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Abstract	OFDM system has an disadvantage in the sense of PAPR problem for the transmitter. In this contribution, we propose the new PAPR reduction scheme, Tone Reservation method, and show the performance results.
Purpose	To propose a new PAPR Reduction scheme suitable for 802.16d/e.
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Patent Policy and Procedures	

Tone Reservation method for PAPR Reduction scheme

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Introduction

In this paper, we consider the reduction of the potential large peak-to-average power ratio (PAPR) of an orthogonal frequency division multiplexing (OFDM) signal in communication systems. The multi-carrier signal can support high-rate data transmission in wireless channel environments. Meanwhile, a large number of subchannels in a multi-carrier signal cause the large PAPR that requires the wide range linearity of the amplifier.

Recently, several PAPR reduction schemes are researched. Among these PAPR reduction schemes, especially, SeLective Mapping (SLM) method and Tone Reservation (TR) method are very efficient because they are very simple and have good performances. The performance of these schemes is as follows:

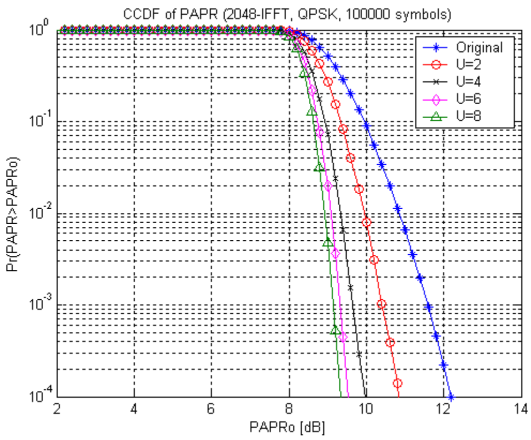

Fig 1. Performance of SLM Scheme

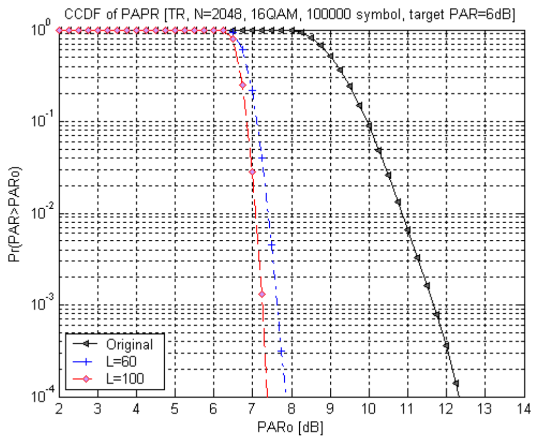

Fig 2. Performance of TR method

Considering the comparison of these schemes, SLM has the following disadvantages:

1) Require the side information
   - In SLM scheme, it requires the transmission of the side information to indicate the used masking pattern. Hence, we should consider the reliability of this side information, which requires the high signalling overhead.
2) Complexity issue
   - Moreover, SLM scheme needs multiple IFFT operation.
3) Additional Receiver Operation is needed
   - In SLM scheme, detection of the making pattern is needed for recovery of data stream from the received signal i.e., masked data stream.

In the view of the above points, TR method has the following advantage:

1) No need for side information
2) Less complex
   - Just one time IFFT operation is needed. But multiple iteration operations are needed after IFFT operation.
3) No special receiver operation is needed
   TR method does not need any side information and any receiver operation.

In this point of view, TR method is considered better than SLM in terms of the application and performance. Therefore, we propose the TR method for PAPR reduction scheme in this paper for incorporation into 802.16 Physical Layer aspects. In the next section, more detail level of TR operation will be described.

Proposed Scheme

In this proposed scheme, some OFDM subcarriers are reserved. These reserved subcarriers don't carry any data information, are only used for reducing PAPR. This method is called *Tone Reservation*.

This method restricts the data vector X, and the peak reduction vector C to lie in disjoint frequency subspaces, i.e., $X_k = 0$, $k \in \{i_1, \cdots, i_L\}$ and $C_k = 0$, $k \notin \{i_1, \cdots, i_L\}$. This formulation is distortionless and leads to very simple decoding of the data subsymbols that are extracted from the received sequence by choosing the set of values $k \notin \{i_1, \cdots, i_L\}$ at the receiver FFT output. Moreover, it allows simple optimization techniques for the computation of the peak reduction vector c. The L nonzero values in C will be called *peak reduction tones*.

Let us assume that the L tones $\{i_1, \cdots, i_L\}$ have been fixed at the beginning of the transmission and that they won't be change until the transmission is over or some new information about the channel is fed back to the transmitter.

Calling $\hat{C}$ the nonzero values of C, i.e. $\hat{C} = \left[C_{i_1} \cdots C_{i_L}\right]^T$, and $\hat{Q} = \left[q_{i_1} | \cdots | q_{i_L}\right]$ the submatrix of Q constructed by choosing its columns $\{i_1, \cdots, i_L\}$, then $c = QC = \hat{Q}\hat{C}$. To minimize the PAPR of $x + c$ we must compute the vector c^* that minimizes the maximum peak value, i.e.:

$$\min_{c} \left\| x + c \right\|_{\infty} = \min_{\hat{C}} \left\| x + \hat{Q}\hat{C} \right\|_{\infty}$$

The gradient algorithm is one of the good solution to compute c^* with low complexity. The basic idea of the gradient algorithm is come from clipping. Clipping the peak tone to the target clipping level can be interpreted as subtracting impulse function from the peak tone in time domain. Impulse function is time shifted to the peak tone location, and scaled so that the power of the peak tone should be reduced to the desired target clipping level. But this operation affect the whole value of OFDM symbol in frequency domain, i.e., not only C but also X is changed. So another impulse-like function is designed, which only has the value in the tone locations $\{i_1, \cdots, i_L\}$. Let $\mathbf{P}_k = 1$, $k \in \{i_1, \cdots, i_L\}$ and $\mathbf{P}_k = 0$, $k \notin \{i_1, \cdots, i_L\}$ and let IFFT output of $\mathbf{P}$ be $\mathbf{p}$, $\mathbf{p} = [p_0 p_1 \cdots p_{N-1}]$. $\mathbf{p}$ is the IFFT output of the vector whose value is 1 at the tone locations $\{i_1, \cdots, i_L\}$, and 0 elsewhere. $\mathbf{p}$ is called *peak reduction kernel* and is only a function of the tone locations $\{i_1, \cdots, i_L\}$. Therefore, one needs to calculate the kernel $\mathbf{p}$ at the beginning of the transmission. $\mathbf{p}$ has its peak at the location p_0 but $\mathbf{p}$ also has the leakage at the location $p_1 \cdots p_{N-1}$. As the number of the reserved tone L become larger, peak at the location p_0 is getting larger and the leakage at the location $p_1 \cdots p_{N-1}$ getting smaller, so the performance is getting better. But redundancy is increasing and the throughput is decreasing.

The gradient algorithm is an iterative clipping algorithm using peak reduction kernel. When $\mathbf{p}$ is circular shifted, scaled, and phase rotated in time domain, the values of $\mathbf{P}$ in the tone locations $\{i_1, \cdots, i_L\}$ are changed but the other tones remained unchanged. So data vector X isn't affected by iterative clipping operations. The optimization is done on the time domain code c. So only one IFFT operation is needed and the complexity is very low. The gradient algorithm can be expressed as following formula:

$$c^{(k+1)} = c^{(k)} - \alpha_k \mathbf{p}[((n-n_k))_N]$$

$$n_k = Arg \max_n \left| x_n + c_n{}^{(k)} \right|$$

where α_k is a scale and phase rotation factor depending on the maximum peak found at iteration k. The notation $\mathbf{p}[((n-n_k))_N]$ means that the kernel has been circularly shifted in time by a value of n_k.

This kernel has its maximum in the time domain at $n = 0$ and its aim is to decrease the high peak found at n_k, without increasing the other values of the OFDM symbol at $n \neq n_k$ too much. So the selection of the tone location $\{i_1, \cdots, i_L\}$ is critical point of the PAPR reduction performance. A pertinent choice for $\mathbf{p}$ and therefore for the reserved tones is obtained by minimizing its secondary peak.

Figure 3 shows the structure of the OFDM system transmitter using proposed scheme. L tones are reserved for PAPR reduction and $N-L$ tones are assigned for data information. All tones are allocated according to predetermined tone locations $\{i_1, \cdots, i_L\}$. Then IFFT is executed and the gradient algorithm is operated.

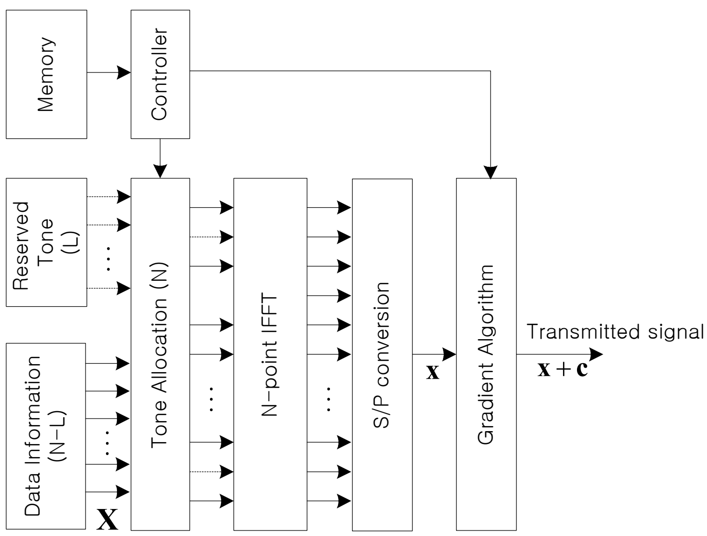

Figure 3. Structure of OFDM transmitter using Tone Reservation scheme.

Figure 4 shows the detail procedure of the gradient algorithm. When new IFFT output x entered, the peak position and value of x are detected. Then peak reduction kernel is circular shifted to the peak position, and scaled and phase rotated. The resulting kernel is subtracted from x and then PAPR is calculated. If the number of iteration reaches predetermined maximum iteration number, control escapes the process and resulting signal is transmitted. If not, clipping operation is executed iteratively.

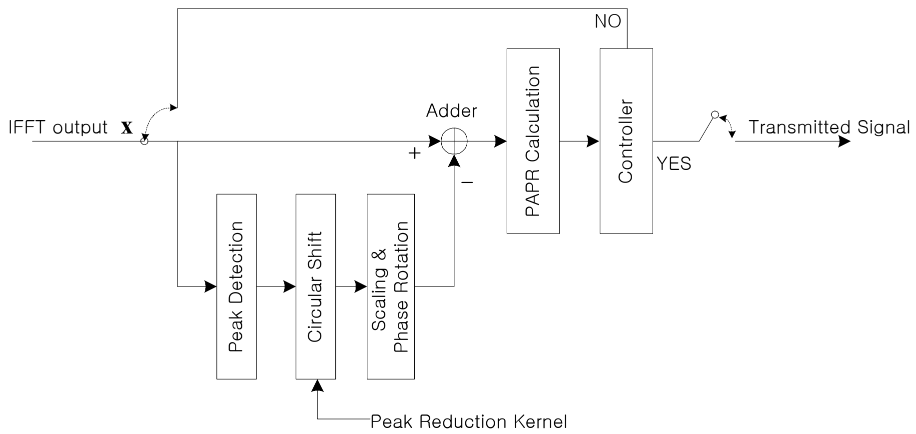

Figure 4. Procedure of Gradient Algorithm.

Performance Analysis

To justify the performance of the TR method, we have done some computer simulations taking into account the following simulation conditions/parameters.

- Simulation parameter set 1
  - 2048-IFFT : 700,000 symbols
  - Modulation : QPSK
  - The number of the reserved tone: L=30, 60
  - Gradient Algorithm : 30 iteration
  - Target PAPR : 6.5 dB

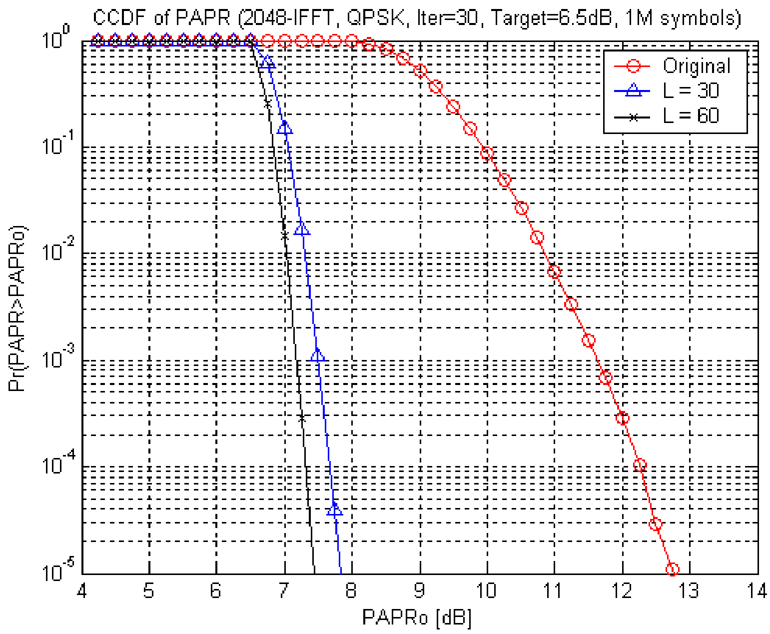

Figure 5. The performance of TR method with QPSK modulation

- Simulation parameter set 2
  - 2048-IFFT : 700,000 symbols
  - Modulation : 16QAM
  - The number of the reserved tone : L=30, 60
  - Gradient Algorithm : 30 iteration
  - Random Set Optimization : 1,000,000 random sets
  - Target PAPR : 6.5 dB

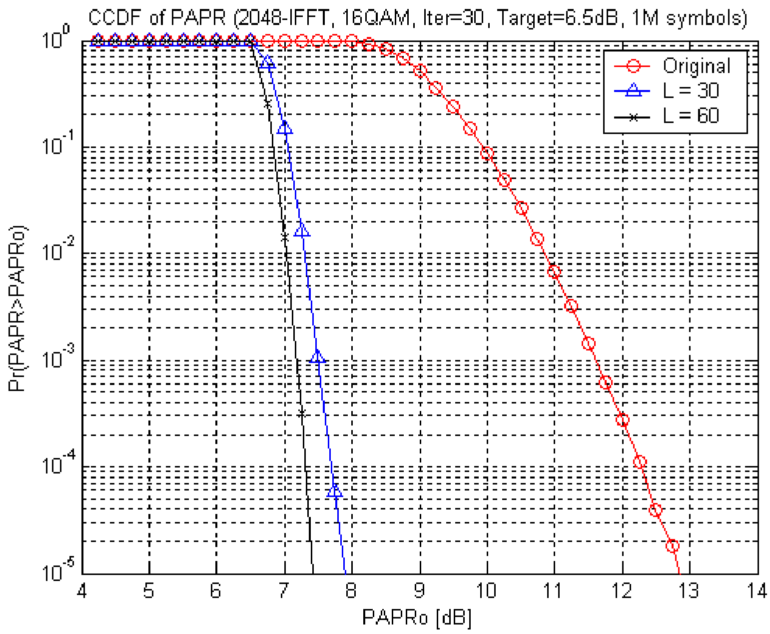

Figure 6. The performance of TR method with QPSK modulation

As can be seen in Figure 5 and 6, TR offers remarkable PAPR reduction when reserving reasonable amount of sub-carriers (approximately 1.5%). The amount of reserved tones corresponds to total throughput loss in the sense that the reserved tones don't contain "actual" information data. But this gives us the enhancement of PAPR. Fig 5 is the performance of TR method in QPSK modulation case and Fig 6 in 16-QAM modulation case. As we can see in Fig 5, we have about 4.5dB gain at the probability 1.0e-3, when compare with the original case that we didn't use any PAPR reduction scheme. Similarly, in 16-QAM modulation case, we also have about 4.5dB gain.

Conclusion

Taking into account the importance of subscriber station power consumption, we'd like to propose incorporation of PAPR reduction method in 802.16 Physical Layer. Of some PAPR reduction schemes, we propose the Tone Reservation (TR) as one of promising techniques in terms of performance and complexity.

Actually, the other PAPR reduction scheme needs the signaling overhead. For example, SLM and PTS need some side information to indicate the used pattern and this also corresponds to total throughput loss. In this point of view, the other PAPR reduction scheme has a similar case with TR method.

As we showed in "performance" section, TR has a good performance. Moreover, TR method doesn't need any operation in receiver side.

Therefore, we suggest that the group consider further extensive evaluation of TR for the enhancement of 802.16 systems.