

Research on PAPR Suppression Algorithm Based on NC-OFDM System

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Abstract. The high peak to average power ratio in the cognitive NC-OFDM system causes the signal to fall into the nonlinear region of the linear amplifier, resulting in large distortion. Combining the advantages of partial transmission sequence algorithm and clipping algorithm in OFDM system, according to the characteristics of NC-OFDM system, a PCF algorithm is proposed in this paper. The simulation results show that the PCF algorithm can effectively reduce the PAPR about 0.7dB compared with the PTS algorithm while guaranteeing a certain bit error rate.

Keywords: NC-OFDM; PAPR; PCF algorithm.

1. Introduction

Although cognitive NC-OFDM technology has many advantages[1], as a special form of multi-carrier modulation technology, when the input signals are in the same phase or similar, the time domain signal will have a large envelope signal due to the multiple carriers [2], making the system produce a larger PAPR. Higher peak-to-average power ratios can cause severe power consumption. High-power amplifiers are the most power-hungry modules. About 41% of the energy is wasted by the HPA[3]. The higher PAPR will cause the signal to fall into the nonlinear region of HPA, causing severe signal distortion. Therefore, it is of great significance to study the PAPR suppression algorithm.

In response to the seriousness of the high PAPR problem, domestic and foreign scholars have proposed many solutions to reduce PAPR. Currently, PAPR for reducing NC-OFDM systems is generally divided into three categories: coding, predistortion, and probability[4]. The typical algorithm of these PAPR solutions are the clipping algorithm [5], selective mapping (SLM) [6] and partial transmission sequence (PTS) algorithm. Aiming at the problem that the error rate is too high due to the clipping, a method of clipping filtering is proposed. This paper analyzes several typical PAPR suppression algorithms in NC-OFDM system, and proposes a new PAPR suppression algorithm based on the characteristics of two algorithms. Compared with the PTS algorithm, this algorithm can effectively reduce the PAPR by about 0.7dB under the error rate of 10^{-3} .

2. NC-OFDM System

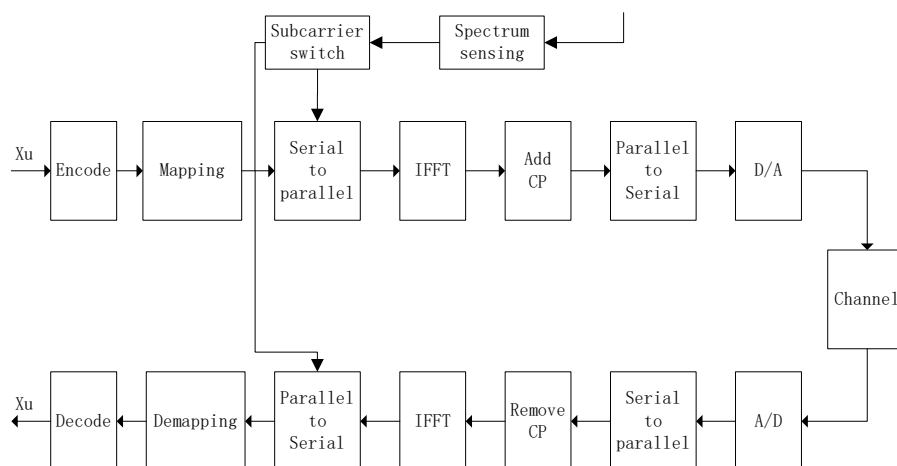


Fig 1. The System block diagram of NC-OFDM

As shown in Figure 1, NC-OFDM system allocates subcarriers by sensing external spectral information. The subcarriers that corresponding to primary users is set to 0, making them become unuseful subcarriers. The modulation data is allocated on the subcarriers that corresponding to cognitive users. Thus the transmitter of NC-OFDM system is formed. Assuming that the number of subcarriers for cognitive users in NC-OFDM system are N_u , and the total number of subcarriers are N , the baseband signal after IFFT(inverse fast Fourier transform) is[6]:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N} \tag{1}$$

where $1/\sqrt{N}$ represents power normalization factor, and $0 \leq n \leq N-1$; X_k denotes the modulation signals allocated to the subcarrier k . When k is primary subcarrier, $X_k = 0$.

The PAPR of NC-OFDM signal is defined as formula (2). That is the ratio of the peak to average power of the signal. After serial to parallel, the signals are grouped, each group multiplied by different phase factors, and the lowest PAPR is chosen as the transmission signal. In the simulation of this paper, we choose the phase factor as $[\pi/4, \pi/2, 3\pi/4, \pi]$.

$$PAPR(dB) = \frac{P_{peak}}{P_{average}} = 10 \log_{10} \frac{\max\{|x(n)|^2\}}{E\{|x(n)|^2\}} \tag{2}$$

We usually use CCDF(complementary cumulative distribution function)[8]to statistic the PAPR of NC-OFDM system. Where CCDF can be defined as:

$$P(PAPR > \lambda) = 1 - (1 - e^{-\lambda})^{\alpha N} \tag{3}$$

It is proved in article [9] that peak points can be captured enough when the sampling factor $J = 4$, and the PAPR obtained is very close to its theoretical value. At this time, we usually take $\alpha = 2.8$. In this paper, according to the suggestion of literature [8] that α is recommended as 2.8.

3. PAPR Suppression Algorithms

In the NC-OFDM system, after the signal is subjected to the IFFT transformation, when the phase of the signal in the time domain is the same or similar, the amplitude of the signal during serial-to-parallel conversion will form a superposition.

3.1 PTS Algorithm

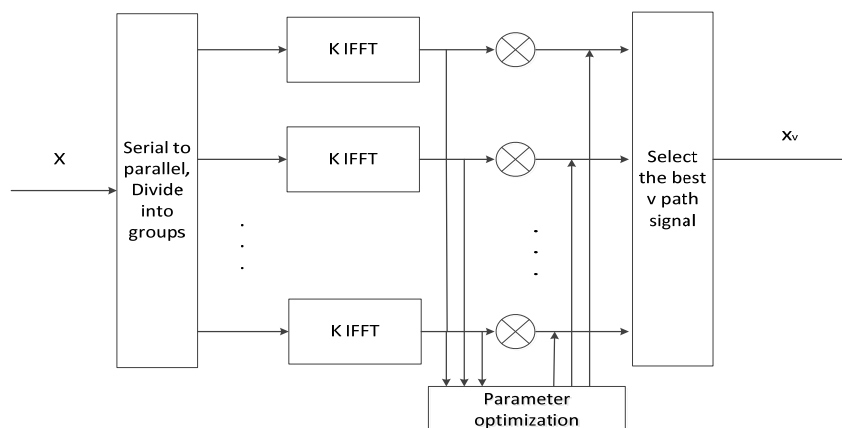


Fig 2. PTS-NC-OFDM Model

The idea of PTS algorithm is to group data and reduce PAPR by optimizing phase factor [7]. Figure 2 depicts the basic block diagram of the PTS algorithm to reduce the PAPR of the NC-OFDM signal. Define the input data vector as $X = [X_0, X_1, \dots, X_{N-1}]$. After the serial-to-parallel transformation, X is divided into V groups by different segmentation methods, which are respectively represented by $\{X_v, v=1, 2, \dots, V\}$. Usually the segmentation method includes three methods of segmentation: random, adjacent and interweave. V groups can be expressed as:

$$X' = \sum_{v=1}^V b_v X_v \quad (4)$$

Which $b_v = \exp(j\varphi_v)$, $\varphi_v \in [0, 2\pi)$ is the weighting coefficient. Then X' conducts IFFT transform, and we can get:

$$x' = IFFT(X') = IFFT\left(\sum_{v=1}^V b_v X_v\right) = \sum_{v=1}^V b_v \cdot x_v \quad (5)$$

By adjusting the weighting coefficient $b_v = \exp(j\varphi_v)$, $\varphi_v \in [0, 2\pi)$ properly, we can get the best PAPR. The optimal weighting coefficient should be satisfied as follow:

$$\{b_1, b_2, \dots, b_v\} = \arg \min_{\{b_1, b_2, \dots, b_v\}} \left(\max_{1 \leq n \leq N-1} \left| \sum_{v=1}^V b_v \cdot x_v \right|^2 \right) \quad (6)$$

In the formula (6), $\arg \min(\cdot)$ represents the conditions that the minimum value is satisfied. The best coefficient is obtained through $V-1$ times IFFT operations, and the lowest PAPR signal transmission is selected. b_v is an arbitrary value from $\{b_1, b_2, \dots, b_v\}$. Take W discrete values from this set to calculate. For the PTS method of subsequence of group V , the value of $\{b_1, b_2, \dots, b_v\}$ has W^{V-1} possible results.

3.2 Clipping Algorithm

The clipping algorithm can be seen as the process of multiplying the NC-OFDM signal by the rectangular window in the time domain. When the amplitude of the NC-OFDM signal is less than A_{\max} , the rectangular window function takes a value of 1. When the amplitude of the NC-OFDM signal is greater than A_{\max} , the original time domain amplitude value of the signal is retained. As shown in Equation 7.

$$x_{clip} = \begin{cases} -A_{\max}, & x < -A_{\max} \\ x, & -A_{\max} \leq x \leq A_{\max} \\ A_{\max}, & x > A_{\max} \end{cases} \quad (7)$$

Although the clipping algorithm can effectively reduce the PAPR of the system, it will inevitably bring corresponding problems to the NC-OFDM system after the system performs nonlinear correction. Firstly, the nonlinear distortion of the NC-OFDM signal will bring a higher Out-of-band radiated power; Secondly, the amplitude of the NC-OFDM signal is distorted, which changes the original amplitude of the signal, causing the system to generate serious in-band noise and out-of-band interference, resulting in the error rate of the receiving end of the system.

3.3 PCF Algorithm

Combining the PTS algorithm and clipping algorithm, this paper proposes a PCF algorithm to reduce the PAPR of the system. The basic process is as follows:

Divide input data block X into groups V that do not overlap each other, which $X = \sum_v X_v$.

Multiply the phase rotation factor $\{b_v = \exp(j\phi_v), v=1,2,\dots,V\}$ with V sub-blocks data and generate V alternate signals.

sub-block data superimposed: $Y = \sum_{v=1}^V b_v X_v$.

IFFT conversion to Y : $y = IFFT(Y) = \sum_{v=1}^V b_v IFFT(X_v)$.

Select the optimal phase rotation factor: $\{b_1, b_2, \dots, b_v\} = \arg \min_{\{b_1, b_2, \dots, b_v\}} (\max_{1 \leq n \leq N-1} |\sum_{v=1}^v b_v \cdot x_v|^2)$.

Set the limit threshold T_h for limiting processing. $\hat{x}_k = \begin{cases} \exp(j\phi(x_k))T_h, & x'_k > T_h \\ x'_k, & x'_k < T_h \end{cases}$

Filtering signal x'_k .

The improved algorithm schematic is shown in Figure 3.

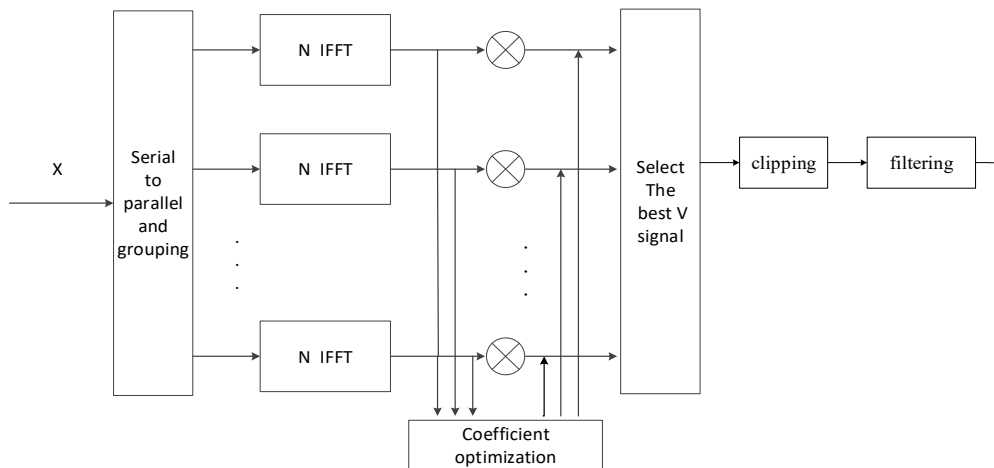


Fig 3. Principle of the PCF algorithm

4. Simulations

In order to analyze the influencing factors of PAPR in NC-OFDM system, different modulation modes are simulated. When the simulation parameters are taken as $N = 512$, $N_u = 16$ 10000 Monte Carlo simulations are performed using BPSK, QPSK and 16QAM modulation respectively. The simulation results are shown in the figure 4 is shown.

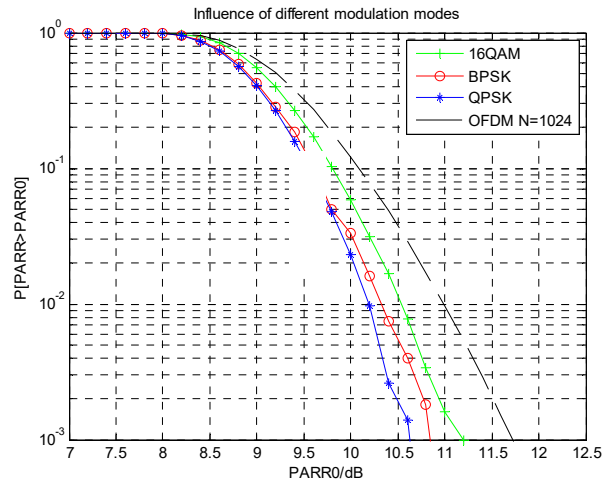


Fig 4. Different modulation mode PAPR characteristic curve

Since BPSK and QPSK belong to constant envelope modulation, and 16QAM belongs to non-constant envelope modulation, its own non-constant amplitude leads to an increased probability of a larger value of PAPR. In the two modulation modes of BPSK and QPSK, since the number of phases in the QPSK constellation is larger than BPSK, the probability of accumulating the amplitude of the time domain signal under QPSK modulation is smaller than BPSK. As can be seen from Figure 4, the probability statistics of PAPR appear from low to high in order of QPSK, BPSK and 16QAM. Subsequent simulation experiments in this paper use QPSK modulation.

The specific parameters are set as: the total number of subcarriers is $N = 512$, the number of effective subcarriers $N_u = 128$, QPSK modulation mode are used, phase rotation factor $b_v = \{1, -1\}$, number of packets $V = 4$, and clipping threshold $T_h = 0.06$. The simulation results are shown in Figures 6 and 7.

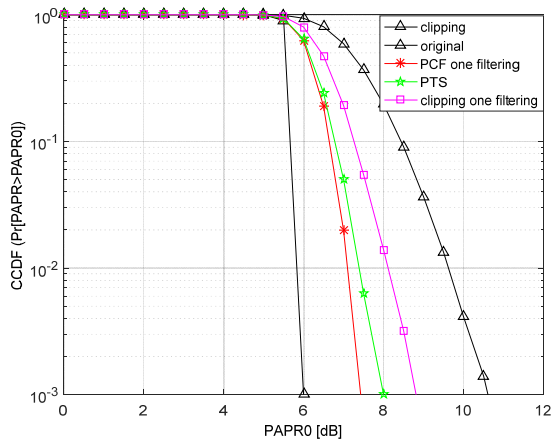


Fig 5. PCF algorithm performance

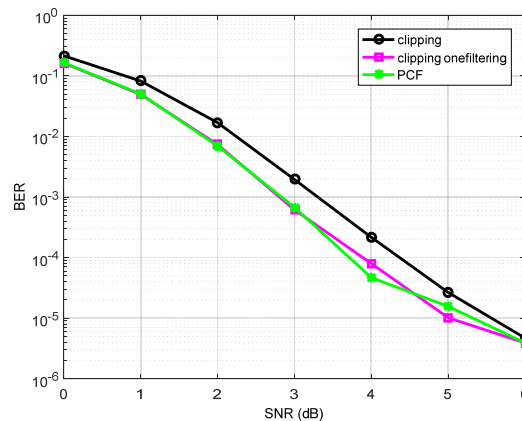


Fig 6. PCF algorithm bit error rate

It can be seen from Fig 5 and Fig 6 that the PCF algorithm can reduce the PAPR of 0.7 dB below the probability of 10^{-3} compared with the PTS algorithm; compared with the first-order clipping filtering algorithm, at the probability of 10^{-3} , it can reduce the PAPR by 1.5 dB. Although there is no limiting effect in PAPR suppression performance, the PCF algorithm can reduce the bit error rate from 2×10^{-3} to 6×10^{-4} when the signal-to-noise ratio is 3dB, and the error of the first-order limiting filter algorithm. At the same time, the code rate is almost the same.

5. Summary

In this paper, the system model of NC-OFDM system is constructed firstly. Then, the simulation results of different modulation methods are verified. For the probability of high PAPR appearing in QPSK modulation mode is the lowest. QPSK is selected as the constellation mapping method. The proposed PCF algorithm can effectively combine the advantages of the PTS algorithm and the clipping algorithm. Under the premise of ensuring the bit error rate, the PAPR can be effectively reduced by about 0.7 dB compared with the PTS algorithm.

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