Peak-to-Average Power Ratio Reduction Method for OFDM Signal by Permutation of Subcarriers

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ABSTRACT

Many PAPR reduction methods for OFDM time domain signal have been proposed up to today, all of which can be classified into two kinds of methods as the distortion and distortion-less methods. The most of distortion-less methods show better PAPR performance without degradation of BER performance. However the distortion-less methods are usually required to control the transmission data information so as to minimize the PAPR performance at the transmitter. From this fact, the distortion-less methods are required to inform the controlled information as the side information to the receiver for the correct demodulation of data information. The side information is usually informed to the receiver with the higher signal quality by using the separate channel or the embedded in the data information which would lead the degradation of transmission efficiency and the increase of hardware complexity of transmitter and receiver.

This paper proposes a novel distortion-less PAPR reduction method which employs the permutation of subcarriers in the frequency domain. The feature of proposed method is to achieve the better PAPR performance with a very few embedded side information for the correct demodulation of data information at the receiver. This paper presents various computer simulation results to verify the effectiveness of proposed method as comparing with the conventional OFDM method in the non-linear channel.

Keywords: PAPR, OFDM, Non-linear Channel

Manuscript received on July 1, 2014 ; revised on September 20, 2014.

Final manuscript received April 19, 2015.

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1. INTRODUCTION

The Orthogonal Frequency Division Multiplexing (OFDM) technique has been received a lot of attentions especially in the field of wireless communications because of its efficient usage of frequency bandwidth and robustness to the multi-path fading. From these advantages, the OFDM technique has already been adopted as the standard transmission techniques in the wireless LAN systems [1] and the terrestrial digital TV broadcasting systems [2]. The OFDM technique is also employed in the next generation mobile communications systems (LTE: Long Term Evolution) [3]. One of the limitations of using OFDM technique is the larger peak to average power ratio (PAPR) of its time domain signal [4-6]. The OFDM signal with larger PAPR would cause the severe degradation of bit error rate (BER) performance and undesirable frequency spectrum regrowth due to the occurrence of inter-modulation noise at the output of non-linear amplifier.

Many PAPR reduction methods have been proposed to overcome the above PAPR problem on the OFDM technique up to today. These techniques can be classified into two kinds of methods as the distortion [7-8] and distortion-less methods [9-15]. Although the distortion techniques including the clipping and filtering method can improve the PAPR performance relatively, it leads the degradation of BER performance and undesirable spectrum regrowth to the adjacent channel due to the clipping distortion. The distortion-less techniques including the multiple signal representation techniques such as the partial transmit sequence (PTS) [9-10], the selected mapping (SLM) [11-12] and Dummy Sequence Insertion (DSI) [13-14]. Although these techniques can achieve better PAPR performance without degradation of BER performance, the transmitter is required to inform the side information to the receiver for the correct demodulation of received signal. The side information is usually informed to the receiver with the higher signal quality by using the separate channel or the embedded in the data information which would lead the degradation of transmission efficiency and the increase of hardware complexity of transmitter and receiver.

To solve the above problem, the PAPR reduction method without requiring the side information was proposed for the WiMAX system based on the PTS method [15]. The phase optimization problem for the PTS method is solved by using the Sequential Quadratic Programming (SQP), Particle Swarm Optimization (PSO) and Least Squares Error (LSE) algorithms [15]. The proposed algorithms make use of the antenna beamforming weights and dedicated pilots at the WiMAX transmitter. Although the proposed method can achieve better PAPR performance without any degradation of signal quality and any side information, the dedicated pilots are required in each cluster which are used in the beamforming. From this fact, the proposed method in [15] is applicable only to the systems of using the dedicated pilots.

In this paper, we propose a novel distortion-less PAPR reduction method which employs the permutation of data subcarriers in the frequency domain and propose the efficient transmission method of side information which employs the embedded side information in the data information.The feature of proposed method is to achieve the better PAPR performance with a very few embedded side information which leads the improvement of transmission efficiency with a lower hardware complexity for the transmitter and receiver.

In the following of this paper, Section II presents the system model of OFDM method in the non-linear channel. Section III presents the proposed method with the permutation of subcarriers (PS). Section IV explains the detection method for embedded side information at the receiver side. V presents the various computer simulation results to verify the performance of proposed PS method, and Section VI concludes the paper.

2. SYSTEM MODEL

Figure 1 shows the OFDM system model to be used in the following evaluation. In the figure, X_n is the modulated signal at the $n-th$ sub-carrier in the frequency domain and x_k is the time domain signal at $k-th$ sample point, which is converted from the frequency domain data by using IFFT. The time domain sampled OFDM signal y_k after adding the guard interval (GI) at the start of every OFDM symbol to avoid the inert symbol interference (ISI) will be converted to the analogue signal by the digital-analogue converter (D/A) and then converted to the radio frequency (RF) by the frequency up-converter (U/C) as shown in Fig.1. The output signal of U/C is inputted to the non-linear amplifier and transmitted to the channel. The output signal of non-linear amplifier can be expressed by the following equation.

$$s(t) = F[|y(t)|]e^{j\{\arg[y(t)]+\Phi[|y(t)|]\}} \quad (1)$$

where, $y(t)$ and $s(t)$ are the input and output RF signal of non-linear amplifier, and $F[\,]$ and $\Phi[\,]$ represent the AM/AM and AM/PM conversion characteristics of non-linear amplifier. The non-linear amplifier assumed in this paper is the Solid State Power Amplifier (SSPA) of which AM/AM and AM/PM conversion characteristics are modeled by the following equations [16].

$$F[\rho] = \frac{\rho}{[1+(\rho/A)^{2r}]^{1/2r}} \quad (2)$$

$$\Phi[\rho] = \alpha_\phi \left(\frac{\rho}{A}\right)^4 \quad (3)$$

where, ρ is the amplitude of input signal, A is the saturated output level, r is the parameter to decide the non-linear level and α_ϕ is phase displacement. In the following evaluations, the values for these parameters are assumed by $A = 1$, $r = 2$ and $\alpha_\phi = 0.01$ of which these parameters can approximate the typical SSPA [16]. Fig.2 shows the input and output relationships of AM-AM and AM-PM conversion characteristics for SSPA when the parameters are given by the above values.

In the OFDM system, M frequency domain data symbols $\{X_n,\ n = 0 \text{ to } M-1\}$ which correspond to subcarriers, are modulated with a set of orthogonal frequency $\{f_n,\ n = 0 \text{ to } M-1\}$.

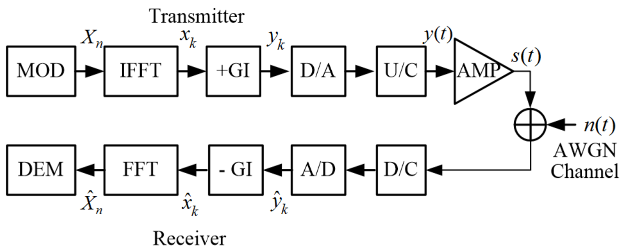


Fig.1: *OFDM system model.*

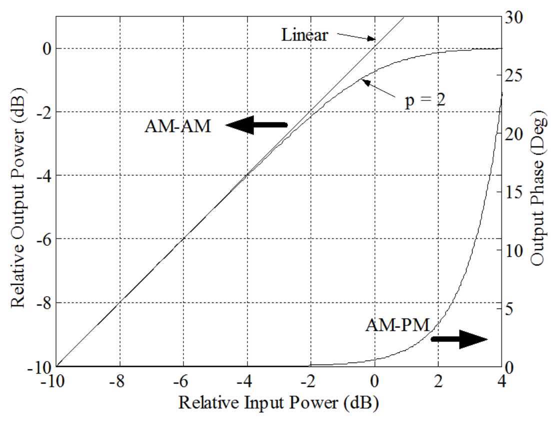


Fig.2: *AM/AM and AM/PM input-output relationships of SSPA.*

The frequency domain M subcarriers are chosen to be orthogonal, i.e. $f_n = n\Delta f$, where $\Delta f = 1/MT$ and T represents the OFDM data symbol period. The resulting baseband OFDM signal x_k can be expressed by the following equation.

$$x_k = \sum_{n=0}^{N-1} X_n \cdot e^{j\frac{2\pi nk}{N}} \quad k = 0 \ \ to \ \ N-1. \quad (4)$$

Where N is the number of IFFT points including $(N - M)$ zero padding added both ends of OFDM M subcarriers, which enables the usage of simple analogue filter to eliminate the alias occurring at the output of D/A converter. From (4), it can be seen that the OFDM time domain signal is generated by the summation of random data information in the frequency domain. From this fact, PAPR of OFDM time domain signal would be relatively larger as compared with the conventional single carrier modulation techniques. The PAPR of OFDM time domain signal is defined by the following equation [5].

$$\text{PAPR(dB)} = 10\log_{10}\frac{\max\limits_{0\le k\le N}|x_k|^2}{E\left[|x_k|^2\right]} \quad (5)$$

where $E[\ ]$ denotes the expected value. To evaluate the PAPR performance for OFDM signal from the statistical point of view, the Complementary Cumulative Distribution Function (CCDF) given in (6) is usually used to represent the probability of exceeding a given threshold PAPR_0.

$$\text{CCDF}(\text{PAPR}_0) = \Pr(\text{PAPR} > \text{PAPR}_0) \quad (6)$$

3. PROPOSAL OF PAPR REDUCTION METHOD WITH PERMUTATION OF SUBCARRIERS

Figure 3 shows the structure of frequency domain OFDM symbol for the proposed PS method. There are two types of permutation methods Type I and Type II as shown in Figs.3 (a) and (b), respectively. Type I is to perform the permutation of subcarriers process only for the first part of $M/2$ subcarriers, while Type II is to perform the permutation process both for the first and the last parts of $M/2$ subcarriers. Although the computational complexity for Type II is larger than Type I, the improvement of PAPR performance for the Type II is better than Type I. Because Type II has the larger number of permutation processes and has the potential capability to find the better PAPR performance than that for Type I. For simple explanation, we only give an example for Type I in the following. As for the Type II, the same procedures of Type I can be performed both for the first and last parts of $M/2$ subcarriers.

The proposed OFDM symbol in Type I consists of $(M-3)$ data subcarriers, two dummy subcarriers and one parity subcarrier which can be expressed by the following equation.

$$\begin{aligned} X \ = \ &[D_1, D_2, P, X_0, X_1, X_2, \cdots, X_{M/2-3}, X_{M/2-2}, \\ &\cdots, X_{M-4}] \end{aligned} \quad (7)$$

Where D is the dummy sub-carriers with power of 0 (Null subcarrier) and P is the parity check subcarrier with power of α of which power is taken as the same as the averaged power of data subcarriers. The dummy (null subcarriers) and parity subcarriers will be used for the detection of the first data subcarrier X_0 at the receiver for the correct demodulation of data information. After the insertion of zero padding to both ends of (7), the first part of $M/2$ subcarriers as shown in Fig.3 (a) are simply rotated circularly one by one so as to achieve the better PAPR performance. The number of permutation of subcarriers performed at the transmitter can be detected by using the dummy and parity check subcarriers at the receiver. When the number of permutation for the first part of $M/2$ subcarriers R is 5 as an example, the resultant ordering of subcarriers is given by the following equation.

$$\begin{aligned} X_{R=5} \ = \ &[X_2, X_3, \cdots, X_{M/2-4}, D_1, D_2, P, X_0, X_1, \\ &X_{M/2-3}, \cdots, X_{M-4}] \end{aligned} \quad (8)$$

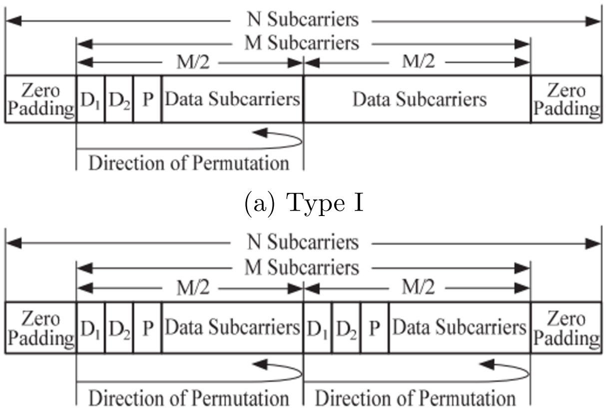
Figure 4 shows the example of proposed PS method when $R = 5$. In this example, the location of 1st subcarrier becomes the data subcarrier X_2 and the parity check subcarrier P becomes $(M/2 - R + 3) - th$ subcarrier in the OFDM symbol after the permutation of subcarriers by $R = 5$ times. In this case, the sign of parity check subcarrier P is set by the following equation in order to detect the number of permutation for the subcarriers with higher accuracy at the receiver.

$$P = (-1)^{(M/2-R+3)} \cdot \sqrt{\alpha} \quad (9)$$

The permutation of subcarriers for the first part of $M/2$ subcarriers is taken from 1 to $M/2$. In the proposed method, the best PAPR performance will be selected from among the permutation of subcarriers from 1 to $M/2$. Then the selected ordering of subcarriers with the best PAPR performance will be converted to the time domain signal by using IFFT. The time domain signal can be given by the following equation

$$\tilde{x}_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \tilde{X}_n \cdot e^{j\frac{2\pi kn}{N}} \quad (10)$$

where $\tilde{x}_n$ is the frequency domain signal after performing the permutation of subcarriers and $\tilde{x}_k$ is the time domain signal with lower PAPR performance. As for Type II, the above procedures are performed both part of $M/2$ subcarriers. Fig. 5 shows the structure of transmitter with the proposed PS method.



(a) Type I

(b) Type II

Fig.3: *Structure of OFDM system for proposed PS method.*

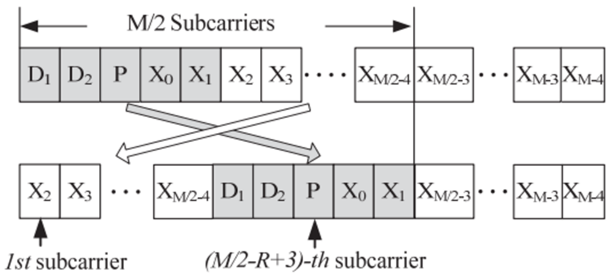


Fig.4: *Example of Permutation Sequence when R=5.*

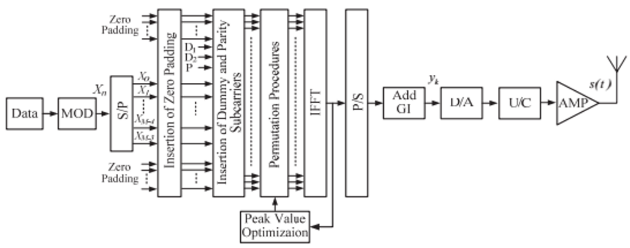


Fig.5: *Structure of transmitter for the proposed PS method with Type I.*

4. DETECTION METHOD FOR EMBEDDED SIDE INFORMATION

The first data subcarrier which is moved to the certain subcarrier number after the permutation of subcarriers performed at the transmitter is required to detect at the receiver for the correct demodulation of data information. The position of first data subcarrier can be detected by finding the position of dummy (null subcarriers) and check the sign of parity check sub-carriers.

Figure 6 show the detection algorithm for the permutation number selected at the transmitter. The proposed detection method is firstly to replace the consecutive two subcarriers to zero from the start of received OFDM signal in the frequency domain and calculate the power of received signal by using the following equation.

$$Power(\ell) = \sum_{n=0}^{M/2} \{R_n^{(\ell)} \cdot conj[R_n^{(\ell)}]\} \quad (11)$$

$$\ell = 0, 1, 2, \cdots, M/2 - 1$$

where $R_n^{(m)}$ is the received frequency domain signal at the $n-th$ subcarrier after replacing two subcarriers to zero at $\ell - th$ and $(\ell + 1) - th$ subcarriers and $conj[\ ]$ represents the complex conjugate. From (11), the maximum power could be obtained when ℓ is equal to the location of first dummy subcarriers. The detection performance can be improved further by checking the sign of parity check subcarrier P for the next subcarrier which is detected at the $\ell - th$ and $(\ell + 1) - th$ dummy subcarriers with having the maximum power given in (11). The sign of parity check subcarrier given by (9) can be used for assuring the detection of the first data subcarrier X_0. The detection performance can be improved by using both two dummy subcarriers and parity check subcarrier base on the procedures as show in Fig. 6.

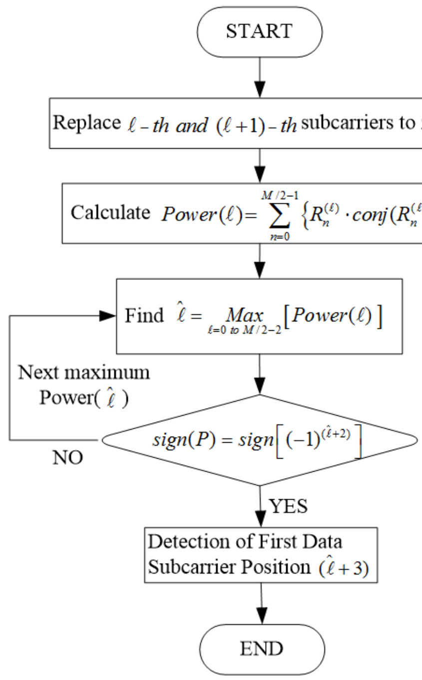


Fig.6: *Detection algorithm for permutation number.*

The proposed PS method enables the correct demodulation of data information by using only two dummy and one parity subcarriers, which can achieve better transmission efficiency and reduce the complexity of receiver as compared with the conventional method of using the side information which is informed to the receiver through the separate channel.

Figure 7 show the structure of proposed receiver of using the above detection algorithm for the embedded side information. By using the above method, the original data sequence can be recovered with higher accuracy and data information can be demodulated correctly. The feature of proposed method is to enable the detection for the number of permutation precisely by using very few embedded side information.

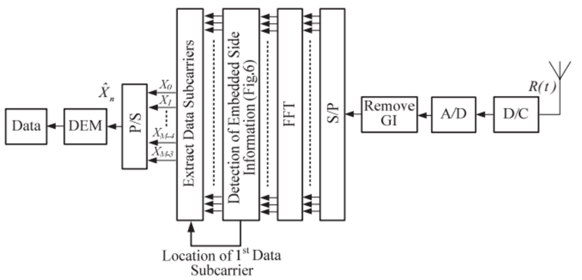


Fig. 7: *Structure of receiver for the proposed method.*

5. EVALUATION OF PROPOSED PS METHOD

This section presents the various computer simulation results to verify the performance of proposed method as comparing with the conventional OFDM by using the M-file script of Matlab program. Table 1 shows the list of simulation parameters. In the simulations, the number of FFT points $N = 256$ is taken by 4 times larger than the number of subcarriers $M = 64$ to evaluate the PAPR performance with higher accuracy.

Table 2 shows the transmission efficiency for the proposed PS method with Type I and Type II. From the table, it can be observed that the proposed method can achieve the higher transmission efficiency because the number of permutation selected at the transmitter can be detected by using only 2 dummy subcarriers and one parity check subcarriers for Type I and 4 dummy subcarriers and 2 parity check subcarriers for Type II, respectively.

As the purpose of easy understanding the effectiveness of proposed PS method, Figures 8 and 9 show the OFDM signals before and after the proposed PS method in the frequency and time domains, respectively. In the simulations, the modulation method is 16QAM and the number of data subcarriers (K), dummy subcarriers (D) and parity subcarrier (P) are taken by 61, 2 and 1 for the PS method with Type I. From Figure 8 which shows the OFDM signals in the frequency domain, it can be observed that the locations of two dummy subcarriers and one parity subcarriers at the 1st to 3rd subcarriers before the proposed PS method are moved to the locations of 18-th to 20-th subcarriers after the PS method in which the best PAPR performance is obtained when the number of permutations R is 15. The frequency domain signals before and after the PS method as shown in Figure 8 are converted to the time domain signals by IFFT which are shown in Figure 9. From Figure 9, it can be observed that the amplitude of time domain signal after proposed PS method is lower than that before the PS method. The PAPR performances before and after the proposed PS method are 7.0dB and 5.1dB, respectively. This means that the proposed PS method can achieve better PAPR performance by 1.9dB than the conventional OFDM.

Table 1: *Simulation parameters.*

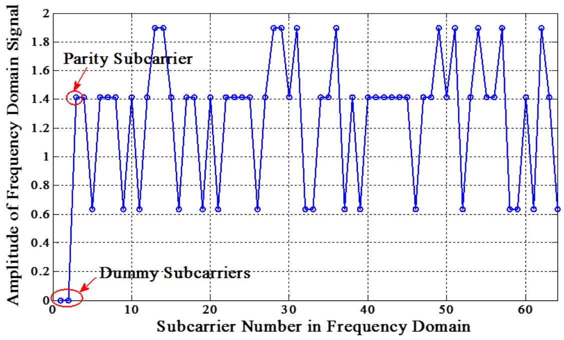
Modulation method	6QAM & 64QAM
Demodulation method	Coherent
OFDM bandwidth	5 MHz
Number of FFT points (N=Z+M)	256
Number of sub-carriers (M=D+P+K)	64
Number of dummy sub-carriers (D)	2
Number of parity sub-carriers (P)	1
Number of data sub-carriers (K)	61
Number of zero padding (Z)	192
Symbol duration	12.8 us
Guard interval	1.2 us
Model of non-linear amplifier	SSPA
Non-linear parameter of Eq. (2)	r=2
Channel model	AWGN

Table 2: *Transmission efficiency from proposed method.*

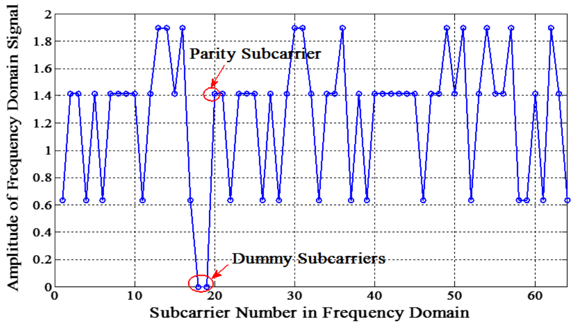
No. of sub-carriers	Transmission efficiency (%)	
	Type I	Type II
64	95.3% (61/64)	95.6% (58/64)
256	98.8% (253/256)	97.7% (250/256)
1024	99.7% (1021/1024)	99.4% (1018/1024)

Figure 10 shows the PAPR performances both for the conventional OFDM and proposed PS methods with Type I and Type II. In the figure, the PAPR performance is evaluated by using the Complementary Cumulative Distribution Function (CCDF). From the figure, it can be observed that the proposed PS method shows better PAPR performance than that for the conventional OFDM by 2.2dB for Type I and 3 dB for Type II at CCDF=10^{-1}, respectively. Here it should be noted that the degradation of BER performance of OFDM signal in the non-linear channel would be dominated by the PAPR performance at the CCDF higher than 10^{-1}. From these results, it can be expected that the proposed PS method could achieve the better BER performance than that for the conventional OFDM method in the non-linear channel.

Figures 11 (a) and (b) show the BER performances



(a) OFDM signal before PS method.



(b) OFDM signal after PS method.

Fig.8: *Comparison of OFDM frequency domain signals before and after the proposed PS Method.*

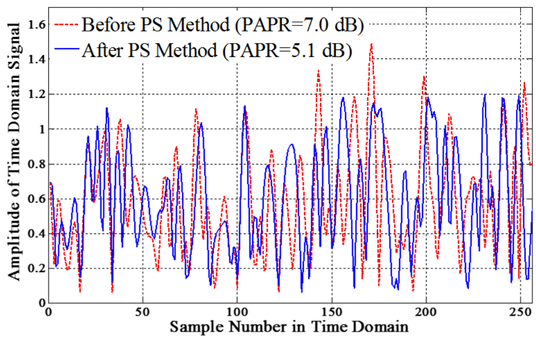


Fig.9: *Comparison of OFDM time domain signals before and after the proposed PS Method.*

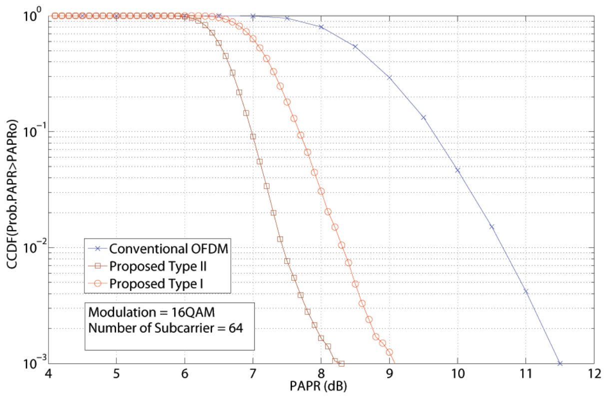
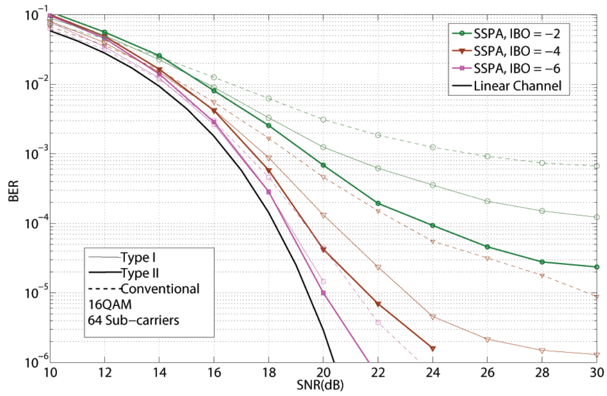
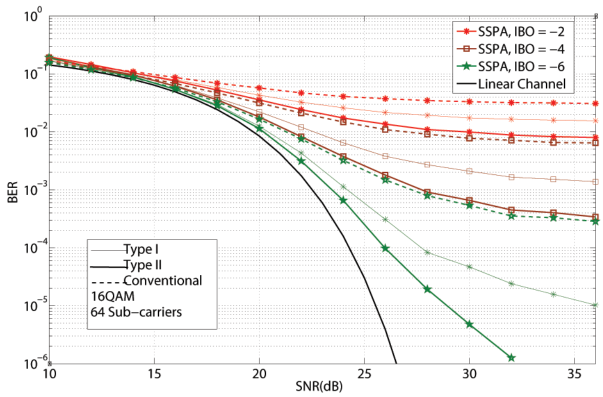


Fig.10: *PAPR performance of proposed method.*

in the non-linear channel when changing C/N for the conventional OFDM and the proposed PS method. The modulation method is 16QAM and 64QAM. In the simulation, the number of data subcarriers, dummy subcarriers and parity subcarrier are taken by 61, 2 and 1 for Type I and 58, 4 and 2 for Type II, respectively. The input back-off (IBO) of non-linear amplifier (SSPA) is taken by -2dB, -4dB and -6dB, respectively. From the figures, it can be observed that the proposed PS method with detection method for embedded side information can achieve much better BER performance than those for the conventional OFDM in the non-linear channel.



(a) 16 QAM



(b) 64 QAM

Fig.11: *BER performance of proposed method in the non-linear channel.*

6. CONCLUSIONS

This paper proposed the distortion-less PAPR reduction method which employs the permutation of data subcarriers in the frequency domain and also proposed the efficient transmission method of side information which employs the embedded side information in the data information. The features of proposed method are to enable the reduction of PAPR performance by rotating the subcarriers in the frequency domain and to enable the correct demodulation of received signal by using a very few embedded side information which enables the detection of rotation number precisely at the receiver. The proposed method can achieve the better PAPR performance and higher transmission efficiency with a lower hardware complexity for the transmitter and receiver. From the computer simulation results, this paper confirmed that the proposed permutation of subcarriers method can achieve the better PAPR performance and better BER performance in the non-linear channel with keeping the higher transmission efficiency as comparing with conventional OFDM systems.

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