

Proposal of New PAPR Reduction Method for OFDM Signal by Using Permutation Sequences

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Abstract—Many PAPR reduction techniques for OFDM signal have been proposed up to today, which can be classified into two major methods as the distortion and distortion-less methods. The most of distortion-less methods show better PAPR performance without degradation of BER performance. This paper proposes a novel distortion-less PAPR reduction method which employs the permutation sequence in the frequency domain with embedded side information. The feature of proposed method is to achieve the better PAPR performance with very few 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

I. 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 technique in the wireless LAN systems and the terrestrial digital TV broadcasting systems. The OFDM technique is also employed in the next generation of mobile communication system (LTE). One of the limitations of using OFDM technique is the larger peak to average power ratio (PAPR) of its time domain signal [1] [2]. The larger PAPR signal would cause the severe degradation of bit error rate (BER) performance due to the inter-modulation noise occurring in the non-linear amplifier.

Many PAPR reduction techniques have been proposed to overcome the PAPR problem up to today. These techniques can be categorized into two major methods as distortion and distortion-less methods. The distortion techniques include the clipping and filtering method [3][4]. Although this method can improve the PAPR performance relatively, it leads the degradation of BER performance and undesirable spectrum regrowth to the adjacent channel. The distortion-less techniques [5-11] include the coding, tone reservation (TR), tone injection (TI), active constellation extension (ACE), and multiple signal representation techniques such as partial transmit sequence (PTS) and selected mapping (SLM). These techniques can achieve better PAPR performance without degradation of BER performance. However these methods improve the PAPR performance at the cost of transmission efficiency, higher

computational complexity, larger memory size, and requirement of separate channel for informing the side information to the receiver. In this paper, we propose a novel distortion-less PAPR reduction method with permutation of data sequence in the frequency domain. The proposed method also employs a few dummy and parity subcarriers as the embedded side information in the data subcarriers which is used for the demodulation of data information at the receiver. The proposed method can achieve the better PAPR performance with higher transmission efficiency.

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 PS method. Section IV presents the various computer simulation results to verify the performance of proposed PS method, and Section V concludes the paper.

II. SYSTEM MODEL

Figure 1 shows the block diagram of OFDM system 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 guard interval (GI) to x_k 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 Φ 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 [12].

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

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

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 [12].

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

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

where N is the number of IFFT points including zero padding. The PAPR [4] of transmitted time domain OFDM signal is defined by,

$$\text{PAPR} = \frac{\max_{0 \leq k \leq N} |x_k|^2}{E[|x_k|^2]} \quad (5)$$

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 used to represent the probability of exceeding a given threshold PAPR_0 .

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

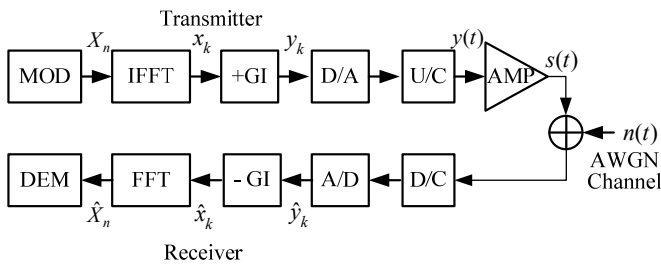


Fig. 1 OFDM system model.

III. PROPOSAL OF PS METHOD

Figure 2 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 the figure. Type I is to perform the permutation only for the first $M/2$ subcarriers, while Type II is to perform the permutation both for the first and the last part of $M/2$ subcarriers. Although the computation complexity for the Type II is larger than Type I, the improvement of PAPR performance for the Type II is better than Type I. For simple explanation, we only give an example explanation for type I in the following. The proposed OFDM symbol consists of $(M-3)$ data sub-carriers, two dummy sub-carriers and one parity sub-carrier which can be expressed by,

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

where D is dummy sub-carriers with power of 0 (Null subcarriers) and P is 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 location for the first data subcarrier X_0 at the receiver for the correct demodulation of data information. After the insertion of zero padding, two null sub-carriers and one parity sub-carrier, the new OFDM symbol can be generated by circularly rotation of subcarriers only for the first part of $M/2$ subcarriers so as to improve the PAPR performance as shown in Fig.2.

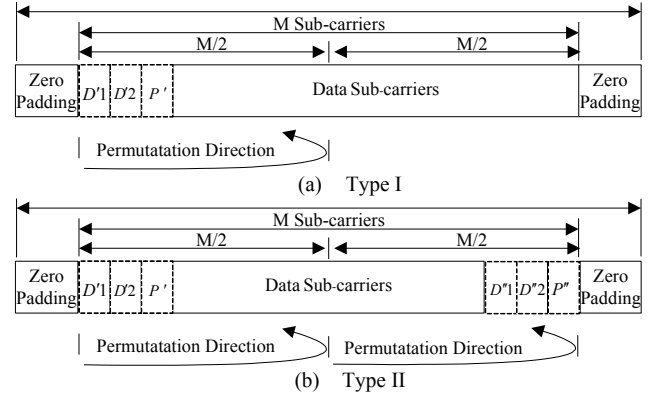


Fig.2 Structure of frequency domain OFDM symbol for proposed PS method.

In the proposed method, the first half of $M/2$ subcarriers are simply rotated in the frequency domain so as to achieve the better PAPR performance. The number of rotation of subcarriers performed at the transmitter can be detected by using the dummy and parity check subcarriers at the receiver. When the number of rotation for the first $M/2$ subcarriers is $L=6$ as an example, the resultant ordering of subcarriers is given by,

$$X_{R=6} = [X_2, X_3, \dots, X_{M/2-3}, D_1, D_2, P, X_0, X_1, X_{M/2-2}, \dots, X_{(M-4)}] \quad (8)$$

The example of proposed permutation sequence method for Type I is shown in Fig.3.

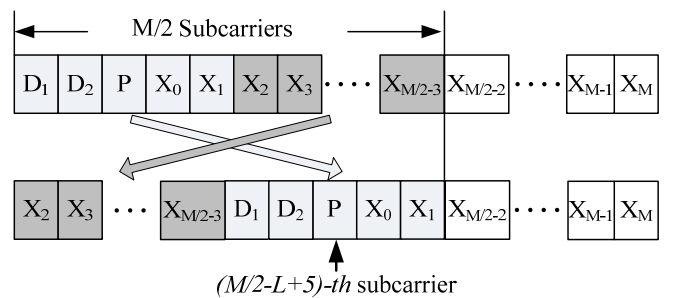


Fig.3 Example of Type I permutation sequence when $L=6$.

When $L=6$, the location of parity check subcarrier P becomes $(M/2-L+5)$ -th subcarrier in the OFDM symbol. In this case, the sign of parity check subcarrier P is set by the following equation in order to detect the number of rotation for the subcarriers with higher accuracy at the receiver.

$$P = (-1)^{(M/2-L+5)} \cdot \alpha \quad (9)$$

The permutation for the rotation of the first part of $M/2$ subcarriers is taken from 0 to $M/2$. In the proposed method, the best PAPR performance will be selected from among the

rotation of subcarriers from 0 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,

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

where $\tilde{X}_n$ is the frequency domain signal after performing the permutation of subcarriers rotation and $\tilde{x}_k$ is the time domain signal with low PAPR performance. As for the Type II, the time domain signal with lower PAPR performance can be achieved by using the same procedures as the Type I. Fig. 4 shows the structure of proposed transmitter.

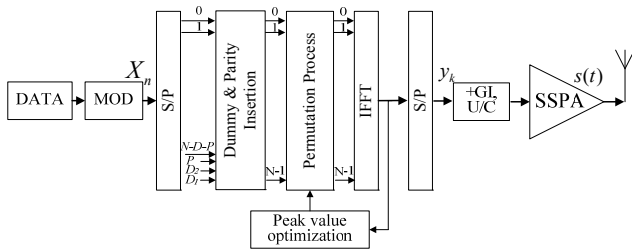


Fig.4 Structure of transmitter for the proposed method.

IV. DETECTION METHOD FOR EMBEDDED SIDE INFORMATION

The first data subcarrier which is moved to the certain subcarrier number after the permutation of subcarriers rotation 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.

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.

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

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

where $R_n^{(m)}$ is the received frequency domain signal at the n -th subcarrier after replacing two subcarriers to zero at ℓ -th and $(\ell+1)$ -th subcarriers and $conj$ indicates 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 by checking the sign of the parity check subcarrier P for the next subcarrier of the detected ℓ -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 assure the detection of the first data subcarrier X_0 . The detection performance can be improved by using two dummy subcarriers and parity check subcarrier. Figs. 5 and 6 show the detection algorithm for permutation number and the structure of proposed receiver.

By using the above method, the original data sequence can be recovered and the data information can be demodulated correctly. The feature of proposed method is to detect the permutation number precisely by using very few embedded side information.

V. 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. 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.

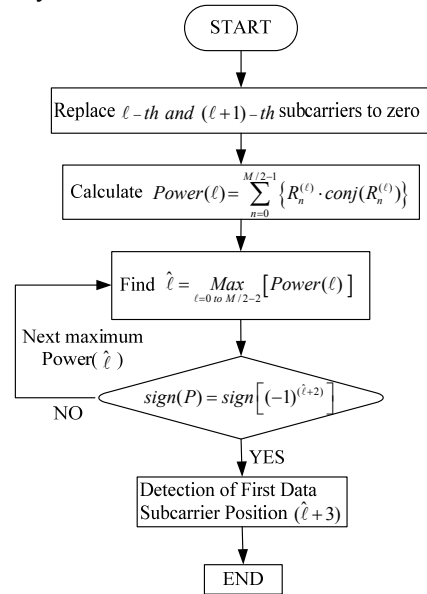


Fig.5 Detection algorithm for permutation number.

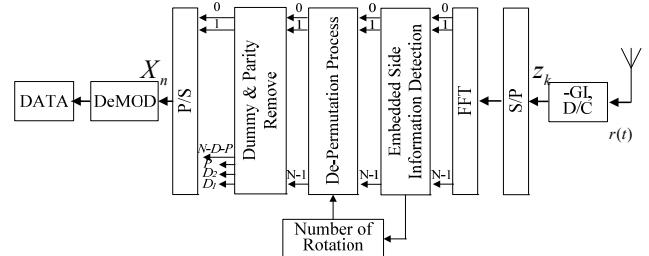


Fig.6 Structure of receiver for the proposed method.

Table 1 Simulation parameters.

Modulation method	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 for Type I 58 for Type II
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 shows the transmission efficiency for the proposed Type I and Type II methods. From the table, it can be observed that the proposed method can achieve the higher transmission efficiency because the number of rotation selected at the transmitter can be detected by using 2 dummy subcarriers and one parity check subcarriers for Type I and 4 dummy subcarriers and 2 parity check subcarriers for Type II at the receiver.

Figure 7 shows the PAPR performance both for the conventional OFDM and proposed PS methods when the number of sub-carriers (M) is 64 including 2 dummy sub-carriers (D) and one parity sub-carrier for Type I and 4 and 2 for the Type II, respectively. In the figure, the PAPR performance is evaluated by using the Cumulative Distribution Function (CDF). 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 of 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.

Table 2 Transmission efficiency for the proposed method.

Number of sub-carriers	Transmission efficiency	
	Type I	Type II
64	61/64 (95.3%)	58/64 (90.6%)
256	253/256 (98.8%)	250/256 (97.7%)
1024	1021/1024 (99.7%)	1018/1024 (99.4%)

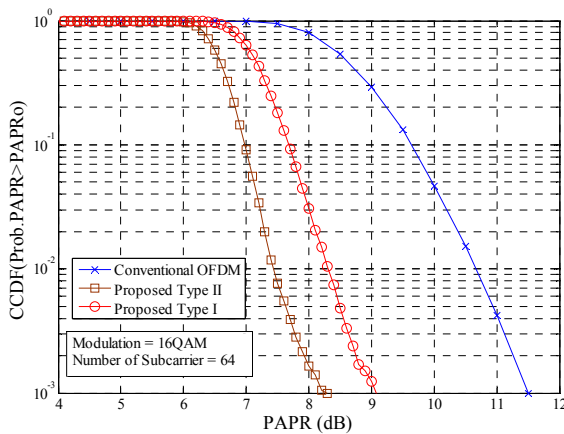


Fig.7 PAPR performance for the proposed method.

Figure 8 shows the BER performances in the non-linear channel when changing C/N for the conventional OFDM and the proposed PS method when using 64QAM as modulation method. In the simulation, the number of data subcarriers (K), dummy sub-carriers (D) and parity sub-carrier (P) 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 SSPA amplifier is taken by 0dB, -2dB, -4dB and -6dB, respectively. From the figures, the proposed PS method can achieve much better BER performance than those for the conventional OFDM in the non-linear channel.

VI. CONCLUSIONS

This paper proposed the new PAPR reduction method which can achieve the better PAPR performance. The salient future of proposed method is to rotate the subcarriers in the frequency domain so as to achieve the better PAPR performance. Since the proposed method enables the detection of rotation number precisely selected at the receiver by using the very few dummy subcarriers which is embedded in the OFDM symbol as the side information, the propose method can achieve the higher transmission efficiency. From the computer simulation results, this paper confirmed that the proposed PS method can achieve the better PAPR performance and better BER performance in the non-linear channel.

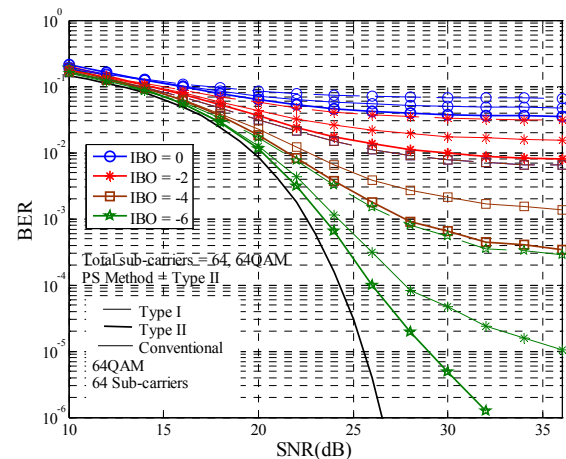


Fig.8 BER performance of proposed method in the non-linear channel.

REFERENCES

- [1] D Dardari, V. Tralli and A Vaccari, "A Theoretical Characterization of Nonlinear Distortion Effects in OFDM Systems," IEEE Trans. on Comm., Vol. 48, no. 10, pp.1775-1764, Oct 2000.
- [2] J. Tellado, "Multicarrier Modulation with Low PAR," Kluwer Academic Publishers, 2000.
- [3] X. Li and L. J. Cimini, Jr., "Effect of Clipping and Filtering on the Performance of OFDM," IEEE Commun.Lett., vol. 2, no. 5, May 1998, pp. 131-33.
- [4] J. Armstrong, "Peak-to-Average Power Reduction for OFDM by Repeated Clipping and Frequency Domain Filtering," Elect. Lett., vol. 38, no. 8, Feb. 2002, pp. 246-47.
- [5] A. E. Jones, T. A. Wilkinson, and S. K. Barton, "Block Coding Scheme for Reduction of Peak to Mean Envelope Power Ratio of Multicarrier Transmission Scheme," Elect. Lett., vol. 30, no. 22, Dec. 1994, pp. 2098-99.
- [6] B. S. Krongold and D. L. Jones, "PAR Reduction in OFDM via Active Constellation Extension," IEEE Trans. Broadcast., vol. 49, no. 3, Sept. 2003, pp. 258-68.
- [7] S. H. Müller and J. B. Huber, "OFDM with Reduced Peak-to-Average Power Ratio by Optimum Combination of partial Transmit Sequences," Elect. Lett., vol. 33, no. 5, Feb. 1997, pp. 368-69.
- [8] L. J. Cimini Jr., N. R. Sollenberger, "Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences," IEEE Communications Letters, vol. 4, no. 3 pp. 86-88, March 2000.
- [9] R. W. Bauml, R.F.H.Fischer and J.B.Huber, "Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping," IEEE Electron Lett., vol. 32, no. 22 pp.2056-2057, Oct. 1996.
- [10] S. H. Müller and J. B. Huber, "OFDM with reduce peak-to-average power ratio by optimum combination of partial transmit sequences," IEEE Electron. Lett., vol. 33, no. 5, pp. 368-369, Feb. 1997.
- [11] H. G. Ryu, J. E. Lee and J.S. Park, "Dummy Sequence Insertion (DSI) for PAPR Reduction in the OFDM Communication System," IEEE Transactions on Consumer Electronics, Vol. 50, No. 1, Feb 2004.
- [12] C. Rapp, "Effects of HPA-Nonlinearity on a 4-DPSK/OFDM-Signal for a Digital Sound Broadcasting System," in Proceedings of the Second European Conference on Satellite Communications, Liege, Belgium, pp. 179-184, Oct. 22-24, 1991.