Peak-to-Average Power Ratio Reduction in OFDM Systems Using Selected Mapping Applied Scheme

Gwo-Ruey Lee[1], Hsiang He Wang[2], Chuang-Hsien Chen[3] and Ho-Lung Hung[2*]

[1] *Department of Computer Science, Taipei Municipal University of Education*

No. 1, Ai-Guo W. Rd., Taipei 100, Taiwan, R.O.C.

[2] *Department of Electrical Engineering, Chienkuo Technology University No.1, Chieh Shou N. RD, Changhua City 500, Taiwan, R.O.C.*

[3] *Metal Industries Research & Development Centre*

e-mail: hlh@ctu.edu.tw * Correspondence authors

***Abstract*—Selected mapping (SLM) schemes are commonly employed to reduce the peak-to-average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) systems. Therefore, it can be applied to mobile consumer electronics that are sensitive to high PAPR because of the limitation of the linear area of a power amplifier. However, high PAPR degrades the system performance. Applying the signal space expansion into the signal selection scheme, PAPR reduction could be implemented in OFDM systems. In this paper, a SLM applied scheme using signal space expansion is proposed. In the scheme, a specific rule is designed to scramble the data sequence for PAPR reduction. The data sequence can be completely extracted at the receiver without any side information. Hence, the scheme can be implemented to reduce PAPR and to avoid bit error rate (BER) degradation in the OFDM system. Then, the numerical results are given to evaluate the performance on PAPR reduction and BER in the OFDM system. The result shows BER performance with the proposed SLM applied scheme is better than that with the ordinary SLM scheme.**

Keywords*—OFDM systems, PAPR reduction, Signal space expansion, Selected mapping applied scheme.

1. INTRODUCTION

This document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please contact the conference publications committee as indicated on the conference website. Information about final paper submission is available from the conference website. Orthogonal frequency division multiplexing (OFDM) has become an essential technique for high-speed wireless communication systems because of its high spectral efficiency and robustness to multipath fading channels [1-3]. Therefore, OFDM has been adapted to various standards, such as IEEE 802.11 a/g/n wireless local area networks (WLANs) [4], IEEE 802.16 e/m mobile worldwide interoperability for microwave access (WiMAX) [5], digital audio broadcasting (DAB) systems, digital video broadcasting terrestrial TV (DVB-T) systems, and 3GPP long term evolution (LTE) [6-7]. However, one of the major drawbacks of the OFDM system is a high peak-to-average power ratio (PAPR). The high PAPR usually affects the mobile consumer electronics such as smart phone, laptop, and tablet PC in uplink communication, since high PAPR may lead to low battery life and the demand of the high linear area for a power amplifier, which increases the cost of the consumer electronics. Fig. 1 shows the uplink communication of mobile consumer electronics in the WLAN and cellular communication system. However, the high peak-to-average power ratio (PAPR) that is inherent in OFDM signals will occasionally drive the high-power amplifier

(HPA) to operate in the nonlinear region of its characteristics curve. For a solid-state power amplifier (SSPA), the nonlinearity exhibits amplitude modulation AM/AM amplitude distortion, which causes loss of orthogonality among the subcarriers, and hence, intercarrier interference (ICI) is introduced [8].

Recently, various methods have been proposed to reduce the PAPR of OFDM signals in the literature [9-11], including clipping [12], nonlinear companding transforms [13], coding technique [14], time-domain symbol combining [15], tone reservation [16], selected mapping (SLM) [17], and partial transmit sequence (PTS) [18], and subblock phase weighting (SPW) method [19], those techniques gives the smallest PAPR. SLM and PTS belong to the probabilistic class because several candidate signals are generated and the one with the minimum PAPR is selected for transmission. It is well known that SLM is more advantageous than PTS if the amount of side information is limited, but the computational complexity of SLM is larger than that of PTS. The basic idea of SLM is that for each OFDM symbol, the input sequence is scrambled by a certain number of scrambling sequence, and the candidate sequence with a lowest PAPR is chosen as the transmitted signal in the OFDM systems [20]. However, the side information needs to be transmitted via a control channel to index the phase information in the receiver. With the correct side information, the source information could be obtained accurately. However, under a noisy channel, the side information is distorted to result in BER degradation in the OFDM systems. Hence, the side information affected the system performance and its bandwidth efficiency.

In this paper, without the transmission of the side information, an SLM applied scheme is proposed to reduce the PAPR and to avoid performance degradation. In the scheme, the parity check coding is used to generate an extended signal space for symbol choosing and benefits to PAPR reduction. In the SLM applied scheme, the parity check information with the different phase rotation is proposed to result a set of sufficiently different signals. The signal with the lowest PAPR is selected to be transmitted. Those coding schemes are used to generate an extended signal space for symbol choosing. With applying the schemes, the PAPR could be greatly reduced in the OFDM system and the system performance on BER could be guaranteed in the system. In the following section, OFDM system is described and the ordinary SLM scheme is introduced.

This paper is organized as follows. In Section2, the conventional SLM scheme is explained. In Section 3, a new PAPR reduction scheme is proposed and its computational complexity is compared with that of the conventional SLM scheme. In Section 4, simulation results are given to compare the PAPR reduction performances of the proposed scheme and the conventional SLM scheme. Finally, the concluding remarks are given in Section 5.

2. OFDM SYSTEM DESCRIPTION AND THE ORDINARY SELECTED MAPPING SCHEME

In general, an OFDM signal consists of N subcarriers that are modulated by N complex symbols selected from a particular phase shift keying (PSK) or quadrature amplitude modulation (QAM) scheme. Generally, a conventional OFDM system contains the function of modulation scheme, parallel transmission and IFFT/FFT modules [1, 4]. Fig. 1 shows a block diagram of a baseband, discrete-time FFT-based OFDM systems.

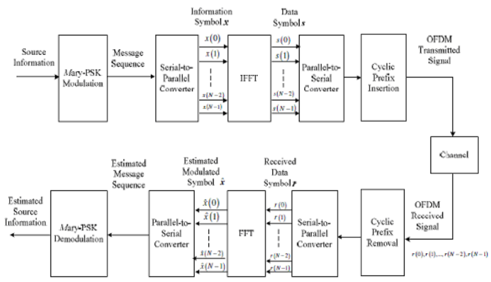

Fig1. The block diagram of FFT based OFDM system

The information sequence $x = \left[x(0), x(1), \cdots, x(N-1) \right]$ is transferred by an IFFT to be the data symbol $s = \left[s(0), s(1), \cdots, s(N-1) \right]$. The nth element s_n in data symbol s could be found according to IFFT.

$$s_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x(k) e^{j2\pi nk/N}, \quad 0 \le n \le N-1 \qquad (1)$$

where $x(k)$ represents the kth element in the information symbol x and N represents the number of subcarriers in IFFT. Then, the data symbol is converted into a serial sequence and, then, the sequence is cyclically extended to obtain an OFDM symbol [1-4]. The OFDM symbol is passed by digital-to analog converter (D/A), lowpass filter and up-converter to form a continuous-time OFDM transmitted signal, *s*(*t*). The resulting complex baseband continuous time signal is serially transmitted over a channel. At the receiver, the received signal is down-converted to obtain a baseband signal.

The PAPR is defined as the ratio between the peak power and average power of the OFDM transmitted signal. Besides, the peak power of the transmitted signal is defined as the maximum of instantaneous power of transmitted signal. Then, the PAPR for a continuous signal $s(t)$ of the baseband OFDM transmitted signals can be defined as

$$PAPR = \frac{\max\left\{|s(t)|^2\right\}}{E\left\{|s(t)|^2\right\}} \qquad 0 \le t \le T_u, \qquad (2)$$

where max(*z*) denotes the maximum value of *z*. The PAPR for discrete time signals can be estimated by oversample the symbols sequence by a factor *L* and computing *N L*-point IFFT. The PAPR in this case is defined as

$$PAPR = \frac{\max\left\{|s_n|^2\right\}}{E\left\{|s_n|^2\right\}}, \; n = 0,1,\cdots,LN-1. \qquad (3)$$

Source information passes through S/P converter and mapping process and, then, information sequence X is copied to generate U sequences, $X^{(1)}, X^{(2)}, \cdots, X^{(u)}, \cdots, X^{(U)}$. Each sequence is rotated with a phase vector $P^{(U)}$ and, then, modulated by IFFT to generate a candidate sequence. In SLM scheme, each phase vector has *N* distinct phase elements and the phase vector could be expressed in Eq. (3).

$$P^{(u)} = \left[P_1^{(u)}, P_2^{(u)} \cdots, P_N^{(u)}\right], \qquad (4)$$

where N is the number of subcarriers, $P_v^{(u)} = e^{j\phi_v^{(u)}}$ and $\phi_v^{(u)} \in [0, 2\pi)$, $v = 1:N$, and $u = 1:U$. The candidate sequence could be obtained as

$$x^{(u)} = IFFT(X^{(u)} \cdot P^{(u)}),$$

where $a \cdot b$ denotes the inner product between vector *a* and *b*.The PAPRs of each candidate sequence are computed, individually. In the scheme, the candidate sequence with a lowest PAPR is chosen as the transmitted signal in the OFDM systems.

3. SLM APPLIED SCHEME

An SLM [21-22] applied scheme using parity check coding is proposed to reduce PAPR and to avoid performance degradation in OFDM systems. In this scheme, a simple rule is designed to scramble the data sequence. The data sequence can be completely extracted at the receiver without any side information.

In this paper, a modified SLM scheme is applied to reduce PAPR and to avoid BER degradation without any side information. The data within the information sequence is not phase rotated, hence, the data could be obtained without any side information. BER performance is not degraded in the system. Besides, only the parity check bits are phase rotated in the scheme, the rotated phase could be estimated in Eq. (5) without any side information.

$$\hat{P}_{v,w} = \frac{O(w \cdot N/W - 1)}{\bmod_2\left(\sum_{i=(w-1)N/W}^{w.N/W-1} sign(O(i))\right)} \qquad (5)$$

where $\bmod_2(o+z)$ denotes modular 2 sum operation between *o* and *z*, i.e., Exclusive OR operation for the variables *a* and *b*. The function, sign($\cdot$), is defined as

$$sign(z) = \begin{cases} 1, & z \ge 0 \\ -1, & z < 0 \end{cases}. \qquad (6)$$

With the estimated phase rotation, the source information could be estimated in Eq.(7).

$$\hat{a}(i) = \begin{cases} sign\left(\dfrac{O(w \cdot N/W - 1)}{\hat{P}_{v,w}}\right), & for\;\; parity\;\; check \\ sign(O(i)), & for\;\; data\;\;\; symbol \end{cases}, \qquad (7)$$

Based on the proposed schemes, the numerical results are given in the following section.

4. Simulation Results

Figs. 2-3 compares the CCDF of two alternative symbol sequences for N= 128, and 512 when 16-QAM are used. In order to evaluate the performance of PAPR reduction with the proposed SLM applied scheme in the OFDM system, the numerical results are given in this section. Figs. 2-3 give the CCDF of the PAPR for the conventional OFDM system and the system with applying the ordinary SLM and the proposed SLM schemes. In the simulations, the number of subcarriers is assumed to be 512 and 128, the number of parity check bits in the proposed SLM scheme is assumed to be 4. Therefore, the lengths of phase rotated vector are 128 and 4 for the ordinary SLM scheme and the proposed SLM scheme, individually. Besides, the PAPR with the proposed SLM scheme with U=2 is similar to that with the ordinary SLM scheme with U=4. In Fig. 2 with N=128, the proposed scheme with U=8 has almost the same performance compared with the ordinary SLM scheme with U=16. The performance of the proposed scheme with is better than that of the ordinary SLM scheme with by 0.2 dB when $CCDF = 10^{-3}$.

However, the BER performance of the proposed SLM applied scheme is better than that with the ordinary SLM scheme in Fig. 4. This is because that the phase rotation is only used in the part of parity check bits. The data within the information sequence is not phase rotated, then, the data could be estimated without any side information. However, in the ordinary SLM scheme, the side information needs to identify the desired phase vector. Under a noisy channel, the side information is distorted. Hence, the BER performance is decayed. Moreover, the result shows that the BER performance with the SLM applied scheme is identical to that with the conventional OFDM system. Hence, the system performance on BER can be guaranteed in the system.

5. CONCLUSIONS

In this paper, we propose a modified selective mapping technique with parity check coding for PAPR reduction of OFDM signal. In this technique, we embed the phase sequence, which is used to lower the PAPR of the data block, in the check symbols of the OFDM data block. Simulation results show that the proposed schemes have better PAPR reduction performance than the conventional SLM and converge to the theoretical CCDF. Furthermore, we can achieve both PAPR reduction and to avoid BER degradation without any side information. However, the BER performance of the proposed SLM applied scheme is better than that with the ordinary SLM scheme. In addition, approximate expression for the complementary cumulative distribution function (CCDF) of the PAPR of the modified SLM technique is derived and compared with the simulation results.

REFERENCES

[1] S. H. Muller and J. B. Huber, "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences," IEE Electron. Lett., 33:5(1997), 368-369.

[2] S. H. Han and J. H. Lee, "An overview of peak-to-average poer ration reduction techniques for multicarrier transmission," *IEEE Wireless Commun*., 12:2 (2005),56-65.

[3] Tao Jiang and Yiyan Wu, "An overview:peak-to-average power ratio reduction techniques for OFDMsignals," *IEEE Trans. on Broadcasting*, 54:2(2008), 257-268.

[4] X. Yang, "IEEE 802.11n: enhancements for higher throughput in wireless LANs," *Wireless Commun.*, 12: 6 (2005), 82-91.

[5] F. Wang, et al., "Mobile WiMAX systems: performance and evolution," *IEEE Commun. Mag*., 46:10 (2008), 41-49..

[6] D. Astely, et al., "LTE: the evolution of mobile broadband," *IEEE Commun. Mag.*, 47:4(2009), 44-51.

[7] M. Rumney, *LTE and the Evolution to 4G Wireless: Design and Measurement Challenges*. Santa Clara, CA: Agilent Technol. Publ., 2009.

[8] D. Park and H. Song, "A new PAPR reduction technique of OFDM system with nonlinear high-power amplifier," *IEEE Trans. Consum. Electron.*, 53:2(2007), 327–332.

[9] M. Engels, *Wireless OFDM systems: How to make them work?* 1st edition, Kluwer Academic Publishers, 2002.

[10] K. Baum, B. Classon and P. Sartori, *Principles of broadband OFDM cellular system design*, John Wiley, 2009.

[11] Y. Wu and W.Y. Zou, Orthogonal frequency division multiplexing: a multi-carrier modulation scheme, *IEEE Transactions on Consumer Electronics*, 41: 3,(1995), 392-399.

[12] Y. Chen, J. Zhang, and A. D. S. Jayalath, "Estimation and compensation of clipping noise in OFDMA systems," *IEEE Trans. Wireless Commun.*, 9: 2(2010), 523–527.

[13] N. Chaudhary and L. Cao, "Non-symmetric decompanding for improved performance of

companded OFDM systems,” *IEEE Trans. Wireless Commun.*, 6:8(2007), 2803–2806.

[14] T. Jiang and G. Zhu, “Complement block coding for reduction in peak-to-average power ratio of OFDM signals,” *IEEE Commun. Mag.*, 43:. 9(2005),. S17–S22.

[15] E. Alsusa and L. Yang, “A low-complexity time-domain linear symbol combining technique for PAPR reduction in OFDM systems,” *IEEE Trans. Signal Process.*, 56: 10(2008), 4844–4855.

[16] J.-C. Chen and C.-P. Li, “Tone reservation using near-optimal peak reduction tone set selection algorithm for PAPR reduction in OFDM systems,” *IEEE Signal Process. Lett.*, 17: 11(2010), 933–936.

[17] Hyun-Bae Jeon, Jong-Seon No, and Dong-Joon Shin, A Low-Complexity SLM Scheme Using Additive Mapping Sequences for PAPR Reduction of OFDM Signals, IEEE Transactions on Broadcasting , 57:4(2011), 866-870.

[18] A. Ghassemi and T.A. Gulliver, “Partial selective mapping OFDM with low complexity IFFTs,” *IEEE Communications Letters*, 12: 1(2008), 4-6.

[19] H.G. Ryu and K.J. Youn, “A new PAPR reduction scheme: SPW (subblock phase weighting),” *IEEE Transactions on Consumer Electronics*, 48:1(2002), 81-89.

[20] D.-W. Lim, C.-W. Lim, J.-S. No, and H. Chung, “A new PTS OFDM scheme with low complexity for PAPR reduction,” *IEEE Transactions on Broadcasting*, 52: 1(2006), 77–82.

[21] Jung-Chieh Chen; Chao-Kai Wen, “A Low-Complexity Scheme to Reduce the PAPR of an OFDM Signal Using Sign-Selection Algorithms,” *IEEE Signal Processing Letters*, 17:2(2010),189-192.

[22] Chih-Peng Li; Sen-Hung Wang; Chin-Liang Wang, “Novel Low-Complexity SLM Schemes for PAPR Reduction in OFDM Systems,” *IEEE Transactions on Signal Processing*, 58:5(2010),2916-2921.

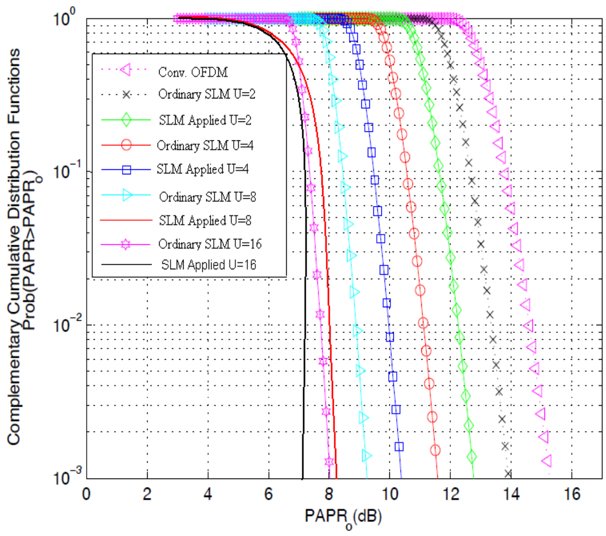

Fig. 2. The CCDE of PAPR for the ordinary and the proposed SLM schemes with N=128 and 16-QAM

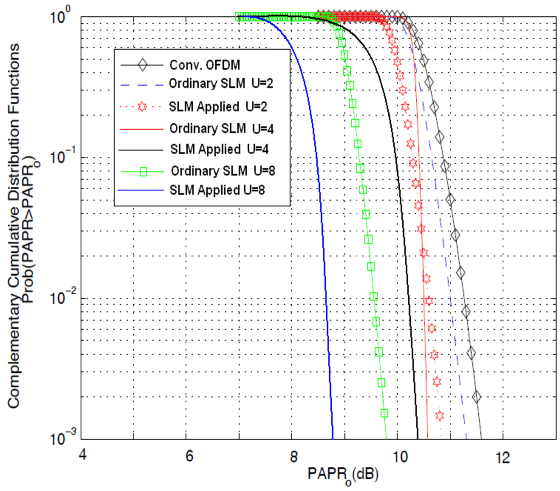

Fig. 3. The CCDE of PAPR for the ordinary and the proposed SLM schemes with N=512 and 16-QAM

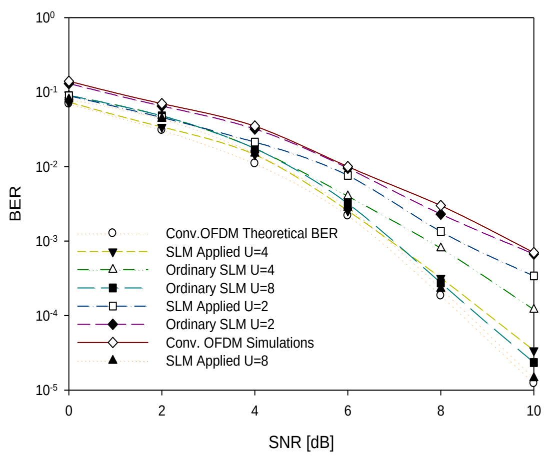

Fig. 4. The BER performance for the ordinary and the proposed SLM schemes