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Blind selective mapping for single-carrier frequency division multiple access system

M.A. Abd El-Hamed [a], Abdelhalim Zekry [b], Salah S. Elagooz [a], Fathi E. Abd El-Samie [c]

[a] Department of Communications and Computer, Higher Institute of Engineering, Elshorouk Academy, Elshorouk City, Egypt
[b] Department of Electronics and Electrical Communications, Faculty of Engineering, Ain Shams University, Cairo, Egypt
[c] Department of Electronics and Electrical Communications, Faculty of Electronic Engineering, Menoufia University, Menouf, Egypt

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ABSTRACT

Single-Carrier Frequency Division Multiple Access (SC-FDMA) signals have a Peak-to-Average Power Ratio (PAPR) problem. So, there is a need for PAPR reduction techniques to be implemented on these signals. The PAPR becomes larger as the modulation order increases. Recently, Conventional Selective Mapping (C-SLM) has been used to reduce the PAPR of SC-FDMA signals. Unfortunately, the standard C-SLM technique requires the transmission of Side Information (SI) to the receiver side. In this paper, a Blind Selective Mapping (B-SLM) technique is proposed to reduce the PAPR in the SC-FDMA system, where there is no change in the C-SLM algorithm at the transmitter and no necessity for SI transmission. Our simulation results show that the PAPR performance of the proposed B-SLM technique is approximately the same as that of the C-SLM technique. The proposed technique is applied to the SC-FDMA system for Single-Input Single-Output (SISO) and Multiple-Input Multiple-Output (MIMO) scenarios. The proposed B-SLM technique provides a reduction in bandwidth without a significant degradation in the Bit-Error Rate (BER) performance. Also, we present a comparison in the PAPR performance between the B-SLM and the other PAPR reduction techniques such as the Partial Transmit Sequence (PTS) and the C-SLM.

1. Introduction

The SC-FDMA is a popular uplink technology in Long Term Evolution (LTE) due to its low PAPR [1] compared with Orthogonal Frequency-Division Multiplexing (OFDM), but the SC-FDMA still suffers from the PAPR problem. Specifically, the SC-FDMA can be considered as an improved OFDM technique. High-order modulations are suggested to achieve high spectral efficiency in 5G because of the small cells, where the Signal-to-Noise Ratio (SNR) may be very high [2]. However, the high-order modulations cause large PAPR in the SC-FDMA signals, especially for interleaved SC-FDMA (IFDMA) with a small roll-off factor [3]. The large PAPR results in low efficiency with a need for high-power amplifiers and leads to failure in satisfying the 5G requirements regarding energy efficiency [4]. Additionally, a low PAPR is desired in battery-oriented terminals because of the power limitations [5]. Hence, there is a need for efficient PAPR reduction schemes for SC-FDMA systems.

The major difference between SC-FDMA and OFDM is that a secondary orthogonal transformation is required for generating SC-FDMA signals. The transformation comprises N-point Discrete Fourier Transforms (DFTs) and M-point Inverse Discrete Fourier Transforms (IDFTs). On the other hand, OFDM signals can be generated through an M-point IDFT, only. Despite the better PAPR performance of SC-FDMA systems compared to OFDM systems, the power variations during signal transmission resemble those of a multi-carrier transmission. Thus, there is still a need for PAPR reduction in SC-FDMA systems.

Recently, the C-SLM technique has been utilized for PAPR reduction [6]. In this technique, several candidate transmit blocks are generated by applying phase rotation on subcarriers after the DFT. The C-SLM can effectively reduce the PAPR of the SC-FDMA signals, but it requires transmission of SI, which is not recommended. The C-SLM without explicit SI has been widely studied for OFDM signal transmission [7–9].

In this paper, we present a B-SLM technique and apply it to interleaved SC-FDMA (IFDMA) and localized SC-FDMA (LFDMA) systems with different phase sequences (U) as a PAPR reduction technique for SISO and MIMO scenarios. The rest of this paper is organized as follows. Section 2 discusses the conventional SC-FDMA system model. Section 3 reviews the time-domain C-SLM technique. Section 4 presents the proposed B-SLM PAPR reduction

E-mail addresses: mohabdelhamed@yahoo.com (M.A. Abd El-Hamed), aaazekry@hotmail.com (A. Zekry), gselagooz@gmail.com (S.S. Elagooz), fathi_sayed@yahoo.com (F.E. Abd El-Samie).

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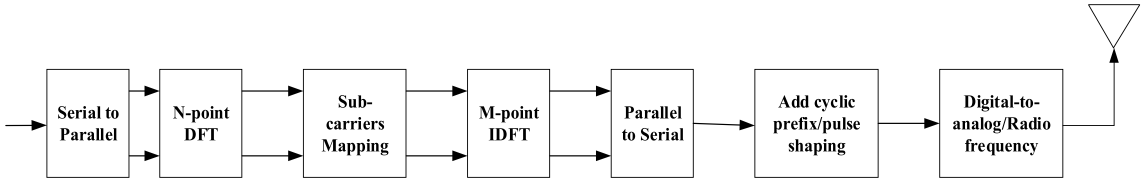

Fig. 1. Block diagram of the SC-FDMA transmitter.

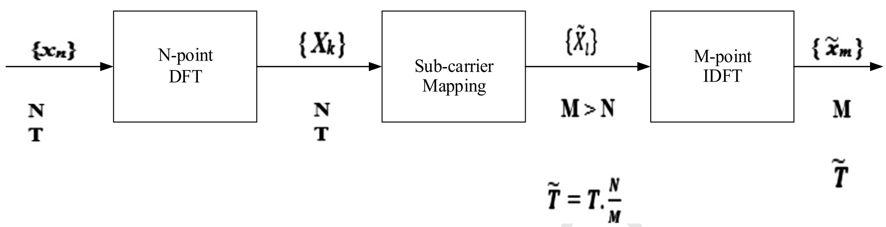

Fig. 2. Generation of SC-FDMA transmit symbols. There are M total subcarriers, among which N ($< M$) subcarriers are occupied by the input data.

technique. Section 5 gives the simulation results. Finally, Section 6 gives the concluding remarks.

2. Conventional SC-FDMA system model

Fig. 1 shows the schematic diagram of the SC-FDMA system. It is possible to refer to SC-FDMA as DFT-spread OFDMA, where time-domain data symbols are converted to frequency domain by DFT before going through OFDMA modulation. Each user occupies different subcarriers in the frequency domain to achieve the orthogonality of the users. As a result, the PAPR is inherently reduced compared to the PAPR of OFDMA, which is based on multicarrier signals.

Generation of the symbols to be transmitted with SC-FDMA is illustrated in Fig. 2. There are in total M subcarriers, and each user is given a subset of subcarriers for the uplink transmission. For simplicity, we assume that each user has the same number of subcarriers N such that $N < M$. The input data symbol in the time domain has a symbol duration of T seconds, which after going through SC-FDMA modulation is compressed to $\tilde{T} = (\frac{N}{M}).T$.

Analysis of the PAPR of the SC-FDMA system in the case of IFDMA subcarriers mapping mode is presented in this section. In the subsequent derivations, we will assume that $M = Q.N$ and follow the notations in Fig. 2, where Q is the bandwidth spreading factor.

Let $\{\mathbf{x_n} : n = 0, 1, \ldots, N-1\}$ be the data symbols to be modulated. So, $\{\mathbf{X_k} : k = 0, 1, \ldots, \ N-1\}$ represents the frequency-domain samples after DFT of $\{\mathbf{x_n} : n = 0, 1, \ldots, N-1\}$, $\{\check{\mathbf{X}}_\mathbf{l} : l = 0, 1, \ldots, M-1\}$ represents the frequency-domain samples after subcarriers mapping, and $\{\tilde{\mathbf{x}}_\mathbf{m} : m = 0, 1, \ldots, M-1\}$ represents the time-domain symbols after IDFT of $\{\tilde{\mathbf{X}}_\mathbf{l} : l = 0, 1, \ldots, M-1\}$. The complex passband transmit SC-FDMA signal, $x(t)$, for a block of data is represented as [10]:

$$x(t) = e^{i\omega_c t} \sum_{m=0}^{M-1} \tilde{x}_m r(t - m\tilde{T}) \tag{1}$$

where ω_c is the carrier frequency of the system and $r(t)$ is the baseband pulse. In our research, a raised-cosine (rc) pulse shaping filter, which is widely implemented in wireless communications, is used. It is defined in the time domain as follows [10],

$$r(t) = sinc\left(\pi \frac{t}{\tilde{T}}\right) \frac{\cos\left(\frac{\pi\alpha t}{\tilde{T}}\right)}{1 - \frac{4\alpha^2 t^2}{\tilde{T}^2}} \tag{2}$$

where α is the roll-off factor, which ranges from 0 to 1.

The PAPR for the transmit signal $x(t)$ in the case of rc pulse shaping is defined as follows, [10]

$$PAPR = \frac{\text{Peak power of } x(t)}{\text{Average power of } x(t)} = \frac{\max_{0 \le t \le M\tilde{T}} |x(t)|^2}{\frac{1}{M\tilde{T}} \int_0^{M\tilde{T}} |x(t)|^2 dt} \tag{3}$$

Without pulse shaping, the PAPR is expressed as follows [10],

$$PAPR = \frac{\max_{m=0,1,\ldots,M-1} |\tilde{x}_m|^2}{\frac{1}{M} \sum_{m=0}^{M-1} |\tilde{x}_m|^2} \tag{4}$$

3. Time-domain C-SLM

In this section, we will describe the SC-FDMA system based on time-domain C-SLM as a PAPR reduction technique. The structure of this system is shown in Fig. 3 [11,12].

Clipping techniques have been widely used as PAPR reduction techniques, but they cause signal distortion [13,14]. On the other hand, the most popular distortionless PAPR reduction techniques are the C-SLM and the PTS. Actually, the PTS has higher computational complexity than that of the SLM. However, it achieves more PAPR reduction [15].

In the time-domain C-SLM technique, the input data block can be expressed as [12],

$$\mathbf{x_n} = \left[x[0], x[1], \ldots, x[N-1]\right]^T \tag{5}$$

It is multiplied by U different phase sequences represented as [12],

$$\mathbf{b_n^u} = \left[\mathrm{b_0^u}, \mathrm{b_1^u}, \ldots, \mathrm{b_{N-1}^u}\right]^T \tag{6}$$

where each $b_n^u = e^{j\emptyset_n^u}$ and $\emptyset_n^u \in [0, 2\pi]$. The $\emptyset_n^u$ is a random discrete value in the range of 0 to 2π for $n = 0, 1, \ldots, N-1$ and $u = 0, 1, \ldots, U-1$ to produce a modified data block, which is denoted as [12],

$$\mathbf{x_n^u} = \left[x_n^u[0], x_n^u[1], \ldots, x_n^u[N-1]\right]^T \tag{7}$$

By applying the N-point DFT, ($\mathbf{F_N}$), each block is converted to the frequency domain, and it can be represented as [12],

$$\mathbf{X_k^u} = \mathbf{F_N}\mathbf{x_n^u} = \left[X_0^u, X_1^u, \ldots, X_{N-1}^u\right]^T \tag{8}$$

where $[F_n]_{k.n} = e^{\frac{j2\pi kn}{N}}$

After that, each $\mathbf{X}$ is delivered to the subcarriers mapping step and the M-point IDFT, $(\mathbf{F_M})^{-1}$, which produces [12],