Physical Communication 29 (2018) 103–111

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

Full length article

Performance analysis of hybrid PAPR reduction technique for LTE uplink communications

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ARTICLE INFO

Article history:
Received 20 September 2017
Received in revised form 2 May 2018
Accepted 6 May 2018

Keywords:
Clipping
Companding
Hybrid
LTE
PAPR
SC-FDMA

ABSTRACT

Long Term Evolution standard implemented Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink communications due to its low peak to average power ratio (PAPR). But for higher order modulations, there is a need for further reduction of PAPR in SC-FDMA systems. There are numerous techniques to decrease PAPR, but clipping and companding techniques are very simple to implement without any side information. μ law companding provides good PAPR reduction but increases the average power of companded signal. In this paper, the distribution of SC-FDMA signal is approximated, and a companding technique is proposed to transform the approximated distribution into a uniform distribution, which reduces PAPR without increasing average power of the signal. For further improvement in PAPR, a hybrid technique is also proposed where the companded signal is clipped to a specific threshold value. Simulation results show that PAPR reduction achieved by the proposed companding technique is better than that of μ law companding with a slight degradation in bit error rate (BER) performance. The proposed companding technique with no decompanding operation has better BER performance when compared to that with approximated decompanding operation. The hybrid technique further reduces PAPR with similar BER performance as that of proposed companding technique by carefully choosing the clipping ratio.

1. Introduction

Single carrier frequency division multiple access (SC-FDMA) is being implemented by long term evolution (LTE) standard in the uplink communications [1]. SC-FDMA has low peak-to-average power ratio (PAPR) when compared to that of orthogonal frequency division multiple access (OFDMA) due to lower signal envelope fluctuations in SC-FDMA signal [2]. But there is a need for further improvement in PAPR in localized SC-FDMA systems, especially for higher order modulations [3]. To meet high PAPR requirements, we need highly linear power amplifiers and high-resolution D/A converters. But they reduce power efficiency and require additional complexity and cost. This problem is serious in the uplink communications, as the mobile terminals are power limited [4].

Pulse shaping, selected mapping, partial transmit sequence, pre-coding and peak insertion techniques [5–10] are some of the methods to reduce PAPR. But these techniques are either complicated or, in need of excess bandwidth for the transmission of side information. Companding is one simple method to reduce PAPR, owing to its low implementation complexity. Besides, it does not require any side information to be transmitted. μ law companding is one of the most popular companding techniques used to reduce PAPR. In [11], authors used μ law companding to reduce PAPR in SC-FDMA systems. But it increases the average power of companded signal. In power function [12], raised cosine-like companding [13] and new error function companding [14] techniques, the authors assumed that an SC-FDMA signal follows a Gaussian distribution. But in [15] authors proved that amplitude of SC-FDMA signal does not have a Gaussian distribution. Moreover, these techniques provide a PAPR reduction of at most 4.5 dB at CCDF $= 10^{-4}$ when compared to the original system. In this paper, the distribution of SC-FDMA signal is approximated by using curve fitting tool and then a companding technique is proposed to transform it into a uniform distribution. Simulation results show that proposed technique provides better PAPR reduction when compared to that of μ law companding without increasing average signal power. But proposed companding technique degrades BER performance of the system due to the approximated decompanding operation at the receiver side. In [16], the authors proposed to abandon the decompanding operation at the receiver and concluded that the proposed companding technique with no decompanding operation can also offer a good BER performance. For further improvement in

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https://doi.org/10.1016/j.phycom.2018.05.005

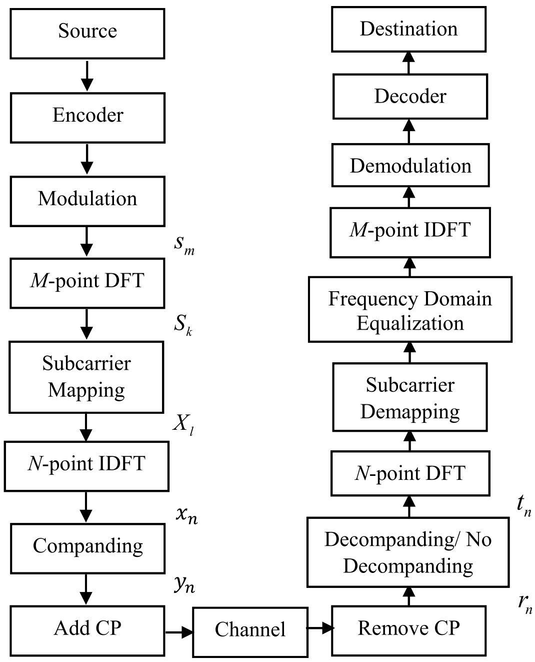

Fig. 1. Single carrier FDMA system with companding.

PAPR, a hybrid technique is also proposed where the companded signal is clipped to a specific threshold value.

The rest of the paper is structured as follows. Section 2 describes the approximation of SC-FDMA distribution and SC-FDMA system with proposed companding technique. Section 3 describes the hybrid companding and clipping technique. Section 4 presents the PAPR and BER results of proposed companding and hybrid techniques. Section 5 provides relevant closing comments on the paper.

2. SC-FDMA system with companding

SC-FDMA transmitter with companding technique is shown in Fig. 1. The encoded input is modulated by using one of the available modulation techniques, such as QPSK, and QAM. These symbols are then passed through an M-point DFT to produce

$$S_k = \sum_{m=0}^{M-1} s_m e^{-j\frac{2\pi mk}{M}} \tag{1}$$

where s_m $(m = 0, 1, \ldots, M-1)$ are the modulated symbols, and S_k $(k = 0, 1, \ldots, M-1)$ are DFT of s_m. These M symbols are then mapped to N subcarriers $(N > M)$.

For subcarrier mapping in SC-FDMA systems, we have two techniques namely, Distributed FDMA (DFDMA) and Localized FDMA (LFDMA). Interleaved FDMA (IFDMA) is one realization of DFDMA. In DFDMA, the subcarriers are spread over the entire bandwidth with zeros occupying the unused subcarriers, whereas in LFDMA each terminal transmits its symbols over consecutive subcarriers.

In distributed mode when the subcarriers are equidistantly occupied with $N = Q.M$, then it is called IFDMA. Here Q is bandwidth expansion factor. So the system can handle Q simultaneous transmissions without co-channel interference. For localized subcarrier mapping, X_l is given by

$$X_l = \begin{cases} S_k(l), & 0 \le l \le M-1 \\ 0 & otherwise \end{cases} \tag{2}$$

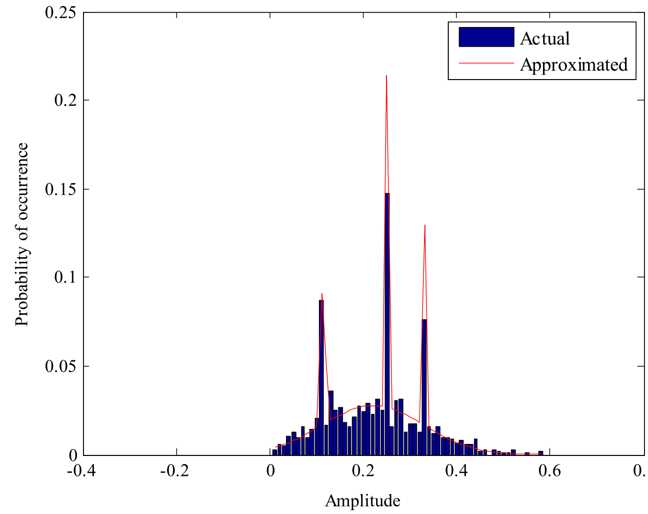

Fig. 2. Actual and approximated distributions of SC-FDMA signal magnitude.

Table 1
Goodness-of-Fit Statistics.

Statistic	Value	Ideal value for better fit
The sum of squares due to error (SSE)	0.0004771	0
R-square	0.9841	1
Adjusted R-square	0.9795	1
Root mean squared error (RMSE)	0.003543	0

where $l = 0, 1, 2, \ldots, N-1$. After subcarrier mapping, X_l is passed through N-point IDFT and the resulting time domain complex signal x_n is given by

$$x_n = \frac{1}{N} \sum_{l=0}^{N-1} X_l e^{j\frac{2\pi}{N}nl}, \; n = 0, \ldots, N-1 \tag{3}$$

Now, the time domain LFDMA signal is given by [17]

$$\begin{aligned} x_n &= x_{Qm+q} \\ &= \begin{cases} \dfrac{1}{Q} s(n)_{\mathrm{mod}\,M}, & q = 0 \\ \dfrac{1}{Q}\left(1 - e^{j2\pi q/Q}\right) \dfrac{1}{M} \displaystyle\sum_{p=0}^{M-1} \dfrac{s_p}{1 - e^{j2\pi\left\{\frac{m-p}{M} + \frac{q}{QM}\right\}}}, & q \neq 0 \end{cases} \end{aligned} \tag{4}$$

where $n = Qm + q, 0 \le m \le M-1, 0 \le q \le Q-1$ and $N = Q.M$.

2.1. Approximation of SC-FDMA distribution

Here, we plotted Probability Density Function (PDF) of the magnitude of LFDMA signal, $|x_n|$ using MATLAB simulations and obtained its expression from the curve fitting tool. The exact and approximated functions are shown in Fig. 2.

The PDF of the magnitude of SC-FDMA signal can be approximated by a sum of Gaussian functions instead of a single Gaussian function as given below.

$$f_{|x_n|}(x) = \sum_{i=1}^{4} a_i e^{-\left(\frac{x-b_i}{c_i}\right)^2}, \quad x \ge 0 \tag{5}$$

The values a_i, b_i and c_i are obtained from curve fitting tool. We considered 50 samples for curve fitting and the goodness of our approximation is described by the statistics given in Table 1.