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

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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

$$\mathbf{X} = [X_0 \ \dots \ X_{N/2-1} \ 0 \ \dots 0 \ X_{N/2} \ \dots \ X_{N-1}]^T \quad (1)$$

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

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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]

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

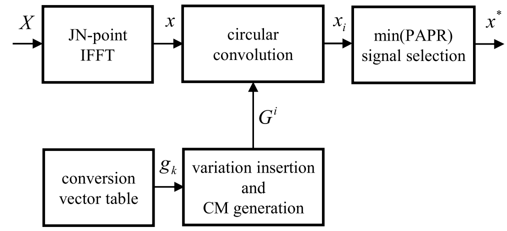

Fig. 1. Block diagram of CM based SLM.

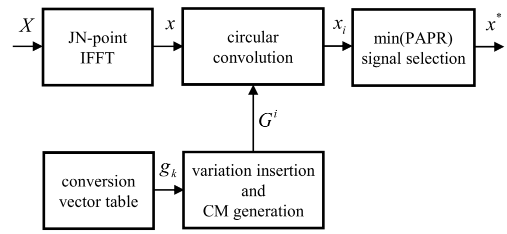

Fig. 2. Block diagram of the proposed scheme.

where

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

where $G^i_{\langle u\rangle}$ 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]:

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

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