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Nonlinear L_2-by-3 transform for PAPR reduction in OFDM systems ☆

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM), the multicarrier modulation technique with high bandwidth efficiency and robustness against multipath fading, is used in several high-speed broadband communication systems including digital video broadcasting (DVB), digital audio broadcasting (DAB), asymmetric digital subscriber line (ADSL), wireless local area network (WLAN IEEE 802.11a,g), high performance radio local area network (HIPERLAN 2), and worldwide interoperability for microwave access (WiMAX IEEE 802.16). However, the transmit signal in OFDM system has a high peak-to-average power ratio (PAPR), one of the major drawbacks of multicarrier transmission, and therefore high dynamic range is required in both the digital to analog converter (DAC) and the power amplifier (PA) for proper operation. Otherwise, the nonlinearities of PA cause out-of-band distortion and increase in bit error rate (BER). Therefore, the reduction in PAPR in OFDM system is desirable in order to obtain power efficiency and increase BER performance. In this paper, a new parametric PAPR reduction technique, L_2-by-3 transform from *sliding norm transform (SNT)* family is proposed. Based on its parameter, a significant PAPR reduction is obtained. This paper presents the analysis of power saving and computational complexity of the proposed method L_2-by-3 and comparison to two other methods; selected mapping and partial transmit sequence.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is very suitable multicarrier modulation method for high-speed communication systems because it provides high bandwidth efficiency and robustness against multipath fading channel. This is due to its nature which divides the wideband channel into flat narrowband subchannels. However, the transmit signal in OFDM system has a high peak-to-average power ratio (PAPR) and therefore high dynamic range is required in both the digital to analog converter (DAC) and the power amplifier (PA) for proper operation. Basically, the maximum amplitude of the OFDM signal at the input of PA must be below the maximum operating point of the PA; 1 dB compression point usually set 1 dB below the PA's saturation level in order to avoid distortions because of nonlinearities of PA. This requirement is met by applying backoff power which reduces the efficiency of PA. Otherwise high PAPR signal can cause an increase in bit error rate (BER) and out-of-band distortion that is limited by regulatory agencies. Thus, the reduction in PAPR in OFDM system is desirable in order to obtain power efficiency and increase BER performance.

Several methods have been proposed to solve the PAPR reduction problem in OFDM systems. Some of the important PAPR reduction methods; amplitude clipping and filtering, coding, partial transmit sequence (PTS), selected mapping (SLM), interleaving, tone reservation (TR), tone injection (TI), and active constellation extension (ACE) are overviewed in [8]. PAPR

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reduction is achieved by these methods at the expense of loss in data rate, increase in computational complexity, transmit signal power and BER. For example, TR, TI, and ACE require a power increase in the transmit signal after PAPR reduction employed. SLM and PTS require a side information to be sent to receiver which results in extra power consumption and loss in data rate. In PTS, SLM, and interleaving, the data bits may be lost if the side information is received with error, therefore BER may increase. The computational complexity is another important factor in PAPR reduction. The complexity is increased at both transmitter and receiver for the methods coding, PTS, SLM, interleaving, TR, and TI. These methods have different PAPR reduction capability and computational complexities. It is important to consider the analysis of power saving in PA due to PAPR reduction and power consumption of implementation due to computational complexity [10]. In this paper, a new parametric PAPR reduction method, L_2-by-3 *sliding norm transform (SNT)*, is proposed. Based on its parameter α, a significant PAPR reduction is obtained. Power saving analysis and computational complexity of L_2-by-3, SLM and PTS are presented.

The major contributions of this paper can be summarized as follows. PAPR reduction and PA efficiency are achieved at the expense of lower computational complexity, the performance of the system is improved in both BER and out-of-band distortion without any loss in data rate or increase in transmit signal power because the proposed method does not require any side information.

The rest of the paper is organized as follows. In Section 2, the OFDM system and definition of PAPR is introduced and two distortionless PAPR reduction methods SLM and PTS are reviewed. In Section 3, a new nonlinear transform, *sliding norm transform (SNT)*, is described and one of the member of SNTs L_2-by-3 method, is proposed for PAPR reduction. In Section 4, performance criteria is defined for PAPR reduction methods and the performance of OFDM system with proposed method is presented. Section 5 presents the conclusions.

2. OFDM system and PAPR definition

In OFDM system, transmission bandwidth is divided into N orthogonal subcarriers, each modulated by quadrature-amplitude (QAM) or phase-shift keying (PSK) modulation. N data symbols modulated by QAM/PSK are applied to inverse discrete Fourier transform (IDFT) to obtain the time domain OFDM signal as in Fig. 1. The complex baseband OFDM signal $x(t)$ is given by

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{j2\pi k \Delta_f t}, \quad 0 \leqslant t \leqslant NT, \tag{1}$$

where $\Delta_f = \frac{1}{NT}$ is orthogonal subcarrier spacing and $X[k]$ are data symbols modulated on each subcarrier. The PAPR of a continuous-time signal is given by Eq. (2):

$$\text{PAPR} = \frac{\max |x(t)|^2}{E\left[|x(t)|^2\right]}. \tag{2}$$

In order to represent PAPR in discrete-time precisely, *L-times oversampled* $x(t)$ is considered, where $L = 1$ denotes the Nyquist rate sampling signal. $L = 4$ can provide sufficiently accurate PAPR results [8]:

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{j2\pi k n \Delta_f T/L}, \quad n = 0, 1, \ldots, NL-1. \tag{3}$$

In Eq. (3), the discrete-time signal $x[n]$ is interpreted as inverse discrete Fourier transform (IDFT) of $X[k]$ with $(L-1)N$ zeros padding [8] therefore for a discrete-time signal PAPR is given by

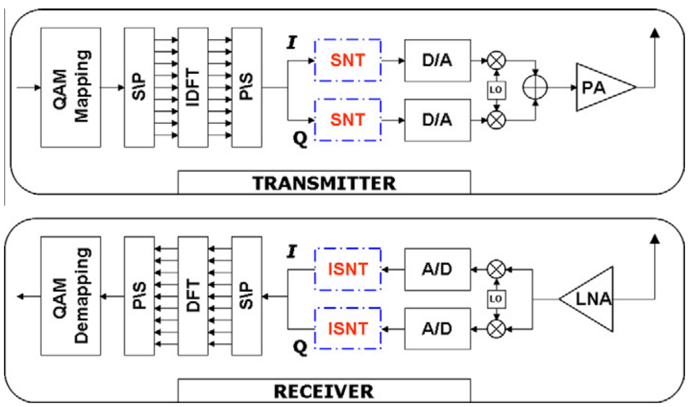

Fig. 1. OFDM transceiver architecture.