Available online at www.sciencedirect.com

ScienceDirect

ICT Express 2 (2016) 63–66

www.elsevier.com/locate/icte

New SLM scheme to reduce the PAPR of OFDM signals using a genetic algorithm[☆]

Insoo Sohn

Division of Electronics & Electrical Engineering, Dongguk University, Seoul, Republic of Korea

Received 11 April 2016; accepted 9 May 2016
Available online 21 May 2016

Abstract

Selected mapping (SLM) is a popular peak-to-average power ratio (PAPR) reduction technique suitable for use in orthogonal frequency division multiplexing (OFDM) systems as it achieves good PAPR reduction performance without signal distortion. However, SLM requires a bank of inverse fast Fourier transforms (IFFTs) to produce candidate signals, resulting in high computational complexity. In this paper, we introduce a novel SLM technique based on conversion matrices (CM) and a genetic algorithm (GA) that requires only one IFFT module. Simulation results indicate that the proposed method obtains desirable PAPR reduction performance with low computational complexity.

Keywords: OFDM; PAPR; SLM; Genetic algorithm; Conversion matrix

1. Introduction

A major drawback of orthogonal frequency division multiplexing (OFDM) systems is the high peak-to-average power ratio (PAPR) of the transmitted signal. Among various PAPR reduction techniques, selected mapping (SLM) [1] is a popular method that achieves good PAPR reduction performance without signal distortion. However, SLM requires a large number of inverse fast Fourier transform (IFFT) operations to generate the candidate signal set. Many schemes have been proposed to reduce the computational complexity of SLM, such as the modified SLM schemes based on conversion matrices [2,3]. CM based SLM (CMSLM) schemes require only one IFFT module as the IFFT modules are replaced by CMs. However, CMs are constructed based on conversion basis vectors, obtained using an exhaustive search method. Furthermore, in order to obtain a sufficient number of CMs to generate candidate signals, an additional variation insertion operation is required in CMSLM schemes. The random variation insertion operation applied to CMs may result in candidate signals with high correlation and poor PAPR reduction performance.

A genetic algorithm (GA) is a stochastic search method based on the principles of natural evolution and employs selection and recombination operations [4]. The GA has been successfully applied in various signal processing areas, including PAPR reduction of OFDM signals [5]. In this paper, we present a novel PAPR reduction technique based on CMs and a GA. The proposed scheme requires only one IFFT module through the use of CMs and obtains an optimum candidate signal set with good PAPR reduction performance by employing a GA.

The rest of the paper is organized as follows. In Section 2, the OFDM model, the conventional SLM scheme, and the CMSLM scheme are described. In Section 3, the proposed SLM scheme based on the GA is presented. Simulation results are presented in Section 4, followed by the conclusion in Section 5.

2. System model

2.1. OFDM model

An OFDM signal is the sum of N independent subcarriers of equal bandwidth that can be expressed as

$$\mathbf{X} = [X_0 \ \ldots \ X_{N/2-1} \ 0 \ \ldots 0 \ X_{N/2} \ \ldots \ X_{N-1}]^T \tag{1}$$

where X_k is the quadrature phase shift keying (QPSK) or quadrature amplitude modulation (QAM) modulated data

---

E-mail address: isohn@dongguk.edu.

Peer review under responsibility of The Korean Institute of Communications Information Sciences.

[☆] This paper has been handled by Prof. Jun Heo.

http://dx.doi.org/10.1016/j.icte.2016.05.002

symbol of the kth subcarrier. Let J be the oversampling rate implemented with $(J-1)\cdot N$ zeros in the middle. The nth oversampled time domain OFDM signal can now be expressed as

$$x_n = \frac{1}{\sqrt{JN}} \sum_{k=0}^{JN-1} X_k e^{j2\pi \frac{nk}{JN}}, \quad n = 0,\ 1,\ \ldots,\ JN-1. \quad (2)$$

Usually, $J \geq 4$ is used to approximate the peaks of the continuous time domain signal. The PAPR of the time domain OFDM symbol is defined as the ratio of maximal instantaneous power to the average power as

$$PAPR = \frac{\max\limits_{0\leq n \leq JN-1} |x_n|^2}{E[|x_n|^2]}, \quad (3)$$

where $E[\cdot]$ denotes the expectation operator.

2.2. SLM scheme

In SLM, the original OFDM symbol is multiplied with M phase rotation sequences to produce M statistically independent sequences representing the same information. Of these, the sequence with the lowest PAPR is selected for transmission. The M candidate signals can be represented as

$$\mathbf{X}_i = [P_0^i X_0\ P_1^i X_1\ \ldots\ P_{N-1}^i X_{N-1}]^T = \mathbf{P}^i \mathbf{X}, \quad (4)$$

where $\mathbf{P}^i$ is the phase rotation matrix with diagonal elements $P_n^i = e^{j\theta_n^i}$ representing ith randomly generated phase $\theta_n^i \in [0,\ 2\pi)$ with $i = 0, 1, \ldots, M-1$ and $n = 0, 1, \ldots, N-1$.

2.3. CM based SLM scheme

The time domain OFDM signal can be expressed as

$$\mathbf{x} = \mathbf{Q}\mathbf{X}, \quad (5)$$

where $\mathbf{Q}$ is the $JN \times JN$ IFFT matrix with elements $q_{n,k} = (1/JN)^{1/2} e^{j2\pi nk/JN}$. Furthermore, the ith candidate signal in the time domain generated by the SLM method can be expressed as

$$\mathbf{x}_i = \mathbf{Q}\mathbf{P}^i \mathbf{X}, \quad (6)$$

where $\mathbf{P}^i$ is the ith phase rotation matrix. Eq. (6) can be represented as

$$\mathbf{x}_i = \mathbf{Q}\mathbf{P}^i \mathbf{Q}^{-1} \mathbf{x}. \quad (7)$$

From Eq. (7), the CM $\mathbf{G}^i$ is defined as $\mathbf{G}^i = \mathbf{Q}\mathbf{P}^i\mathbf{Q}^{-1}$. From the convolution property, the time domain vector $\mathbf{x}_i$ can be obtained by taking a circular convolution operation of the IFFT of the phase rotation vector and the original time domain OFDM signal. Note that the circular convolution operations can be replaced with simple multiplication operations through the use of a circulant matrix. Thus, we can express Eq. (7) as [2]

$$\mathbf{x}_i = \mathbf{G}_c^i \mathbf{x}, \quad (8)$$

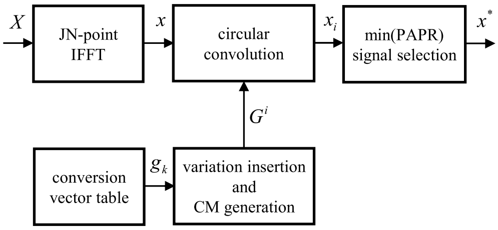

Fig. 1. Block diagram of CM based SLM.

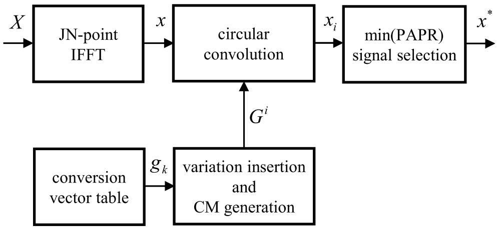

Fig. 2. Block diagram of the proposed scheme.

where

$$\mathbf{G}_c^i = [G^i\ G_{\langle 1\rangle}^i\ G_{\langle 2\rangle}^i\ \cdots\ G_{\langle JN-1\rangle}^i], \quad (9)$$

where $G_{\langle u\rangle}^i$ is a circularly down shifted version of the column vector G^i by u elements. To reduce the computational complexity of the CMSLM approach, the following conditions are applied to all the CMs used for generating candidate signals [2]: (1) The number of nonzero elements is restricted to four and (2) The nonzero values are selected from ± 1, $\pm j$. When these conditions are satisfied, only $3JN$ complex additions are needed without any complex multiplications.

Fig. 1 shows the block diagram of the CMSLM scheme and one can see that only one IFFT module is required. However, compared to the SLM scheme, an additional variation insertion operation is required. Based on this additional operation, alternative candidate signals are generated through operations such as adjusting the number of zero elements between the nonzero values in conversion vectors as shown below [2]:

$$\begin{aligned}\mathbf{G}^n = \Bigg[& g_0\ zeros\left(\frac{JN}{2^{n+2}}-1\right)\ g_1\ zeros\left(\frac{JN}{2^{n+2}}-1\right)\ g_2 \\ & zeros\left(\frac{JN}{2^{n+2}}-1\right)\ g_3\ zeros\left(\frac{JN}{2^{n+2}}-1\right) \\ & zeros\left(JN-\frac{JN}{2^n}\right)\Bigg],\end{aligned} \quad (10)$$

where $n = 0, 1, \ldots, \log_2(JN/4)$, g_k is the nonzero value of a conversion vector from the conversion vector table, and $zeros(m)$ is a row vector with m zero elements.

3. Proposed method

In the proposed method, a GA is employed to search for a set of optimal CMs used to generate candidate signals based on one-IFFT module structure of the CMSLM scheme. As shown in Fig. 2, the GA module in the proposed scheme replaces the exhaustive search operation of conversion vectors and random variation insertion of the CMSLM scheme with a search process consisting of genetic encoding of nonzero values and spacing parameters. The chromosomes used in the proposed algorithm consist of two genes representing the possible nonzero values and spacing parameters for constructing a CM. The binary encoded chromosome can be represented as a $1 \times (K + R)$ vector as follows.

$$\mathbf{C}^i = [a_1\ a_2\ \ldots\ a_K\ b_1\ b_2\ \ldots\ b_R], \tag{11}$$

where $a_k \in (0, 1)$ represents the possible nonzero values from $(\pm 1, \pm j)$ and $b_r \in (0, 1)$ represents the possible number of zeros between the nonzero values, g_k. To satisfy the complexity conditions of the CM in [2], the number of nonzero elements is fixed to four, resulting in $K = 8$ to represent all 256 combinations. Furthermore, the number of zeros is selected from $(0, R)$, where $R = JN/4 - 1$. Based on the GA module output, the CM can be expressed as

$$\mathbf{G}^i = [g_0\ zeros(h)\ g_1\ zeros(h)\ g_2\ zeros(h)\ g_3\ zeros(h)\ zeros(JN - 4(h+1))], \tag{12}$$

where h is selected from $(0, JN/4 - 1)$ and $zeros(w)$ is a row vector with w zero elements. As for the evaluation function for calculating a fitness value for a conversion vector set, a criterion based on the mathematical correlation analysis proposed in [6] for calculating low variance of correlation (VC) is used in the proposed scheme. VC is defined as [6]

$$VC = \left(\sum_{0 \le u < v \le M-1} Var\left\{ |R_{uv}(\tau)|^2 \right\}_{\tau=0}^{N-1} \right) \Big/ \binom{M}{2}, \tag{13}$$

where $Var\{\bullet\}$ denotes the variance and $R_{uv}(\tau)$ denotes the correlation between any two alternative conversion vectors u and v. The detailed procedure for optimum CM generation in the proposed SLM scheme based on the GA is described below.

1. Initialize evolution related parameters: The population size D, the crossover rate p_c, the mutation rate p_m, and the maximal iteration number L are set.
2. Generate initial population: D chromosomes are generated with random binary bits representing nonzero values and spacing between the nonzero values in CMs.
3. Evaluate and assign fitness to the population: Based on the binary encoded nonzero values and spacing information in each chromosome, D conversion vectors are generated. Using the VC criteria, calculate i fitness values corresponding to a conversion vector set when a conversion vector based on chromosome $\mathbf{C}_i$ is excluded from the set, where $i = 1, 2, \ldots, D$.
4. Generate next-generation population: Tournament selection method is used for the crossover operation to select parent chromosomes and produce offsprings. $D/2$ parent chromosomes with the highest fitness values and $D/2$ child chromosomes with the highest fitness values are combined to create the new population.
5. Mutation operation is applied to the new population through random bit alterations.
6. If the maximum iteration count L has not been reached, the process of evaluation, selection, recombination, and mutation is repeated.

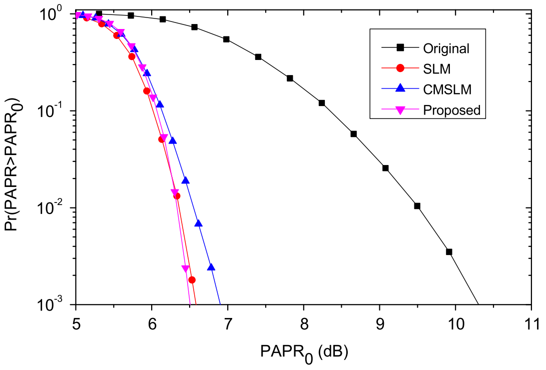

Fig. 3. PAPR CCDF comparison of the original OFDM, SLM, CMSLM, and proposed method with $N = 64$ and 16-QAM modulation.

7. Obtain the circulant conversion matrix based on the final population: The circulant conversion matrix is obtained by circularly down shifting the conversion vector.

4. Simulation results

In this section, we evaluate the PAPR reduction performance of the proposed method based on computer simulations. The considered OFDM system has $N = 64$ subcarriers with 16-QAM modulation and the oversampling rate was set to $J = 4$. For comparison purposes, simulation results were obtained for the original OFDM system, the conventional SLM scheme, the CMSLM [2], and the proposed SLM scheme based on the GA. For the SLM method, $M = 32$ candidate signals are generated based on random phase set $\theta_n^i \in \{0, \pi/2, \pi, 2\pi\}$. For CMSLM, $M = 32$ candidate signals are generated based on conversion matrices listed in Table IV of [2]. As for the proposed scheme, the population size was set to $D = 32$. Furthermore, the crossover rate, the mutation rate, and the maximal iteration rate number were set to $p_c = 0.7$, $p_m = 0.05$, and $L = 30$, respectively. Fig. 3 shows the PAPR reduction performance of the original OFDM system, the conventional SLM scheme, the CMSLM scheme, and the proposed SLM scheme using the complementary cumulative distribution function (CCDF) defined as $CCDF_{PAPR} = Pr(PAPR > PAPR_0)$, where $PAPR_0$ is a given clip level. It is shown that at $CCDF = 10^{-3}$, the PAPR reduction achieved by SLM based schemes is quite significant with values greater than 3 dB compared to that of the original OFDM signal. However, the proposed SLM scheme shows the highest PAPR reduction among all the SLM schemes with only one IFFT module. Fig. 4 compares the BER performance of the proposed technique to that of SLM, CMSLM, and the original OFDM signal over an additive white Gaussian noise (AWGN) channel. From the figure, we can see that CMSLM and the proposed method have almost similar BER performance.

5. Conclusion

In this paper, we proposed a new CMSLM method based on a GA. The proposed scheme requires only one IFFT module and provides an optimum candidate signal set by genetic

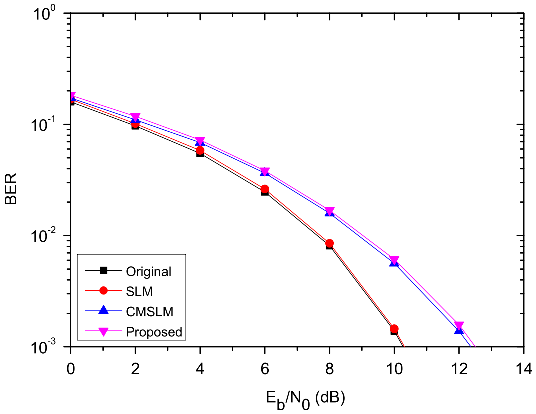

Fig. 4. BER comparison of the original OFDM, SLM, CMSLM, and proposed method with $N = 64$ and 16-QAM modulation over AWGN channel.

encoding of CM related parameters. From the simulation results, it was observed that the proposed scheme achieves significant PAPR reduction performance improvement compared to the conventional SLM and the CMSLM schemes.

Acknowledgment

This work was supported by the Dongguk University Research Fund.

References

[1] R.W. Bauml, R.F.H. Fisher, J.B. Huber, Reducing the peakto-average power ratio of multicarrier modulation by selected mapping, Electron. Lett. 32 (22) (1996) 2056–2057.

[2] C.-L. Wang, Y. Ouyang, Low-complexity selected mapping schemes for peak-to-average power ratio reduction in OFDM systems, IEEE Trans. Signal Process. 53 (12) (2005) 4652–4660.

[3] J.-Y. Woo, H.S. Joo, K.-H. Kim, J.-S. No, D.-J. Shin, PAPR analysis of class-III SLM scheme based on variance of correlation of alternative OFDM signal sequences, IEEE Commun. Lett. 19 (6) (2015) 989–992.

[4] J. Koza, Genetic Programming: On the Programming of Computers by Means of Natural Selection, MIT Press, 1992.

[5] W.C. Lee, J.P. Choi, C.K. Huynh, A modified tone injection scheme for PAPR reduction using genetic algorithm, ICT Express 1 (2) (2015) 76–81.

[6] P. Cheng, Y. Xiao, L. Dan, S. Li, Improved SLM for PAPR reduction in OFDM system, in: Proc. 2007 IEEE Symp. Personal, Indoor, and Mobile Radio Commun., pp. 1–5.