A SLM based localized SC-FDMA uplink system with reduced PAPR for LTE-A

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Received 11 October 2011; accepted 16 April 2012

KEYWORDS
Selected mapping (SLM); Peak-to-average power reduction (PAPR); Single carrier frequency division multiple access (SC-FDMA); QPSK

Abstract This paper presents a selected-mapping (SLM) based peak-to-average power ratio (PAPR) reduction technique for the localized single carrier frequency division multiple access (LFDMA) uplink system. The SLM is a distortionless technique as it selects the transmit signal with low PAPR from a set of alternative signals representing the same information. Extensive Matlab simulations have been carried out to validate the proposed idea. At the clip rate of $10^{-4}$ with user’s subcarriers $M = 16$, system’s subcarriers $N = 512$ and dissimilar phase sequences $V = 32$: the PAPR gain of the proposed SLM based LFDMA system is 7.8 dB and 3.8 dB respectively, when compared with the conventional localized orthogonal frequency 18 division multiple access (OFDMA) uplink systems and the conventional LFDMA uplink systems for QPSK modulation.

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1. Introduction

Single carrier frequency division multiple access (SC-FDMA) has been adopted for the uplink communications in release 8 LTE. SC-FDMA utilizes single carrier modulation with frequency domain equalization (FDE) at the receiver. The main advantage of using SC-FDMA over the orthogonal frequency division multiple access (OFDMA) is its low peak-to-average power ratio (PAPR) (3GPP, 2007). In 3GPP (2007) the long term evolution advanced (LTE-Advanced) requirements were agreed but the radio interface schemes are still debatable. However, the SC-FDMA uplink system still has PAPR problem. The transmitted localized SC-FDMA (LFDMA) uplink signals have higher PAPR as compared to the interleaved SC-FDMA (IFDMA) uplink signals (Myung et al., 2006).

The literature is replicated with the selected-mapping (SLM) and its different variants for PAPR reduction in the OFDM (Bäuml et al., 1996; Lim et al., 2005; Park et al., 2011; Baig and Jeoti, 2010, 2011), OFDMA (Wang et al., 2011) and MC-CDMA (Wang et al., 2007) systems respectively. There is room for SLM implementations with the SC-FDMA uplink systems to reduce the PAPR. In this paper, we present a SLM based LFDMA uplink system with reduced PAPR. This paper is organized as follows: Section 2 presents the proposed SLM based LFDMA uplink system model for PAPR reduction, and Section 3 presents computer simulation results and Section 4 concludes the paper.
2. SLM based LFDMA Uplink system

Fig. 1 shows the block diagram of the proposed SLM based LFDMA uplink system. Suppose the data stream after S/P conversion is \( X = [X_0, X_1, \ldots, X_{M-1}]^T \), and each data block is multiplied by \( V \) dissimilar phase sequences, each with length equal to \( M_1, B^{(v)} = [b_{1,0}, b_{1,1}, \ldots, b_{1,M-1}]^T, (v = 1, 2 \ldots V) \), which results in the altered data blocks. Let us denote the altered data blocks as \( Y_m \). Then the sub-carrier mapping of this precoded signal is done as:

\[
y_m = \sum_{l=0}^{L-1} p_{m,l} X_l^T \quad m = 0, 1, \ldots L - 1
\]

where, \( p_{m,l} \) means DFT precoding matrix of \( m \)th row and \( l \)th column.

Eq. (1) represents the DFT precoded constellations signal. Then the sub-carrier mapping of this precoded signal is done in localized-mode. Mathematically the sub-carrier mapping in the localized-mode for SLM-LFDMA uplink systems can be written as:

\[
\tilde{y}_m = \begin{cases} 
Y_m & 0 \leq m \leq M - 1 \\
0 & M \leq m \leq N - 1
\end{cases}
\]

where, \( N \): system sub-carriers; \( M \): user sub-carriers; \( Q \): sub-channels/users (\( Q = N/L \)).

The sub-channel (\( q \)) is composed of sub-carriers with index set \( \{(qM_1, (qM_1 + 1), (qM_1 + 2), \ldots (qM_1 + M_1 - 1)) \} \), where \( q = 0, 1, 2, \ldots Q - 1 \). Suppose the \( k \)th user is assigned to sub-channel \( k \) then the complex baseband LFDMA uplink signal for \( k \)th user can be written as:

\[
\chi^{(k,o)}_n = \frac{1}{\sqrt{N}} \sum_{m=0}^{M-1} \left( \tilde{y}_m^{(k,o)} \cdot e^{2\pi i \frac{m+n}{Q}} \right)
\]

\( \tilde{y}_m^{(k,o)} \) is a modulated signal on sub-carrier \( m \) for \( k \)th user. The complex passband signal of the LFDMA uplink system in (3) after root-raised-cosine (RRC) pulse shaping can be written as:

\[
x(t) = e^{j\alpha_0 \tau} \sum_{n=0}^{N-1} \tilde{y}_n^{(k,o)} \cdot r(t - nT)
\]

where \( \alpha_0 \) is carrier frequency, \( r(t) \) is baseband pulse, \( \tilde{T} = \frac{\tau}{T} \), \( T \) is symbol duration in seconds. \( T \) is compressed symbol duration after IFFT. The RRC pulse shaping filter can be defined as:

\[
r(t) = \frac{\sin \left( \frac{\tau}{\tau} \left( 1 - z \right) \right)}{\tau} + 4z \frac{\cos \left( \frac{\tau}{\tau} \left( 1 + z \right) \right)}{\tau} \left( 1 - \frac{\tau}{\tau} \right)
\]

\( 0 \leq z \leq 1 \), where \( z \) is rolloff factor. The PAPR of LFDMA uplink signal in (4) with RRC pulse shaping can be written as:

![Figure 1 SLM-LFDMA uplink system.](image)
The SLM technique needs \( V \) (dissimilar phase sequences) IFFT operations and the information bits required as side information for each data block is \( \log_2 V \). SLM technique is applicable for any number of sub-carriers and all types of modulation techniques.

The PAPR reduction for SLM technique depends on the number of phase sequences \( V \) and the output data with lowest PAPR is selected by the transmitter for transmissions.

3. Simulation results

Extensive simulations in MATLAB® have been carried out to evaluate the performance of the proposed SLM-LFDMA system. We evaluate the performance of the proposed system for \( V = 4 \) and \( 32 \). To show the PAPR analysis of the proposed system, the data are generated randomly then modulated by QPSK, 16-QAM and 64-QAM, respectively. We evaluate the PAPR statistically by using complementary cumulative distribution function (CCDF). The CCDF of the PAPR for LFDMA uplink signal is used to express the probability of exceeding a given threshold \( \text{PAPR}_0 (CCDF = \text{Prob} (\text{PAPR} > \text{PAPR}_0)) \). We compare the simulation results of the proposed system with the conventional localized OFDMA uplink system, the clipping based LFDMA system and the conventional localized SC-FDMA uplink system respectively. All the simulations have been performed based on the \( 10^5 \) random data blocks. Simulation parameters that we use are given in the following Table 1.

Fig. 2 shows the CCDF comparisons of PAPR for the conventional localized OFDMA uplink system, the conventional LFDMA uplink system, the clipping based LFDMA system, the SLM based LFDMA uplink system with \( V = 4 \) and the SLM based LFDMA uplink system with \( V = 32 \), for \( M = 16 \) and \( N = 512 \) with QPSK modulation. At a clip rate of \( 10^{-4} \), the PAPR is 11.2, 8.1, 7, 6.1 and 4.1 dB for the conventional localized OFDMA uplink system, the conventional LFDMA uplink system, the clipping based LFDMA system, the SLM based LFDMA uplink system with \( V = 4 \) and the SLM based LFDMA uplink system with \( V = 32 \) respectively.

Fig. 3 shows the CCDF comparisons of PAPR for the conventional localized OFDMA uplink system, the conventional LFDMA uplink system, the clipping based LFDMA system, the SLM based LFDMA uplink system with \( V = 4 \) and the SLM based LFDMA uplink system with \( V = 32 \), for \( M = 16 \) and \( N = 512 \) with 16-QAM modulation. At a clip

<table>
<thead>
<tr>
<th>Table 1</th>
<th>System parameters.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel bandwidth</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Oversampling factor</td>
<td>4</td>
</tr>
<tr>
<td>User sub-carriers</td>
<td>( M = 16 )</td>
</tr>
<tr>
<td>System sub-carriers</td>
<td>( N = 512 )</td>
</tr>
<tr>
<td>Precoding</td>
<td>DFT</td>
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<td>Modulation</td>
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<td>Data blocks/dissimilar phase sequences</td>
<td>( V = 4 ) and ( 32 )</td>
</tr>
<tr>
<td>Subcarrier mapping</td>
<td>Localized</td>
</tr>
<tr>
<td>mode of SC-FDMA</td>
<td>RRC pulse shaping factor</td>
</tr>
</tbody>
</table>

\[
PAPR = \frac{\max_{0 \leq t < T} [x(t)]^2}{\int_{0}^{T} [x(t)]^2 dt}
\]  \( (6) \)

fig2.png

**Figure 2**  CCDF comparison of PAPR of the localized OFDMA uplink system, the localized LFDMA uplink system, the clipping based LFDMA, the SLM based LFDMA uplink system with \( V = 4 \) and the SLM based LFDMA uplink system with \( V = 32 \).
The rate of $10^{-4}$, the PAPR is 10.9, 8.7, 7.6, 6.6 and 5.3 dB for the conventional localized OFDMA uplink system, the conventional LFDMA uplink system, the clipping based LFDMA system, the SLM based LFDMA uplink system with $V = 4$ and the SLM based LFDMA uplink system with $V = 32$ respectively.

Fig. 4, shows the CCDF comparisons of PAPR for the conventional localized OFDMA uplink system, the conventional LFDMA uplink system, the clipping based LFDMA system, the SLM based LFDMA uplink system with $V = 4$ and the SLM based LFDMA uplink system with $V = 32$.
LFDMA uplink system, the clipping based LFDMA uplink system, the SLM based LFDMA uplink system with $V = 4$ and the SLM based LFDMA uplink system with $V = 32$, for $M = 16$ and $N = 512$ with 64-QAM modulation. At a clip rate of $10^{-4}/C_0$, the PAPR is 10.8, 9, 8.2, 7 and 6.2 dB for the conventional localized OFDMA uplink system, the conventional LFDMA uplink system, the clipping based LFDMA system, the SLM based LFDMA uplink system with $V = 4$ and the SLM based LFDMA uplink system with $V = 32$ respectively.

Table 2 summarizes the PAPR analysis of the proposed SLM based localized SC-FDMA uplink system, the clipping based LFDMA uplink system, conventional localized OFDMA uplink systems and the conventional LFDMA uplink systems respectively. At a clip rate of $10^{-4}$, it is obvious from Table 2 that the proposed uplink system has lower PAPR than the clipping based LFDMA uplink system, conventional LFDMA uplink systems and the conventional localized OFDMA uplink systems. In clipping based PAPR reduction technique the signal with high peak is deliberately clipped which results in loss of useful information. Due to this loss of useful information, the clipping based technique introduces in-band distortion and out-of-band radiation. Hence, the clipping method is not suitable for PAPR reduction. On the other hand, the SLM based PAPR reduction technique does not create any in-band distortion and out-of-band radiation. Therefore, the SLM based technique is always better than the clipping based technique.

4. Conclusions

In this paper, we present SLM based LFDMA uplink system for PAPR reduction. Simulation results have shown that the proposed system has lower PAPR than the conventional localized OFDMA uplink systems, the conventional LFDMA uplink systems and the clipping based LFDMA uplink systems respectively. The PAPR of the proposed system can be further reduced if we increase the size of $V$ but the increase in size of $V$ increases the complexity of the proposed system. So the values of $V$ should be selected carefully. Due to low PAPR, the proposed SLM based LFDMA uplink system is more suitable for the upcoming 4G cellular standard release 10 LTE-Advanced than the LFDMA uplink system which is implemented in the release 8 LTE.

References

3GPP, TS36. 201 (V8.1.0), LTE physical layer-general description (Release 8), Nov. 2007.