Cuckoo Search Optimization Algorithm

The cuckoo search (CS) algorithm, proposed by Yang and Deb [19], is a recently developed promising optimization algorithm that utilizes the offensive reproduction tactics of the cuckoo bird. The CS algorithm is built on the following basic assumptions: each cuckoo can lay only one egg in a randomly chosen nest at a time, high-quality eggs in best nests can receive more chances to survive in next generation, the number of convenient host nests is limited and possibility of discovering cuckoo egg is defined in a range between 0 and 1. In the case of cuckoo egg detection, the host bird can either abandon the nest or throw out the cuckoo egg. The cuckoo eggs in CS algorithm represent the potential solutions.

The replacement of a host bird egg with a cuckoo egg is the goal of the CS algorithm. The eggs of host bird and cuckoo represents the “not so good solution” and “better solution” in the algorithm. The assumption of each nest has only one cuckoo egg provides no difference between egg, nest and cuckoo, and makes the application of CS algorithm simpler. The CS algorithm starts with the generation of an initial population forthe nests with size n. In this initial population, the nests are randomly deployed over the search space and design variables are also randomly assigned between the lower and upper bound values of them.

A new solution, $x_i^{(t+1)}$, for the i^{th} cuckoo is generated by Levy flight using the following expression:

$$x_i^{(t+1)} = x_i^t + \alpha \oplus Levy(\lambda) \quad (5)$$

where α is the step size and is defined with respect to scale of the problem of interests. The step size must be greater than 0, and in most cases, can be unity or some other constant. Levy Flight is a random walk in which Levy distribution determines the random step size.

$$Levy \sim u = t^{-\lambda}, 1 < \lambda \leq 3 \quad (6)$$

5. Simulations

The randomly generated OFDM signals with $N = 256$ sub-carriers with $16 - QAM$ modulation were used in computer simulations. The number of the generation, NG, number of the population,NP, number of sub-blocks, M, and the number of the phase factor, W, was selected as 50, 20, 16, 4 respectively. Complementary cumulative density functions (CCDFs) of the PAPR were obtained with the use of 10000 random OFDM symbol generations. The solid state power amplifier (SSPA) with smoothness factor, $p = 2$and input back-off factor, $IBO = 9\ dB$was employed as an amplifier. The additive white Gaussian noise (AWGN) channel was chosen as communication channel. The fundamental parameters of the simulationswere summarized in Table 1.

Table 1. Parameters for simulations

Quantity	Symbol	Value
modulation method	QAM	
number of phase factor	W	4 (±1±j)
number of the population	NP	20
number of the generation	NG	50
number of sub-blocks	M	16
number of sub-carriers	N	256
input back-off	IBO	9 dB
smoothness factor	p	2
linear amplifier	SSPA	
channel	AWGN	

The CCDFs of PAPR for PTS schemes based on cuckoo search optimization algorithm (CS), optimum PTS andrandom search (RS)are illustrated in Figure 3. The PAPR values at $\mathrm{CCDF} = 10^{-3}$ are 10.96 dB for original, 7.62 dB for random search algorithm, 7.45 dB for PSO algorithm, 6.8 dB for cuckoo search algorithm, 6.37 dB for Optimum algorithm. It is shown that cuckoo search optimization algorithm provides the best PAPR reduction performance while random search yields the worst PAPR reduction performance.

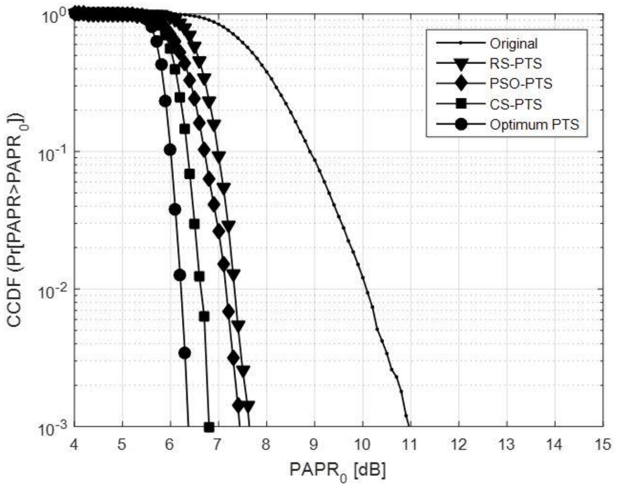

Figure 3. Comparison of the $PAPR_0$ (dB) versus CCDF of the original, CS-PTS, RS-PTS, PSO-PTS and optimum-PTS

In Figure 4, the variations of CCDFs are plotted according todifferent number of generations, NG, with $NP = 20$. It is seen that$NG = 100$is resulted with the best PAPR reduction performanceand the worst performance is established for $NG = 25$. At $CCDF = 10^{-3}$, the PAPR is $7.32\,dB$, $7.10\,dB$, $7.00\,dB$ and $6.86\,dB$ for $NG = 25$, $NG = 50$, $NG = 75$, and $NG = 100$, respectively.

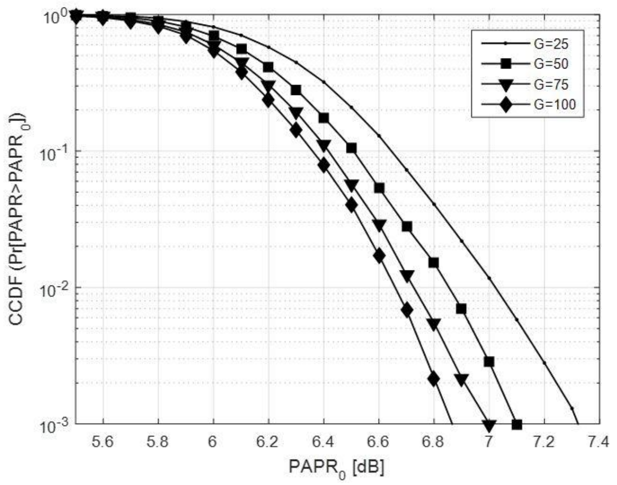

Figure 4. Comparison of the $PAPR_0$ (dB) versus CCDF for CS-PTS with different values NG for $W = 4, M = 16, NP = 20$

According to Figure 5, the PAPR values at $CCDF = 10^{-3}$ are $7.28\,dB$for $P = 25$,$7.04\,dB$for $P = 50$,$6.93\,dB$for $P = 75$,and $6.81\,dB$for $P = 100$. It is shownthat an increase in population is resulted with an improvement in PAPR reduction.

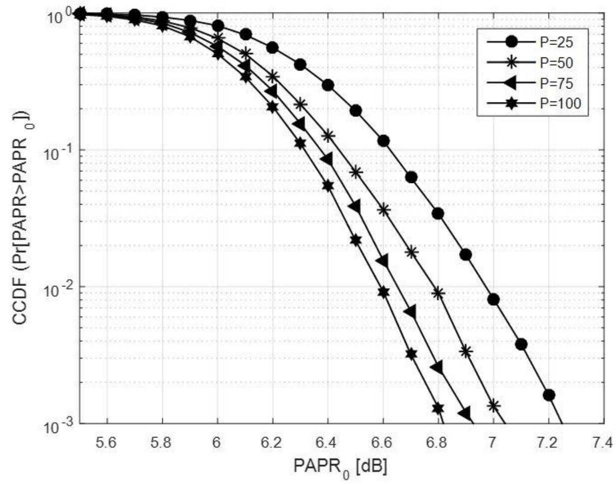

Figure 5. Comparison of the $PAPR_0$ (dB) versus CCDF for CS-PTS with different values G for $W = 4$, $M = 16$, $NP = 20$, and $NG = 25$.

6. Conclusion

In this paper, PTS based on cuckoo search optimization algorithm in OFDM system is proposed for the PAPR reduction with less computational load. The CCDF simulations are performedto evaluate the PAPR reduction performance of the proposed CS-PTS scheme. Also, its performance is compared with the performances of original PTS, O-PTS, PSO-PTS and RS-PTS in the OFDM systems. Simulation results show that the PAPR reduction performance of the CS-PTS in the OFDM system is better than that of O-PTS, PSO-PTS and RS-PTS in the OFDM system.

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