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OFDM PAPR Reduction Using Hybrid Partial Transmit Sequences Based On Cuckoo Search Algorithm

[1]Maninder Singh, [2]Charanjit Singh, [3] Amandeep Singh Bhandari
[1,2,3]Electronics and Communication Engineering Department, Punjabi University, Patiala

Abstract:
The past decade has seen many radical changes and achievements in the field of wireless communication. Applications of wireless communication have grown swiftly in the recent past. This rigorous growth leads to more throughput over wireless channels along with increased reliability. But still the bandwidth demands are endless and increasing day by day. Today we need to constantly work towards achieving reliable wireless communication with high spectral efficiency, low complexity and good error performance results. Orthogonal frequency division multiplexing (OFDM) technique is a promising technique in this regard as it offers high data rate and reliable communications over various fading channels. But the main drawback of OFDM is the high peak to average power ratio (PAPR). In this paper we present the technique to reduce the PAPR using Cuckoo Search Algorithm in multicarrier modulation system. Simulation results show that the proposed scheme considerably outperforms the conventional system.

I. INTRODUCTION

In multi-carrier modulation, the most frequently used method is Orthogonal Frequency Division Multiplexing (OFDM); it has become very general in wireless communication. Unfortunately the main disadvantage of OFDM transmission is its large wrapping fluctuation which is quantified as Peak to Average Power Ratio (PAPR). For decrease of this PAPR lot of algorithms have been established. All of the methods have some sort of benefits and drawbacks [1]. Clipping and Filtering is one of the simple method in which some part of transferred signal undergoes into distortion. Also the Coding arrangement decreases the data amount which is undesirable. If we go for the Selected Mapping (SLM) and Partial Transmit Sequence (PTS) system, the PTS method has additional complexity than that of SLM method. This Selected Mapping is one of the promising methods due to its simplicity for implementation which familiarizes no distortion in the transmitted signal. It has been designated first in [2] i.e. to be recognized as the traditional SLM method. An OFDM signal consists of a number of individually modulated subcarriers, which can give a large Peak-to-Average Power Ratio (PAPR) when added up coherently. When N signals are added with the same phase, they generate a peak power that is N times the average power. To escape nonlinear distortion, highly linear amplifiers are essential which cause a severe decrease in power efficiency. Several methods are explained in the literature in order to solve this problem.

OFDM Transmission Theory

The basic principle of OFDM is to split input data stream into a number of lower rate streams that are transferred simultaneously over a number of subcarriers, the transmission rate is slower in parallel subcarriers, a frequency selective channel seems flat to each subcarrier. ISI is reduced almost completely by adding a guard interval at the beginning of each OFDM symbol. However, instead of using an empty guard time, this interval is filled with a cyclically extended version of the OFDM symbol. This method is used to avoid ICI.

In OFDM, subcarrier spacing is kept at minimum, while still preserving the time domain orthogonality between subcarriers, even though the individual frequency spectrum may overlap. The least subcarrier spacing should equal to 1/T, where T is the symbol period. An OFDM symbol in baseband is defined as:

$$x(t) = \sum_{i=-\frac{N}{2}}^{\frac{N}{2}-1} a_{i+\frac{N}{2}} \exp\left(j\frac{2\pi i t}{T}\right) s(t) \qquad 0 \le t \le T$$

where, $a_{i+N/2}$denotes the complex symbol modulating the i-th carrier, *s(t)* is the time window function defined in the interval [0,T], N is the number of subcarriers, and T is the OFDM symbol period. Subcarriers are spaced $\Delta F = 1/T$apart. The correlation coefficient between the subcarriers may be defined as:

$$\rho_{kn} = \frac{1}{T}\int_0^T \exp\left(j\frac{2\pi k t}{T}\right)\exp\left(-j\frac{2\pi n t}{T}\right)dt$$

As can be seen from (1)

$$\rho_{kn} = \begin{Bmatrix} 1, & n = k \\ 0, & n \neq k \end{Bmatrix}$$

The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. These subcarriers are overlapped with each other.

PAPR Reduction Techniques

Several PAPR [13] reduction techniques have been proposed in the literature. These techniques are divided into two groups. These are signal scrambling techniques and signal distortion techniques.

(A) Signal Scrambling Technique

1. Tone reservation

The main idea of this method is to keep a small set of tones for PAPR reduction. This can be originated as a convex problem and this problem can be solved accurately. Tone reservation method is based on adding a data block and time domain signal. A data block is dependent time domain signal to the original multicarrier signal to minimize the high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at the receiver. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones.[12]

2. Block coding

The fundamental idea is that of all probable message symbols, only those which have low peak power will be chosen by coding as valid code words for transmission. No introduction of distortion to the signals. If there have N subcarriers, they are represented by $2N$ bits using QPSK modulation and thus 2^{2N} messages. Using the whole message space corresponds to zero bits of redundancy.

3. Selective Level Mapping

The simple idea of this method is first produce a number of alternative OFDM signals from the original data block and then transmit the OFDM signal having least PAPR. But data rate loss and complexity at the transmitter side are two simple drawbacks for this method.

4. Tone injection

Tone Injection (TI) technique is based on general additive method for PAPR reduction. Using an additive method achieves PAPR reduction of multicarrier signal without any data rate loss. TI uses a set of equivalent constellation points for an original constellation points to reduce PAPR. The main idea behind this method is to increase the constellation size.

(B) Signal Distortion Techniques

1. Clipping and Filtering

This is a humblest method used for PAPR reduction. Clipping [15] means the amplitude clipping which limits the peak envelope of the input signal to a prearranged value.

$$\mathrm{x_c(n)} = \mathrm{f(x)} = \begin{cases} -\mathrm{A} & \mathrm{x[n]} \quad \leq \mathrm{A} \\ \mathrm{x[n]} & \mathrm{x[n]} < A \\ \mathrm{A} & \mathrm{x[n]} \quad \geq \mathrm{A} \end{cases}$$

Where, A is the pre-specified clipping level.

2. Peak Windowing

The peak windowing method proposes that it is possible to remove large peaks at the cost of a slight amount of self-interference when large peaks arise less frequently. Peak windowing reduces PAPRs at the cost of increasing the BER and out-of-band radiation. It offers better PAPR reduction with better spectral properties. In peak windowing method we multiply large signal peak with a specific window, for example; Gaussian shaped window, cosine, Kaiser and Hamming window.

3. Cuckoo Search Algorithm

Cuckoos are fascinating birds, not only because of the beautiful sounds they can make, but also because of their aggressive reproduction strategy. Some species such as the ani and Guira cuckoos lay their eggs in communal nests, though they may remove others' eggs to increase the hatching probability of their own eggs. Quite a number of species engage the obligate brood parasitism by laying their eggs in the nests of other host birds (often other species). Some cuckoo species such as the New World brood- parasitic Tapera have evolved in such a way that female parasitic cuckoos are often very specialized in the mimicry in colour and pattern of the eggs of a few chosen host species. This reduces the probability of their eggs being abandoned and thus increases their productivity.

For the implementation point of view, we can use the following simple representations that each egg in a nest represents a solution, and each cuckoo can lay only one egg (thus representing one solution), the aim is to use the new and potentially better solutions (cuckoos) to replace a not-so-good solution in the nests. For this present work, we will use the simplest approach where each nest has only a single egg. In this case, there is no distinction between eggs, nest or cuckoo, as each nest corresponds to one egg which also represents one cuckoo. When generating new solutions x^{t+1} for, say, a cuckoo i, a Levy fight is performed.

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus Levy(\curlywedge)$$

Where $\alpha > 0$ is the step size which should be related to the scales of the problem of interests, in most cases, we can use $\alpha = O(L/10)$ where L is the characteristic scale of the problem of interest.

Proposed Work:

Orthogonal frequency division multiplexing (OFDM) offers high data rate and reliable communications over fading channels. But the major disadvantage of OFDM is the high peak to average power ratio. Our objective is to develop a technique to reduce the PAPR using Cuckoo Search algorithm. We will use Cuckoo Search Algorithm for reducing PAPR of OFDM system incorporating Partial Transmit Sequence (PTS), which would allow achieving solution with reduced computational burden and try and evaluate the resultant system performance with and without Cuckoo Search Algorithm.

System Model

The transmitter system used in our result simulations is shown in figure 3.1.

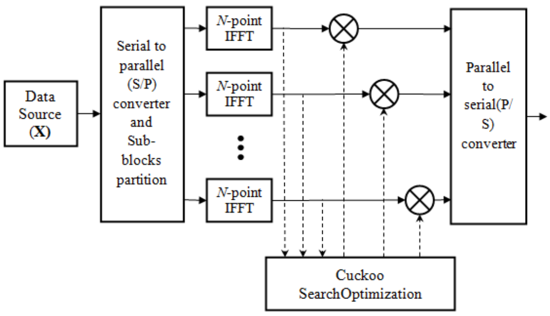

Fig.1 Transmitter

The functional block diagram of a multicarrier modulation system with PTS scheme is shown in Figure 3.1. The data source block **X** is partitioned into M disjoint sub-blocks X_m, where m = 1, 2... M, such that,

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

Here, it is assumed that the sub-blocks X_m consist of a set of subcarriers of equal size N. The partitioned sub-blocks are converted from the frequency domain to the time domain using *N*-point IFFT. Due to IFFT being a linear transformation, the representation of the block in the time domain is given by,

$$\mathbf{x} = \text{IFFT}\left\{\sum_{m=1}^{M} X_m\right\} = \sum_{m=1}^{M} \text{IFFT}\{X_m\} = \sum_{m=1}^{M} x_m$$

As shown in Figure 1, if the system follows the dashed line path then the Cuckoo Search Algorithm will optimize the system by generating appropriate phase vector **b**, by minimizing the fitness function given by,

$$PAPR = \frac{\max_{m=0}^{M-1}|\mathbf{x}'|}{\sigma^2}$$

Where, $\sigma^2$is the average power of the transmitted signal.

Table 4.1: Parameter Settings for Simulation.

Parameter	**Description**	**Value**
Available Sub-Blocks	Sub-Block size	2, 4, 8, 16
OFDM Blocks	Input bits	Available Sub-Blocks * 10^5
Number of Sub-Carriers	No. of subcarriers	128, 256, 512
M	Constellation Size	16-QAM
m	Bits/Symbol	$\log_2(M) = 4$
PAPR (dB)	PAPR in dB	4 to 14
fitnessFunc	Fitness Function	@(x) max(abs(x(1)^2)) ./ mean(x(1))
numOfNests	Number of Nests	10
maxIterations	Max Iterations	5

Results:

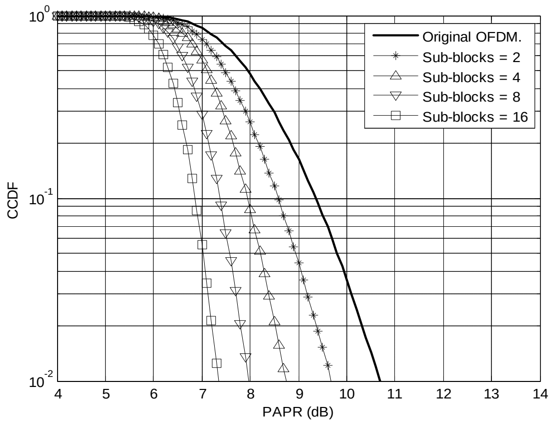

Fig. 2. System performance for *N*=128 and 16-QAM

Fig. 2 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation and *N*=128 subcarriers. It can be seen that by increasing the number of sub-blocks PAPR reduces significantly. At CCDF of 10^{-2} PAPR is 9.7 dB for 2 sub-blocks, 8.8 dB for 4 sub-blocks, 7.9 dB for 8 sub-blocks and 7.35 dB for 16 sub-blocks. Moreover, a reduction of about 1.0 dB with respect to the original OFDM (without sub-blocks or rather 1 sub-block) is achieved if compared with PAPR of 2 sub-blocks.

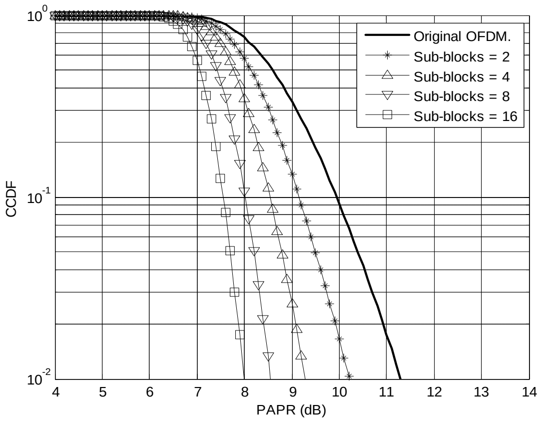

Fig. 3. System performance for *N*=256 and 16-QAM

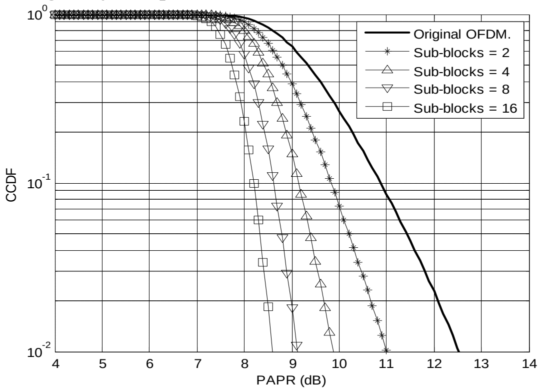

Fig. 4. System performance for *N*=512 and 16-QAM

Fig. 3 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation and *N*=256 subcarriers. It can be seen that by increasing the number of sub-blocks PAPR reduces significantly. At CCDF of 10^{-2} PAPR is 10.2 dB for 2 sub-blocks, 9.3 dB for 4 sub-blocks, 8.65 dB for 8 sub-blocks and 7.97 dB for 16 sub-blocks. Moreover, a reduction of about 1.1 dB with respect to the original OFDM (without sub-blocks or rather 1 sub-block) is achieved if compared with PAPR of 2 sub-blocks.

From the above figures (4.1 and 4.2) it can be noted that there is significant improvement with increase in the number of sub-blocks.

Fig. 4 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation and *N*=512 subcarriers. It can be seen that by increasing the number of sub-blocks PAPR reduces significantly. At CCDF of 10^{-2} PAPR is 11 dB for 2 sub-blocks, 9.9 dB for 4 sub-blocks, 9.15 dB for 8 sub-blocks and 8.6 dB for 16 sub-blocks. Moreover, a reduction of about 1.5 dB with respect to the original OFDM (without sub-blocks or rather 1 sub-block) is achieved if compared with PAPR of 2 sub-blocks.

Fig. 5 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation, for 2 & 8 sub-blocks and for subcarriers *N*=128, 256, & 512.It can be seen that for the same number of sub-blocks if we decrease the number of subcarriers, then the PAPR reduces significantly. At CCDF of 10^{-2} and sub-blocks = 2, PAPR is 11 dB for 512 subcarriers, 10.2 dB for 256 subcarriers and 9.7 dB for 128 subcarriers.

Similarly, at CCDF of 10^{-2} and sub-blocks = 8, PAPR is 9.15 dB for 512 subcarriers, 8.55 dB for 256 subcarriers and 7.95 dB for 128 subcarriers.

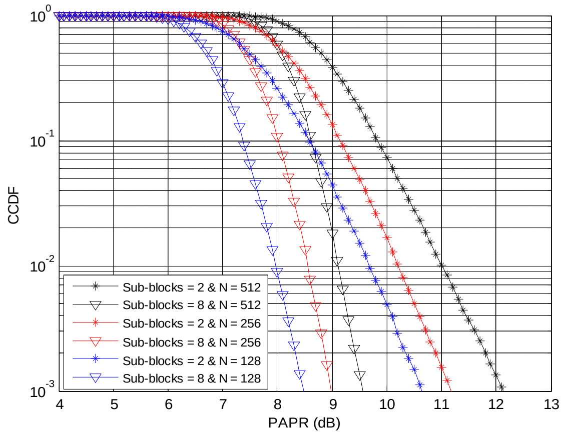

Fig. 5. System performance for 2 & 8 sub-blocks, various *N* and 16-QAM.

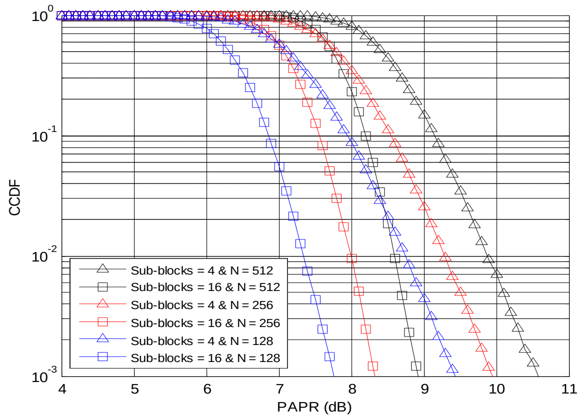

Fig. 6. System performance for 4 & 16 sub-blocks, various *N* and 16-QAM.

Fig. 6 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation, for 4 & 16 sub-blocks and for subcarriers *N*=128, 256, & 512.Here also we see that for the same number of sub-blocks if we decrease the number of subcarriers, then the PAPR reduces significantly. At CCDF of 10^{-2} and sub-blocks = 4, PAPR is 9.9 dB for 512 subcarriers, 9.3 dB for 256 subcarriers and 8.75 dB for 128 subcarriers.

Similarly, at CCDF of 10^{-2} and sub-blocks = 16, PAPR is 8.6 dB for 512 subcarriers, 8.0 dB for 256 subcarriers and 7.35 dB for 128 subcarriers.

The above results are compared with Genetic Algorithm block coding (GA) technique. Genetic Algorithm block coding technique is distortion less method and is combination of partial transmit sequence and dummy sequence insertion methods. It takes apart the original signal into two parts and selects the part having minimum PAPR. The following Table 4.2 illustrates the parameter values used for GA system. Parameter description is given along with.

Table 4.2: Parameter Settings for GA.

Parameter	Description	Value
Number of Sub-Blocks	Sub-Block size	2
Number of Sub-Carriers	No. of subcarriers	64
PAPR (dB)	PAPR in dB	3 to 10
Tx	Transmit Antennas	2
Rx	Receive Antennas	1

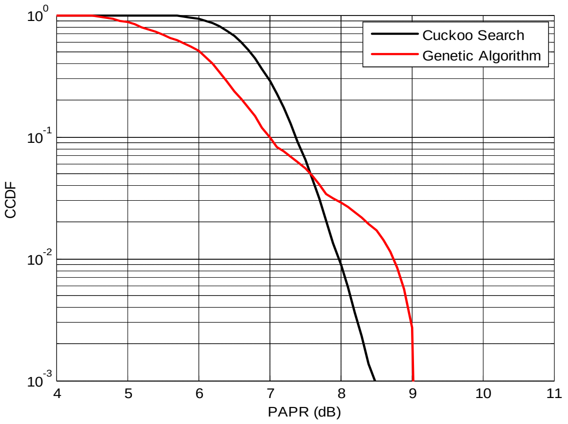

Fig. 7: Comparison of CS (128 sub-carriers) with Genetic Algorithm technique.

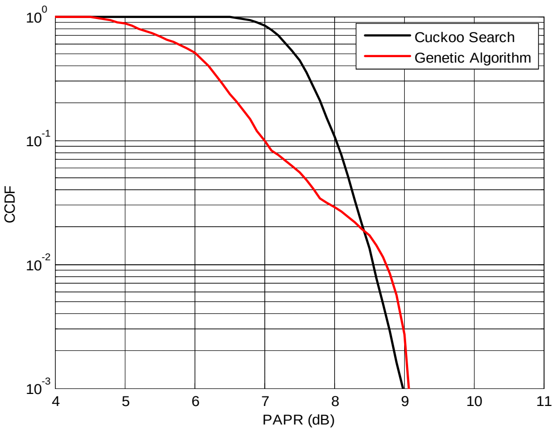

Fig. 8: Comparison of CS (256 sub-carriers) with Genetic Algorithm technique.

Fig. 7 and 8 compare the system performance (CCDF vs. PAPR) for CS and GA schemes, the only difference being the number of subcarriers used for CS, 128 in Fig. 7 and 256 in Fig. 8. The number of sub-blocks used are 4 in both the cases (CS and GA), for both figures (4.6 and 4.7).

From Fig. 7, it can be seen that for the same number of sub-blocks (2) and same number of subcarriers (64), the PAPR obtained using CS is less than that obtained with GA system. At CCDF of 10^{-2}, PAPR is 8.1 dB for CS and 8.7 dB for GA system, thereby having an improvement of 0.6 dB. At CCDF of 10^{-3}, an improvement of 0.6 dB is seen, with PAPR of 8.4 dB for CS and 9 dB for GA system.

Fig. 8, compares the GA system used in Fig. 4.6 with CS (having 256 subcarriers). It can be seen that even with more number of subcarriers (64), the PAPR obtained using CS is nearly equal to that obtained using GA system.

CONCLUSION

OFDM is a multicarrier modulation scheme which plays an important role in long distance communication. One of its biggest challenges in OFDM is the peak to average power ratio (PAPR) which is ratio of maximum power of given OFDM symbol to the average power of that OFDM symbol. The simulation results shows that CS is an effective method to reduce the PAPR problem. This method reduces the probability of having PAPR value. Simulation Results are compared with GA coding technique. Also effect of changing various simulation parameters such as subcarriers, sub-blocks is studied. By changing simulation parameters, system performance changes in terms of PAPR values and probability of PAPR values.

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