Improving the PAPR of OFDM Systems by Using the CES-PTS with Iterative Flipping Algorithm

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Abstract— The orthogonal frequency division multiplexing (OFDM) signal has high peak to average power ratio (PAPR) which reducing the efficiency of high power amplifier at the transmission end. This paper proposes a new method to improve the PAPR of OFDM systems by combining the constellation extension scheme (CES), partial transmit sequence (PTS) and iterative flipping algorithm. The simulation results show that the proposed method has better PAPR efficiency and can improve the decreasing of data rate caused by PTS.

Keywords— OFDM, PAPR, PTS, CES, iterative flipping algorithm.

1. INTRODUCTION

Reducing peak to average power ratio (PAPR) is a hot study subject of multi-carriers technology. At present, many ways of upgrading PAPR have been published; including the block codes [1-3], partial transmit sequence (PTS) [4-6], selective mapping (SLM) [7-9], tone reservation (TR) [10-16] and constellation extension scheme (CES) [17-18], etc. Using the block codes is a method of inputting data to make encoding process, making it to enable the PAPR that generates the code words can be maintained within a defined domain and able to correct errors. Multiple signal representation (MSR) is used to map the data inputted into multiple signal candidates, pick up the signal with minimum PAPR to be the transmitted signal, used to improve the high PAPR that might happen in signal transmission. Both the PTS and SLM belong to the MSR technology. PTS makes multi-sub-block-dividing on the block signals inputted, in which the block-dividing should satisfy two conditions: the sum of all sub-blocks is the block data originally inputted; and no intersection occurs among the sub-blocks. PTS is to multiply a phase factor on each sub-block after being converted to multi-time-domain signal, which can change the phase change of time- domain signals; and finally makes a linear combination on these time-domain signals with phase-change. PTS is the picked minimum PAPR signal, in the prospective of lowering the possibility of making PAPR during signal-transmission. SLM is to multiply diverse phase-change combination on the inputted frequency-domain data, used to generate multiple signal candidates, pick up a signal under transmission that has the minimum PAPR. Tone reservation is the method of dividing the subcarriers into two parts, one is used to transmit data inputted, and the other one is used to produce the peak constellation signal instead of data transmission. Tone reservation combines the aforesaid two parts of signal to generate multiple signal candidates, pick up the signal with minimum PAPR to be the transmitted signal. The constellation extension scheme (CES) adjusts the inputted data into multiple constellation points that form multiple signal candidates, then, pick up the signal with minimum PAPR to transmit signal.

This paper mainly focuses on the method recommended by reference [19], use it to make PAPR upgrading task; meanwhile, it applies the iterative flipping algorithm to maintain the feature of low algorithm. The simulation result indicates that the recommended method is better than the one introduced in reference [19] in improving PAPR; moreover, it maintains the advantages of low algorithm and CES-PTS that won't reduce the data-transmission flow rate.

2. OFDM SYSTEM and PAPR

Fig. 1 shows the transmission and receiving ends of OFDM technology. The main theorem of OFDM technology is to divide a serial and high speed transmitted data string into sub data strings under low speed transmission; assembled from the orthogonal and independent subcarriers and sent out. In brief, for an OFDM signal $S_X(t)$, with N subcarriers, it can be mathematically expressed in below:

$$S_X(t) = \sum_{k=1}^{N} X_k e^{j2\pi f_k t}, \quad 0 \le \mathrm{t} \le \mathrm{T}$$

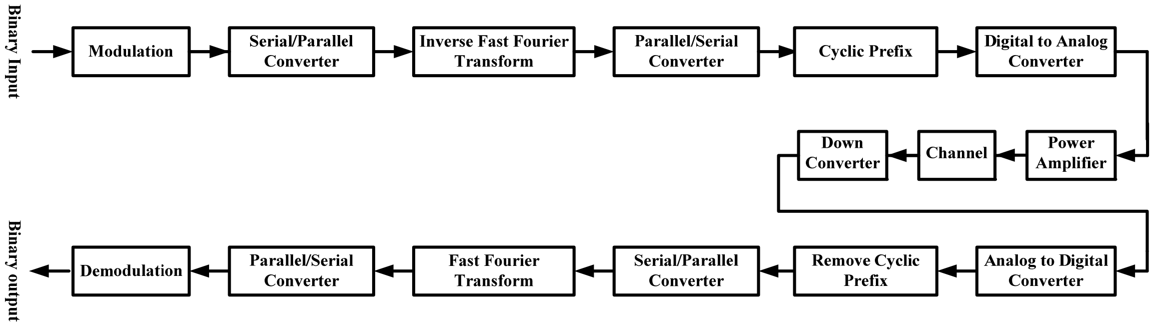

Fig. 1 Block diagram of traditional OFDM system

where

$$X = (X_1, X_2, \cdots, X_N)$$

is a complex number variable signal, X_k is the variable message of *k*th subcarrier. On the other hand, the signal's instantaneous envelope power $P_X(t)$ can be expressed by

$$P_X(t) = |S_X(t)|^2$$

The peak-to-average power ratio (PAPR) of signal $S_X(t)$ can be defined as:

$$PAPR(S_X(t)) = \frac{\max\limits_{0 \le t \le T} P(t)}{P_{av}}$$

where P_{av} is the average power of $S_X(t)$. In normal, in order to approach the PAPR of consecutive-time signal $S_X(t)$, OFDM signals can be obtained by sampling over *LN* points

$$S_x\left(\frac{iT}{LN}\right), 0 \le i \le LN-1,$$

That means, obtain these samples through sending

$$\{X_0, X_1, \cdots, X_{N-1}\}$$

and point *(L-1) N* to point *LN* over inverse fast Fourier transformation. In this paper, we apply *L*=4 to make numerical simulation; this value is sufficient to approach the PAPR of consecutive time signal.

In addition, the complementary cumulative distribution function (CCDF) of PAPR is always used to calculate the performance of lowered PAPR; its definition can be expressed as: after setting a referenced datum $PAPR_0$ of PAPR, the CCDF of PAPR means the possibility of PAPR larger than $PAPR_0$ in signal transmission; expressed in the formula below:

$$\mathrm{CCDF(PAPR)} = \Pr(\mathrm{PAPR} > \mathrm{PAPR}_0)$$

3. CONSTELLATION EXTENSION SCHEME

The CES is to extend the modulated constellation point to multiple points; these extended points have input-data identical to the original constellation point. Fig 2 shows the 16-QAM CES of modulated constellation diagram by using gray code digits, in which Fig (a) is the original 16-QAM constellation diagram, Fig (b) is the CES under 16-QAM modulation. The example of using 16-QAM CES to modulate the OFDM is interpreted in below. First, divide the 16 constellation points shown in Fig (a) to two groups, as shown in Fig (b); they are:

- The constellation points group excludes the extended constellation points: {[0,0,0,0], [0,0,0,1], [0,0,1,0], [0,0,1,1]}
- The constellation points group includes the extended constellation points: {[0,1,0,0], [0,1,0,1], [0,1,1,0], [0,1,1,1], [1,0,0,0], [1,0,0,1], [1,0,1,0], [1,0,1,1], [1,1,0,0], [1,1,0,1], [1,1,1,0], [1,1,1,1]}

Next, perform 16-QAM modulation on the inputted data if the inputted digital data belongs to the group that contains extended constellation points, the inputted data will be able to generate two types of constellation points as the options of signal candidates; on the other hand, if the inputted digital data belongs to the group that doesn't contain extended constellation points, the inputted data is merely converted to the mapped original constellation point. For example, if data-inputted is:

[0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0]

Since [0, 0, 0, 0] belongs to the group that doesn't contain extended constellation point, whereas [0, 1, 0, 0] belong to the group that contains extended constellation point, therefore,

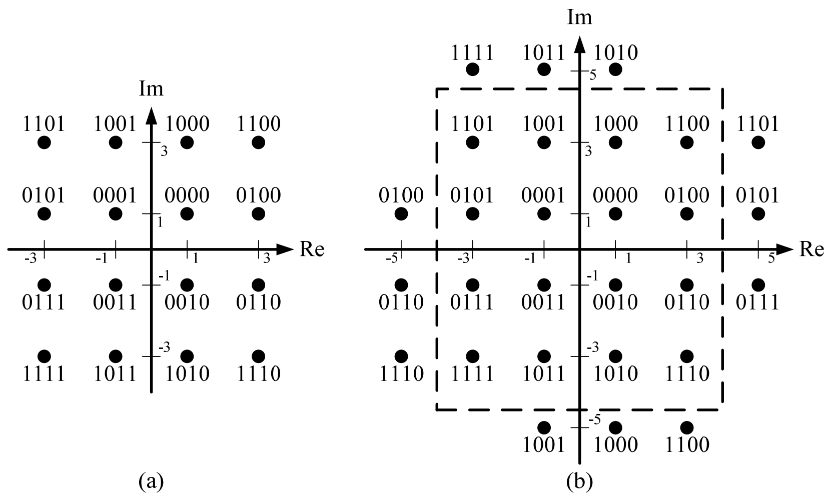

Fig. 2 (a) 16-QAM signal constellation; (b) 16-QAM extension signal constellation

after 16-QAM CES, it can generate 4 types of modulated symbols combination:

1. [1+i, 3+i, 1+i, 3+i];
2. [1+i, 3+i, 1+i,-5+i];
3. [1+i, -5+i, 1+i, 3+i];
4. [1+i, -5+i, 1+i, -5+i];

Send these 4 types of modulated symbols combination into the inverse discrete Fourier transformation, to form the signal candidates; the OFDM signal under transmission is the one having minimum PAPR.

Although the frequency band reservation and frequency band injection process won't destroy the original data under transmission, yet, to achieve better PAPR improvement, both processes need massive algorithm amount to find out the signal with the best PAPR for signal transmission. Therefore, in this study, we try to combine the concepts of both frequency band reservation and frequency band injection, cooperated with the second priority of search mechanism to rise up a upgraded frequency band reservation technology with low complexity, analyze its PAPR performance on single-carrier frequency division multiple access and orthogonal frequency division multiple access conditions.

4. UPGRADED CES [19]

The upgraded constellation extension scheme (also called the CES-PTS) firstly divides the non-extended mapping symbols into the same sub-block, then, follows whether or not the mapping is the same extended symbols to step-by-step divide the sub-blocks; in which the dividing method is in a random way, and the receiving end can undo the original input data over the modulation method; therefore, CES-PTS process needs not apply identical random dividing mechanism for each of the data inputted. Overall speaking, CES-PTS process differs from the PTS process that undoes the data inputted, it also needs not to send extra message to the receiver; therefore, CES-PTS process can elevate the overall data transmission flow rate effectively.

For example, assume data inputted is {[0, 0, 1, 0], [0, 0, 1, 1], [1, 1, 1, 1], [1, 1, 1, 1]}, in which the mapped content of {0010, 0011} are non-extended symbols, whereas the mapped content of {1111, 1100} are extended symbols; after CES judgment and handling, it can get 4 different modulating results listed in below:

1. {1-i, -1-i, -3-3i, -3-3i}
2. {1-i, -1-i, -3-3i, -3+5i}
3. {1-i, -1-i, -3+5i, -3-3i}
4. {1-i, -1-i, -3+5i, -3+5i}

Next, according to the symbol content, divide them into 3 sub-blocks, contents and phase factors of them are shown in below:

$$X_1 = [1-i, \quad -1-i, \quad 0, \quad 0],\ b_1 = 1$$

$$X_2 = [0, \quad 0, \quad 1, \quad 0],\ b_2 = -3-3i \text{ or } -3+5i$$

$$X_3 = [0, \quad 0, \quad 0, \quad 1],\ b_3 = -3-3i \text{ or } -3+5i$$

For the phase factor, it selects the extended and non-extended symbols in the specific sub-block, explained in below:

Since the PTS technology needs to satisfy

$$\sum_{i=1}^{M} X_i = X \text{ and } X_i \cap X_j = \phi, i \neq j$$

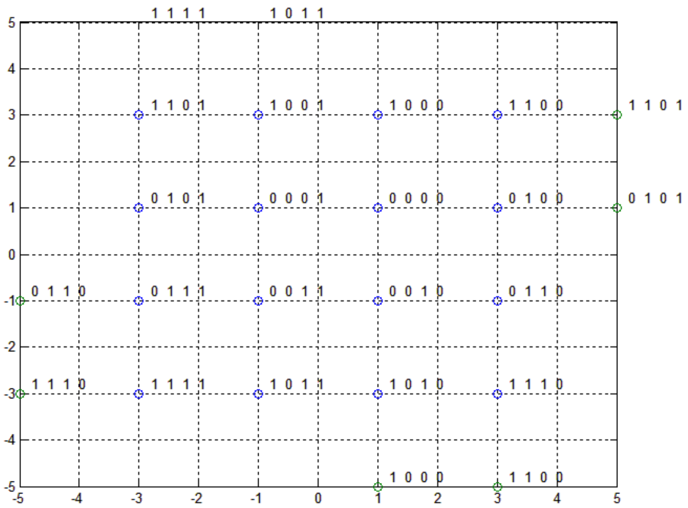

Fig 3. The extended constellation diagram of 8-point CES-PTS

The signal transmission can be expressed mathematically as

$$S_b(t) = \sum_{i=1}^{M} b_i S_{X_i}(t);$$

according to the sample above, we can get when $b_2 = -3-3i$ and $b_3 = -3-3i$, it becomes the original signal-transmission pattern, the respective PAPR efficiency of dividing method will be same to CES, reduce the 4 IFFT runs to 3 runs. If CES-PTS applies the same extending symbols to divide the same sub-block, we can further reduce the use of IFFT operator. For example, if data transmitted is

{[0, 0, 1, 0], [0, 0, 1, 1], [1, 1, 1, 1], [1, 1, 1, 1]}

the respective sub-block contents and phase factors are:

$$X_1 = [1-i \quad -1-i \quad 0 \quad 0], b_1 = 1$$

$X_2 = [0 \quad 0 \quad 1 \quad 1], b_2 = -3-3i$ 或 -3+5i

Thus, CES-PTS process can deduct the 4 IFFT runs of CES process to 2 IFFT runs, the corresponded PAPR performance still have permissible efficiency.

5. RECOMMENDED METHOD

This paper bases on the CES-PTS [19] structure; use the iterative flipping algorithm to upgrade the PAPR performance of OFDM system. For example, if data-inputted is [0, 0, 0, 0,0, 0, 0, 0, 1, 0, 0, 0, 1, 1, 0, 0], follow the mapping method and sub-block dividing shown in Fig 9(b) and Fig 6 (a), we can get **C**= [1+i,1+i, 0, 0, 0] and **D**= [0, 0, 1+i3, 3+i3]. If following the iterative flipping algorithm to generate signal candidates, it can use CES-PTS to deduct 4 signal candidates generated to 3; the procedure is illustrated in below:

1. After modulation, input [1+i, 1+i, 1+i3, 3+i3], calculate its PAPR, take the PAPR as the PAPR_1;
2. Calculate the PAPR of data [1+i, 1+i, 1-i5, 3+i3] inputted, take the PAPR as the PAPR_2; if $\mathrm{PAPR}_2 < \mathrm{PAPR}_1$, change input-data to [1+i, 1+i, 1-i5, 3+i3]; otherwise, keep the input-data unchanged.
3. If input-data changes to [1+i, 1+i, 1-i5, 3+i3], calculate the PAPR of input-data [1+i, 1+i, 1-i5, 3-i5], take the PAPR as the PAPR_3; if $\mathrm{PAPR}_3 < \mathrm{PAPR}_2$, change input-data to [1+i, 1+i, 1-i5, 3-i5]; otherwise, keep the input-data unchanged.
4. Repeat the above steps until all D elements are calculated and compared to their PAPR values.

In this paper, we use 10,000 16-QAM-modulated OFDM signals generated randomly to make simulation; the amounts of subcarriers are 32 and 128 respectively. The CES-PTS applies the extended constellation diagram of 8-point CES-PTS shown in Fig 3to make modulation. Fig 4 and Fig 5 display the cases of 32-subcarrier and 128-subcarrier in respective, both figures are the CCDF curve of PAPR of 16-QAM-modulated OFDM system. In Fig 4, under the condition of 10^{-3} possibility, the PAPR efficiency acquired from the recommended method is higher than the one made in reference [19]; while comparing the simulation result shown in Fig 5, we can see that when increasing the subcarrier amount, the recommended method will elevate the efficiency-improving effort.

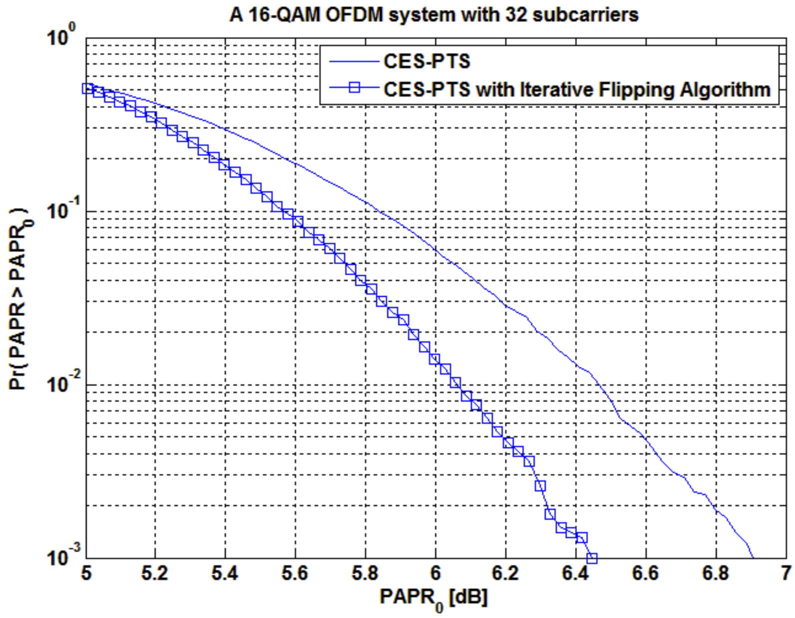

Fig 4. Comparison of PAPR made between the recommended method and the method made from reference [19]

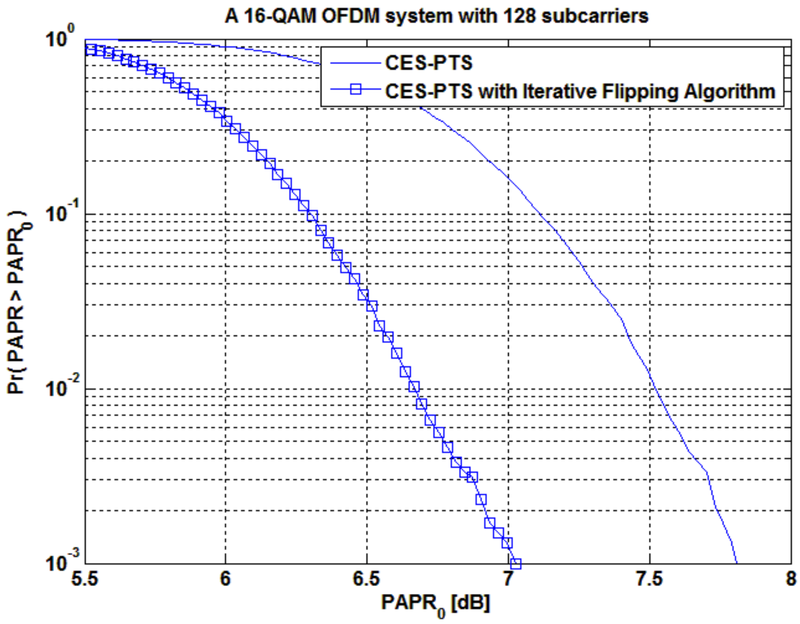

Fig 5. Comparison of PAPR made between the recommended method and the method made from reference [19]

6. CONCLUSION

In this study paper we mainly improve the PAPR of OFDM system by combining both the iterative flipping algorithm and CES-PTS. The recommended method bases on the CES-PTS structure, undo the data transmitted by means of the demodulation technology; the transmission end needs not to transmit extra signal to the receiving end. In addition, the recommended method also can significantly simplify the complexity of massive runs on CES-PTS operation over the use of iterative flipping algorithm in generating signal candidates.

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