PAPR Reduction in OFDM Systems with proposed Selective Mapping Technique

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***Abstract*—This paper proposes a modified selective mapping (SLM) technique to improve the high computational complexity required for the SLM technique in the orthogonal frequency division multiplexing (OFDM) system, and it can be regarded as a suboptimal SLM technique for peak to average power ratio (PAPR) reduction. The proposed method which generates W candidate signals is through the phase factor to carry out the first phase scrambling for the input signal to produce $W/2$ signals, followed by the inverse fast Fourier transform (IFFT) and then the second phase scrambling to produce the remaining $W/2$ signals. The generation mechanism of the phase factor is mainly based on the sub-code of the Reed-Muller codes with random ordering. The simulation results show that adopting the proposed method results in the improved performance of PAPR that are suboptimal compared to adopting the SLM technique but it simplifies the number of adders and multipliers required by the traditional SLM technique.**

***Index Terms*—OFDM, SLM, PAPR, Reed-Muller codes, phase factor.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) technique, which has the advantages of high spectral efficiency and anti-inter-symbol interference, has been chosen by many communication transmission standards such as IEEE 802.11a, digital video broadcasting, digital voice broadcasting etc., to serve as transmission technique [1]. Besides, OFDM technique is also listed as one of the candidate transmission technologies by the next generation mobile communication system. The OFDM signal mainly transfers data through multiple subcarriers separately for parallel transmission. In order to achieve that subcarriers can keep orthogonal among each other, it adopts the InverseFast FourierTransform (IFFT) and the fast Fourier transform (FFT) respectively for modulation and demodulation. Because the OFDM signal is composed of multiple signals, it may generate the phenomenon of high peak-to-average power ratio (PAPR). When the transmit signal has a high PAPR, it not only reduces the performance of high power amplifiers but also increases the complexity of the analog-to-digital converter and the digital-to-analog converter. In order to reduce the occurrence of high PAPR in OFDM signals, various methods of improvement have been proposed, such as the tone reservation (TR) [2], [3], the tone injection (TI) [4], [5], the selective mapping (SLM) [6]–[8] and so on. Although each of the above techniques results in a better PAPR improved performance, each is also accompanied by some flaws which needs to be ameliorated. Therefore, how to improve the occurrence of high PAPR in OFDM systems is still has more scope for research

The SLM technique performs phase scrambling of the transmitted modulation data to generate multiple frequency domain signals and converts these frequency domain signals into multiple candidate signals through IFFT while the transmission signals with the lowest PAPR signal are selected from the candidate signals to be transmitted. Although the SLM technique can effectively improve the PAPR of the OFDM system, it also needs to use multiple IFFTs to generate candidate signals. As a result, the overall required amount of computation is also relatively enhanced. On the other hand, in order to let the SLM technique generate candidate signals with better PAPRs, the generation mechanism of phase factor will be one of the important factors determining the performance of the PAPR reduction whereas the phase factor is used to determine the type of phase scrambling to be performed for the modulation data. The purpose of this paper is to improve the required high computational complexity of the SLM technique by using the generation mechanism of the suboptimal phase factor. Assuming W is the number of candidate signals, the proposed method first uses the generation mechanism proposed in this paper to randomly generate the $W/2$ codewords of Reed-Muller codes, and change the contents of each codeword for which 0 is replaced with 1 and 1 is replaced with -1 to form $W/2$ phase factors, and then each of these phase factors is multiplied by the transmitted data after modulation, and then they are sequentially converted into time-domain signals through IFFT, and then let each of them multiplied by -1 to produce another $W/2$ time-domain signals. Next, the signal with the lowest PAPR is selected as the transmission signal after the PAPRs of the W time-domain signals are computed. The simulation results show that the traditional SLM technique produces a better PAPR performance than the proposed method but the traditional SLM technique requires the use of W IFFT operations while the proposed method requires only $W/2$ IFFT operations. Furthermore, the improved performance of PAPR in the proposed method can achieve the similar performance of PAPR in the traditional SLM technique which adopts $W/2$ IFFT operation so it can simplify the IFFT operation required by traditional SLM technique.

The remaining chapters of this paper are arranged as follows: Section II mainly describes the mathematical representation formula of the OFDM signal and the definition of PAPR. Section III illustrates the system framework of the traditional SLM technique and shows the block diagram of such system. Section IV and Section V describe the recommended method and the simulation results respectively while the conclusions of this paper are described in Section VI.

II. OFDM AND PAPR

An OFDM signal with N subcarriers can be described as follows:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j\frac{2\pi kt}{T}}, \quad 0 \le t \le T \tag{1}$$

where X_k is complex data symbol and T is the period of an OFDM signal. This paper uses the 16-QAM as the modulation scheme. The complex 16-QAM symbol X_k can be expressed as

$$X_k = \frac{1}{\sqrt{2}} jc_{1,k} + 2c_{2,k} + \sqrt{2j}c_{3,k} + 2c_{4,k} \; k = 0, \ldots\ldots N \tag{2}$$

where$\{c_{1,k}, c_{2,k}, c_{3,k}, c_{4,k}\} \in Z_2$. The PAPR of OFDM signal can be defined as follows:

$$PAPR = 10 log_{10} \left(\frac{max_{0 \le t \le T} |x(t)|^2}{E\{|x(t)|\}^2} \right) \tag{3}$$

where Eu is the expected value of u. In general, the evaluation for the performance of the PAPR reduction technique is analyzed using the complementary cumulative distribution function (CCDF). Assuming that the value of the reference level for the PAPR is PAPR_0, CCDF(PAPR) is the probability when the PAPR of the transmitted signal is greater than PAPR_0, which can be expressed as

$$\mathrm{CCDF(PAPR)} = \Pr(\mathrm{PAPR} > \mathrm{PAPR}_0) \tag{4}$$

To accurately estimate the PAPR of the OFDM signal, oversampling was conducted on OFDM signals. Oversampling performs a zero-padding procedure on the input data block. $(X_0, X_1, \ldots, X_{N-1})$ and $(L - 1)N$ zeros were zero-padded to form a vector with the length of LN; this was then sent to the IFFT of LN point for calculating and processing. In this paper, $L = 4$ was used to conduct numerical simulations.

III. SLM

Fig. 1 shows a block diagram of the transmission side of an OFDM system using the SLM technique. The SLM technique is a PAPR reduction technique based on the linear operation, for which the input data block $\mathrm{X} = (X_0, X_1, \ldots, X_{N-1})$ is multiplied by W phase factors $\mathrm{b}^{(i)} = (b_0^{(i)}, b_1^{(i)}, \ldots, b_{N-1}^{(i)})$ in the scrambling phase. Each element of the phase factor is defined as

$$b_j^{(i)} = e^{j\emptyset_j^{(i)}} \quad \in (0,2\pi) \qquad ^{(i)}$$

$i = 0, 1, \ldots, W$ and $j = 0, 1, \ldots, N-1$. Then, the W signals after phase-scrambling are generated after multiplication

$$\mathrm{X}^{(i)} = \mathrm{X} \cdot \mathrm{b}^{(i)} = (X_0 b_0^{(i)}, \ldots, X_{N-1} b_{N-1}^{(i)}), \; i = 0, 1, \ldots, W,$$

which are converted to the time domain signals

$$X^{(i)} = IFFT(X^i), \qquad i = 0,1, \ldots\ldots W$$

through the IFFT operation. Serving as W candidate signals, the signal with the lowest PAPR is select as the transmission signal of the OFDM system.

IV. RECOMMENDED METHOD

Fig. 2, it shows a block diagram of the system for the recommended method. Assuming that the modulation data with the length of N is $\mathrm{X} = (X_0, X_1, \ldots, X_{N-1})$ and the number of candidate signals is W. The recommended method is to adopt the random ordering Reed-Muller code [9] to generate the phase factor. The generation mechanism for the phase factor is described as follows. First, in the recommended method, the generator matrix G of rth order Reed-Muller code with length N, RM(r,$\log_2 N$), can be written as

$$\mathrm{G} = [\mathrm{G}_0, \mathrm{G}_1, \ldots, \mathrm{G}_r]^T .$$

Then the two sub-matrices with Hamming weights of N (sub-matrix G_0) and Hamming weights of 1 (sub-matrix G_r) are removed respectively, So that the generator matrix $\underline{\mathrm{G}}$ for generating the phase factor in the recommended method can be formed as

$$\bar{\mathrm{G}} = [\mathrm{G}_1, \ldots, \mathrm{G}_{r-1}]^T .$$

Assuming that the number of candidate signals is $W/2$, the candidate signals for $W/2 \le \log 2N$ are randomly generated as $W/2$ codewords c_i, $i = 1, 2, \ldots, W/2$, through adopting $W/2$ generator matrices $\mathrm{G}_{r-1}, \ldots, \mathrm{G}_{r-1-(w/2)-1}$ in order; the candidate signals for $W/2 > log_2 N$ are randomly generated in cycling order as $W/2$ codewords c_i, $i = 1, 2, \ldots, W/2$, through adopting $log_2 N$ generator matrices $\mathrm{G}_1, \ldots, \mathrm{G}_{\log_2 N}$. Afterwards, $W/2$ phase factors are computed through the conversion of the mathematical formula

$$\mathrm{b}_i = (-1)^{\mathrm{c}_i}, \; i = 1, 2, \ldots, W/2.$$

As shown in Fig. 2, the recommended method is to multiply each of the input modulation data by $W/2$ phase factors to generate $W/2$ signals after phase-scrambling, which are then fed into the IFFT to be converted into the time domain signals serving as candidate signals. Meanwhile, the other $W/2$ candidate signals are generated by multiplying each of the original $W/2$ candidate signals by (-1). More specifically, the W candidate signals are composed of $W/2$ candidate signals and their corresponding inverted $W/2$ candidate signals. The transmission signal is the signal with the minimum PAPR selected among the W candidate signal. Table I shows the number of adders and multipliers required for the traditional SLM technique and the recommended method. In Table I, taking the case of adopting W candidate signals as an example, the recommended method saves $(W/2)((N/2)\log_2 N)$

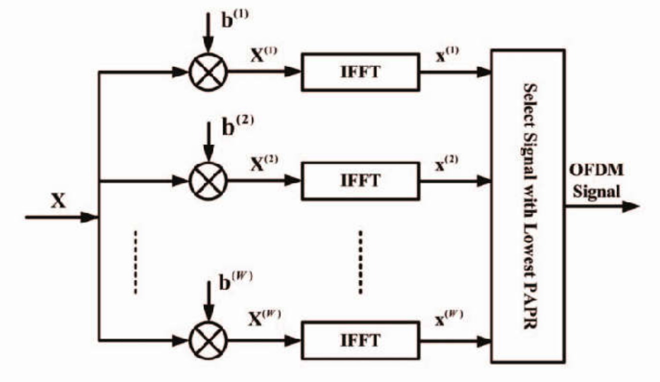

Fig. 1. SLM block diagram.

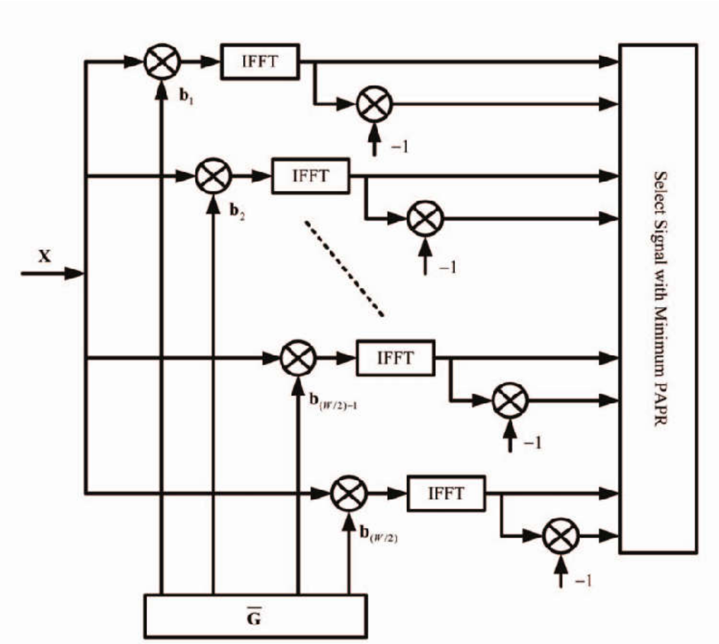

Fig. 2. Block diagram of an OFDM system adopting the recommended method.

multipliers and $(W/2)(N\log_2 N)$ adders compared to the traditional SLM technique.

V. SIMULATION RESULT

For the selection of simulation parameters, this paper is based on the OFDM system of the 16-QAM modulation selecting the number (N) of subcarriers as 256 and 1,024 respectively. 100,000 OFDM signals are randomly generated as the input data for simulation and the CCDF curve diagram is plotted statistically based on each generated PAPR value. As for the selection of the phase factor, the phase factor contents of both the recommended method and the traditional SLM technique change by ± 1 while the phase factor contents of the traditional SLM technique are generated in a random manner. Fig. 3 shows that CCDF curve diagram of the 16-QAM OFDM system with 256 subcarriers in the traditional SLM technique and in the recommended method respectively. Fig. 3, it shows that the traditional SLM technique improves in the PAPR performance better than the recommended method the case of the same number of candidate signals (W) but the recommended method can save $(W/2)((N/2)\log_2 N)$ multipliers and $(W/2)(N\log_2 N)$ adders compared with the Traditional SLM technique. On the other hand, in the case of the same number of IFFT, the recommended method only needs to add NW multipliers to achieve the similar PAPR and improved performance shown in the traditional SLM technique adopting the random phase factors to improve. Fig. 4 shows that CCDF curve diagram of the 16-QAM OFDM system with 1,024 subcarriers in the traditional SLM technique and in the recommended method respectively. According to the simulation results shown in Fig. 4, the PAPR improved performance of the recommended method dose not decrease due to the increase in the number of subcarriers so that

TABLE I
COMPARISON BETWEEN THE NUMBER OF MULTIPLIERS AND THE NUMBER OF ADDERS

Operation complexity	PAPR reduction technique	
	Traditional SLM technique	Recommended method
Number of multipliers	$W \quad \frac{N}{2}\log_2 N \quad + NW$	$\frac{W}{2} \quad \frac{N}{2}\log_2 N \quad + 2 \quad N\frac{W}{2}$
Number of adders	$W(N\log_2 N)$	$\frac{W}{2}(N\log_2 N)$

it preserves both the PAPR improved performance and the simplification of the high computational volume shown in Fig. 3.

VI. CONCLUSION

This paper presents a phase factor generation mechanism that can simplify the computational volume required for the SLM technique. It adopts parts of sub-codes of the random ordering Reed-Muller code to generate the factors. The recommended method mainly adopts the two-phase scrambling approach to generate candidate signals and can effectively simplify the computational volume required by the traditional SLM technique for candidate signal generation. In addition, the simulation results show both the recommended method and the traditional SLM technique achieve similar PAPR and improved performances in the case of adopting the same number of IFFT. In the case of generating the same number of candidate signals, though the recommended method does not achieve the same PAPR improved performance in the SLM technique, it can simplify the number of adders and multipliers required for the SLM technique.

REFERENCES

[1] U. Reimers, ”Digital Video Broadcasting,” IEEE Communications Magazine, vol. 36, pp. 104-110, 1998.
[2] C. Ni, Y. Ma and T. Jiang, ”A Novel Adaptive Tone Reservation Scheme for PAPR Reduction in Large-Scale Multi-User MIMO-OFDM Systems,” IEEE Wireless Communications Letters, vol. 5, pp. 480-483, 2016.
[3] T. Jiang, C. Ni, C. Ye, Y. Wu and K. Luo, ”A Novel Multi-Block Tone Reservation Scheme for PAPR Reduction in OQAM-OFDM Systems, ” IEEE Transactions on Broadcasting ,vol. 61, no.4, pp. 717-722, Dec. 2015.
[4] W. Wang, M. Hu, Y. Li and H. Zhang, ”A Low-Complexity Tone Injection Scheme Based on Distortion Signals for PAPR Reduction in OFDM Systems,” IEEE Transactions on Broadcasting, vol. PP, pp. 1-9, 2016.
[5] J. Hou, X. Zhao, F. Gong, F. Hui and J. Ge, ”PAPR and PICR Reduction of OFDM Signals with Clipping Noise-based Tone Injection Scheme,” IEEE Transactions on Vehicular Technique, vol. PP, pp. 1-11, 2016.
[6] J. Y. Woo, H. S. Joo, K. H. Kim, J. S. No and D. J. Shin, ”PAPR Analysis of Class-III SLM Scheme Based on Variance of Correlation of Alternative OFDM Signal Sequences, ” IEEE Communications Letters, vol. 19, pp. 989-992, 2015.
[7] N. Taspinar and M. Yildirim, ”A Novel Parallel Artificial Bee Colony Algorithm and Its PAPR Reduction Performance Using SLM Scheme in OFDM and MIMO-OFDM Systems,” IEEE Communications Letters, vol. 19, pp. 1830-1833, 2015.
[8] J. Ji, G. Ren and H. Zhang, ”A Semi-Blind SLM Scheme for PAPR Reduction in OFDM Systems With Low-Complexity Transceiver, ” IEEE Transactions on Vehicular Technique, vol. 64, pp. 2698-2703, 2015.
[9] H. Chen and H. Liang, ”A Modified Selective Mapping With Block Coded Modulation for PAPR Reduction in OFDM Systems,” International Journal of Electrical Engineering, vol. 13, pp.331-338, 2007.

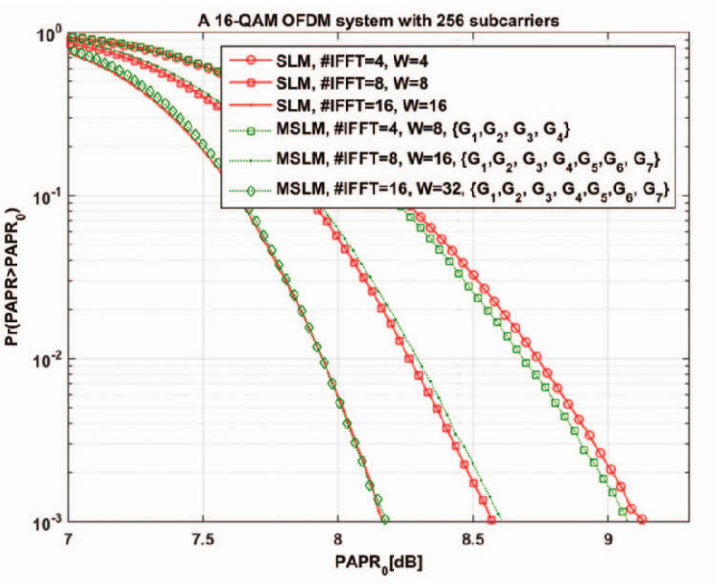

Fig. 3. The CCDF curve diagram of the 16-QAM OFDM system with 256 subcarriers in the traditional SLM technique and in the recommended method respectively.

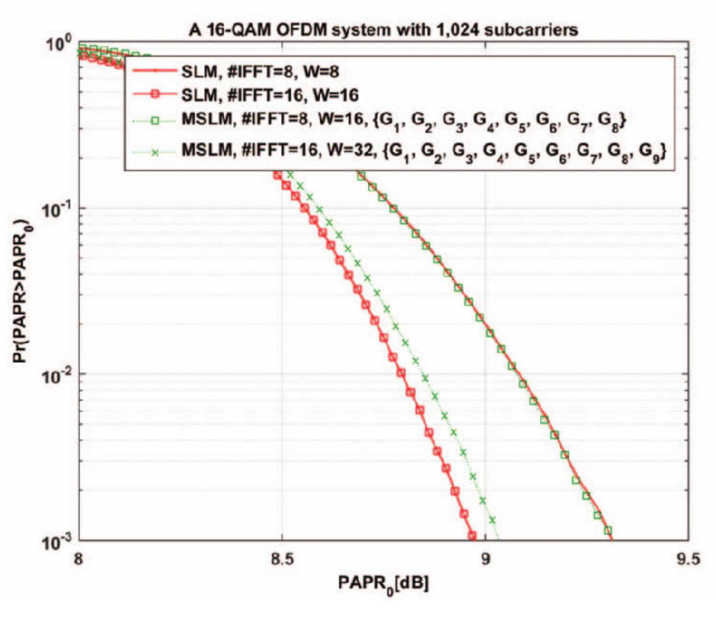

Fig. 4. The CCDF curve diagram of the 16-QAM OFDM system with 1,024 subcarriers in the traditional SLM technique and in the recommended method respectively.