PAPR Reduction with a Recoverable Peak Cancellation Technique for OFDM

Lei Wang*, Dongweon Yoon*, Sang Kyu Park* ***Regular Members***

ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is one of the most promising techniques for 4th generation communication systems. One of the main disadvantages of OFDM is the Peak to Average Power Ratio (PAPR). In this paper, a recoverable peak cancellation (RPC) technique that recovers the cancelled part for the peak-cancelled OFDM signal is introduced. Using the RPC technique, the bit error rate (BER) performance can be greatly improved and the efficiency of the PAPR reduction is nearly that of the clipping method, at a cost of slightly reducing the transmission data rate.

Key Words : Peak Cancellation, Clipping, M-sequence, OFDM

Ⅰ. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a special case of multicarrier transmission because a high-rate data stream is transmitted over a number of lower-rate subcarriers (SCs). OFDM causes a serious Peak to Average Power Ratio (PAPR) problem. The simplest and most effective methods to reduce PAPR might include clipping and filtering[1],[2]. However, the original signal suffers from clipping noise that significantly reduces the bit error rate (BER) of the received signals. The peak cancellation technique given in [3] reduces the peak power of an OFDM signal by subtracting the reference signals from the OFDM signal. However, a reference signal that has the same bandwidth as the OFDM signal will induce subtracting values throughout the OFDM signal, including regions with high points, which leads to poor BER performance. The extent of the poor performance is worse than that of the clipping method. In this paper, a new peak cancellation technique is introduced, which uses a set of reference signals in both the transmitter and the receiver to eliminate the high points (samples that have larger amplitudes than the maximum permissible amplitude) and recover the original signal. This technique requires a short transmission of the side information to the receiver. It is shown that the reconstruction of the signals according to this side information is simple to implement and improves error performance.

Ⅱ. Background

An OFDM symbol can be expressed as the sum of many independent symbols modulated onto sub-channels of equal bandwidth. The periodic OFDM signal in discrete time is given as

$$s(n) = x_n + y_n = \sum_{k=1}^{N} (a_k + jb_k) e^{j2\pi f_k n \frac{T}{N}} \qquad (1)$$

where n is the sample number of the OFDM signal, N is the number of subcarriers, $a_k + jb_k$ denotes an input data symbol for a QPSK modulated OFDM signal, $a_k,\ b_k \in [-1,1]$, T is the period of the signal, and $f_k = k/T$. The PAPR of the OFDM symbol is defined as the ratio of the peak power and the average power,

* 한양대학교 전자통신컴퓨터공학부(skpark@hanyang.ac.kr),
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$$PAPR = \frac{\max\{|s(n)|^2\}}{E\{|s(n)|^2\}}, n \in [1, N] \quad (2)$$

where $E\{.\}$ denotes the statistical expectation. Because of the serious PAPR problem for the OFDM system with a large number of subcarriers, the PAPR becomes one of the main disadvantages of an OFDM system.

Ⅲ. Recoverable Peak Cancellation Method

In order to reduce the PAPR, an OFDM system model is proposed with a new peak cancellation technique, which is called the Recoverable Peak Cancellation method (RPC). RPC is implemented symbol-by-symbol for an OFDM signal. The transmitter and receiver of the proposed system model are shown in Fig. 1 and Fig. 2.In the transmitter, the amplitude of the output samples of the OFDM symbol is detected and the high points, which have amplitudes that are higher than the maximum permissible amplitudes, are selected. The high points are initially organized according to the quadrants shown in Fig. 3. Then their positions are coded and transmitted as side information. Reference signals are generated, according to the quadrant and the position information. The reference signals have the same amplitudes and 4 different phases. For example, as shown in Fig. 4, the reference signals have $\frac{\pi}{4}$ phase shift from X axis, and the phase difference between the adjacent reference signals is $\frac{\pi}{2}$. The amplitude of the reference signals is given by

$$ref(n) = \begin{cases} B, & r_n \geq l \\ 0, & r_n \leq l \end{cases} \quad (3)$$

where B is the amplitude of the reference signal, the value of B will be discussed later in this paper, $r_n = |s(n)| = \sqrt{x(n)^2 + y(n)^2}$ and l is the maximum permissible amplitude for an output signal. In the proposed technique, peak cancellation is used at only the high points. The reference signals are subtracted from the high points, which are in the same quadrant as the reference signals.

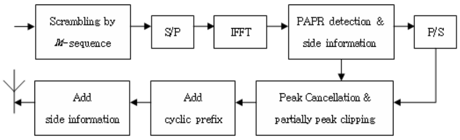

Fig. 1. Transmitter of the proposed OFDM system

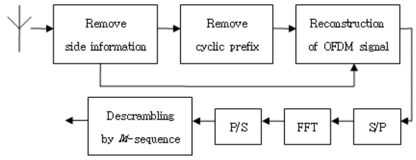

Fig. 2. Receiver of the proposed OFDM system

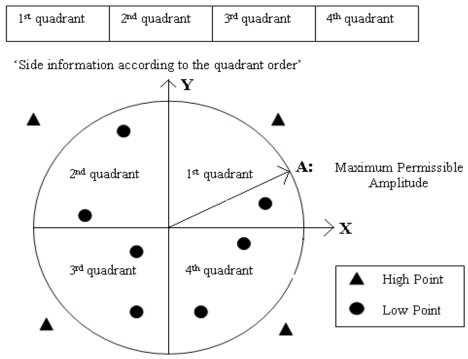

Fig. 3. Distribution of samples according to the quadrants

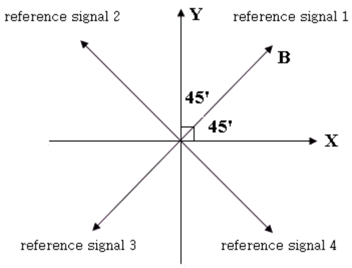

Fig. 4. Reference signals for each quadrant

In the receiver, the peak-canceled parts of the OFDM signal are recovered by an inverse process. Because the high points in the side information are organized by quadrant, the phases of the reference signals can easily be found. After decoding the received side information, the receiver can find the positions of the high points and regenerate the reference signals according to the phase and position information. Then the reference signals are added to the received signal. Because of this addition, peak cancellation is a nonlinear operation and the peak-canceled signal has serious out-of-band power radiation. Therefore, filtering is necessary in analogue OFDM signal processing, in order to avoid frequency interference. It is well known from [1] that if clipping is performed on the signals at the Nyquist sampling rate, all of the distortion noise falls in the band of the OFDM signal. Similarly, when peak cancellation is performed on the signals at the Nyquist sampling rate, there is no out-of-band radiation in the digital OFDM signal processing.

Ⅳ. Practical Implementation

In order to improve the BER performance, effectively reduce the PAPR, and reduce the influence on the transmission data rate, an OFDM system is proposed, which combines the RPC method and several simple techniques that do not greatly increase the system complexity.

4.1 M-Sequence Masking Scheme

The value B should be chosen carefully because if B is too large, at the positions where the amplitude of the high points is very close to the maximum permissible amplitude, subtraction may induce new high points in the antipodal direction. To solve this problem, input data sequences are first scrambled by a pseudo random sequence which is generated by an *M*-sequence and has the same bits number of one OFDM symbol. For example, the data sequence of 512 bits for one OFDM symbol is exclusive-or with a pseudo random sequence, in which one zero was affixed to a 511-bit *M*-sequence generated from a 9-degree polynomial generator. Pre-scrambling can moderately reduce the PAPR [4], therefore keeping the PAPR of each OFDM symbol within a suitable range. In the proposed OFDM system, only one *M*-sequence is used to pre-scramble the data sequence, the *M*-sequence is known in both the transmitter and the receiver.

4.2 Partial Peak Cancellation and Partial Clipping

The RPC technique reduces the amplitude of the high points in each OFDM symbol by the same value, which excessively reduces those high points that are slightly larger than the maximum permissible amplitude. Moreover, when the majority of the signal is above a specific limit, the PAPR of the OFDM signal after peak cancellation will remain at a high level. Computer simulations demonstrate that error is mainly caused by high points that have amplitudes near the peak amplitude of the OFDM symbol. Therefore, only recovering the high points that are near the peak amplitude can improve the error performance. In practical implementation, peak clipping and peak cancellation are used together, and a cancellation threshold is set for the RPC method. After performing the RPC method, the high points that are smaller than the cancellation threshold and larger than the maximum permissible amplitude are clipped. The clipped high points are not recovered at the receiver. Therefore, the reference signal becomes

$$ref(n)=\begin{cases} B, & r_n \geq \rho+l \\ 0, & r_n \leq \rho+l \end{cases} \tag{4}$$

where $\rho=w(\max|s(n)-l|)$ and $0<w<1$. The number of high points that are peak canceled can be reduced by choosing a smaller value of w. The maximum permissible amplitude is l and the cancellation threshold is $\rho+l$. In the following, γ is used to denote $\rho+l$, then the output signal after the RPC and clipping is

$$\widetilde{r_n} \equiv \begin{cases} r_n - B, & r_n > \gamma \\ A, & A \leq r_n \leq \gamma \\ r_n, & r_n < A \end{cases} \tag{5}$$

In Fig. 5, a part of peak-canceled OFDM signal is illustrated.

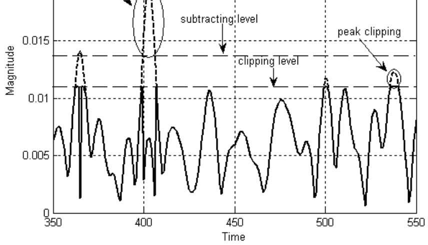

Fig. 5. A part of peak-canceled OFDM signal

4.3 Side Information

The side information is transmitted without OFDM modulation. Sending longer side information costs more energy and decreases the transmission data rate. The side information length was evaluated for the non-oversampled QPSK OFDM symbol with 256 subcarriers. Through the computer simulation, we observed the number of high points larger than a given γ with different values of ν and showed the result in Table I. For example, when $w=0.4$, we observed the number of high points over $\gamma_{0.4}$ is around 6. If 8 bits are used to represent one of the 256 samples, the total number of bits used to denote the peak-canceled high points is approximately 48 bits. If the side information is modulated at the same modulation level and the same bit rate as the OFDM symbol, the side information length is ~9.4% of the OFDM symbol length. In order to further decrease the side information length, high level modulation techniques could be used. For example, 16-QAM modulation can compress the side information length to approximately ~4.7% of the OFDM symbol length.

The performance of the proposed system was examined by using a computer simulation. In the simulation, the number of the subcarriers was *N* = 256, and the modulation technique was QPSK for the OFDM symbol. The data sequence was initially exclusive-or with a pseudo random sequence, which had a length of 256in which one zero was affixed to a 511-bit *M*-sequence generated from a 9-degree polynomial generator. The reference signals had the same amplitude and 4 different phases. The amplitude was set equal to the difference between the maximum permissible amplitude and the peak amplitude for each OFDM symbol. The modulation techniques for the side information were QPSK and 16-QAM, respectively, and the side information signal had the same power as the peak-canceled OFDM signal. Initially, the performance of the proposed OFDM system was compared with the clipping OFDM system. The value of w was set to 0.3 and the clipping ratio (CR) to 1.2 and 1.6. CR is the ratio of the maximum permissible amplitude and rms power of the OFDM signal. Fig. 6 shows the BER performance of the cancelled part-reconstructed OFDM signal and the peak-clipped OFDM signal. The BER is plotted against the standard E_b/N_0, where E_b includes the transmitted power and a portion of the energy required to send the side information. As E_b/N_0 increases, the RPC technique with QPSK side information provides improvement in the BER performance. The BER performance obtained by using the RPC technique with 16-QAM side information gradually improves for larger E_b/N_0. Fig. 7 compares the cumulative density function of the PAPR for a peak-canceled signal and the

Table 1. Number of High Points

ν	0.2	0.4	0.6	0.8
Number of High Points	~11.2	~6.2	~3.4	~1.8

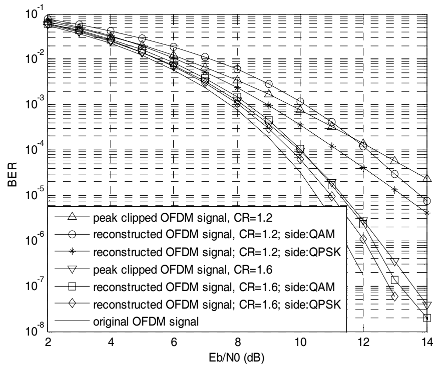

Fig. 6. BER performance of peak reconstructed OFDM signal and peak-clipped OFDM signal

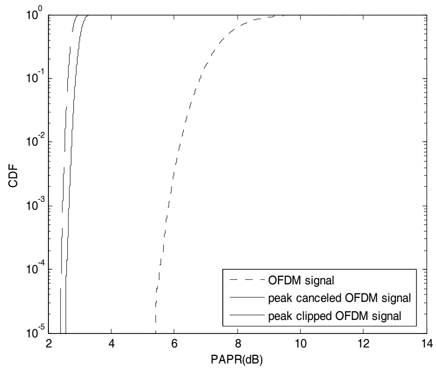

Fig. 7. PAPR distribution for the OFDM signal, peak-canceled OFDM signal, and peak-clipped OFDM signal

peak-clipped signal. It was found that the PAPR reduction ability of the RPC method is very close to that of the clipping method.

V. Conclusions

In this paper, a recoverable peak cancellation technique is presented, which gives a stronger PAPR reduction ability and an acceptable BER performance. Combined with an *M*-sequence and partial clipping, this technique can be easily implemented in the conventional OFDM system and can effectively be used to reduce PAPR. The disadvantage of this technique is the transmission of the side information. With transmission of longer side information, the system transmission data rate is decreased to some extent.

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왕 뢰 (Lei Wang) 정회원

2001년 7월 중국 대련이공대학교 전자통신공학과 공학사

2003년 9월 영국 뉴캐슬대학교 전자전기컴퓨터공학과 공학석사

2004년 8월~현재 한양대학교 전자통신컴퓨터공학과 박사과정

<관심분야> 디지털 통신, OFDM 시스템

윤 동 원 (Dongweon Yoon) 정회원

1989년 2월 한양대학교 전자통신공학과 공학사

1992년 2월 한양대학교 전자통신공학과 공학석사

1995년 8월 한양대학교 전자통신공학과 공학박사

1995년 3월~1997년 8월 동서대학교 정보통신공학과 조교수

1997년 9월~2004년 2월 대전대학교 정보통신공학과 부교수

2004년 3월~현재 한양대학교 전자통신컴퓨터공학부 교수

<관심분야> 디지털 통신, 무선통신

박 상 규 (Sang Kyu Park) 정회원

1974년 2월 서울대학교 전기공학과 공학사

1980년 5월 듀크대학교 전기공학과 공학석사

1987년 5월 미시건대학교 전기공학과 공학박사

1987년 3월~현재 한양대학교 전자통신컴퓨터공학부 교수

<관심분야> 디지털 통신, 확산대역통신, MIMO, OFDM 시스템