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Original Article

PAPR Reduction in 4G Cellular Network: A SLM-based IFDMA Uplink System

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Abstract*:* This paper presents a selected-mapping (SLM) based peak-to-average power ratio (PAPR) reduction technique for the interleaved single carrier frequency division multiple access (IFDMA) 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^{-3} with user's subcarriers $M = 16$, system's subcarriers $N = 512$ and dissimilar phase sequences $V = 16$: the PAPR gain of the proposed SLM based IFDMA system is 6.8 dB and 2.3 dB when compared with those of conventional interleaved OFDMA uplink systems and the conventional IFDMA uplink systems respectively, for the QPSK modulation.

Keywords: Selected mapping (SLM); peak-to-average power reduction (PAPR); interleaved single carrier frequency division multiple access (IFDMA)

1. INTRODUCTION

Single carrier frequency division multiple access (SC-FDMA) has been adopted for the uplink communications in release 8 LTE [1]. 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). However, the SC-FDMA uplink system has still PAPR problem.

The literature is replicated with the selected-mapping (SLM) and its different variants for peak-to-average power ratio (PAPR) reduction. SLM based orthogonal frequency division multiplexing (OFDM) [2], SLM based precoded OFDM [3], SLM based OFDMA [4], SLM based precoded OFDMA [5] and SLM based multicarrier code division multiple access (MC-CDMA) [6] respectively, are most popular. There is still room for SLM implementations with the SC-FDMA uplink systems to reduce the PAPR. Therefore, in this paper we study the SLM based interleaved SC-FDMA (IFDMA) uplink system with reduced PAPR.

2. SINGLE CARRIER SYSTEM (SC-FDMA)

Fig. 1 illustrates the block diagram of SC-FDMA uplink systems [7]. In SC-FDMA uplink systems, the baseband modulated symbols are passed through serial-to-parallel (S/P) converter which generates complex vector of size M as $X = [X_0, X_1, X_{2\ldots}\ X_{M-1}]^T$. After discrete Fourier transform (DFT) precoding and N subcarrier mapping to the X, we get $\hat{X}_m = [\hat{X}_0, \hat{X}_1, \ldots\ \hat{X}_{N-1}]^T$. The complex baseband IFDMA uplink signal with M user subcarriers and N system subcarriers can be written as follows:-

$$x_n^{(k)} = \frac{1}{\sqrt{N}} \sum_{m=0}^{M-1} (\hat{X}_m^{(k)} \cdot e^{j2\pi \frac{(mQ+k)}{N} n}),$$
$$n = 0, 1 \ldots N-1 \quad (1)$$

where, $j=\sqrt{-1}$, n = 0,1,2...N-1, $\hat{X}_m^{(k)}$ is modulated signal on subcarrier m for k^{th} user and users index $k = 1,2,\ldots,Q-1$.

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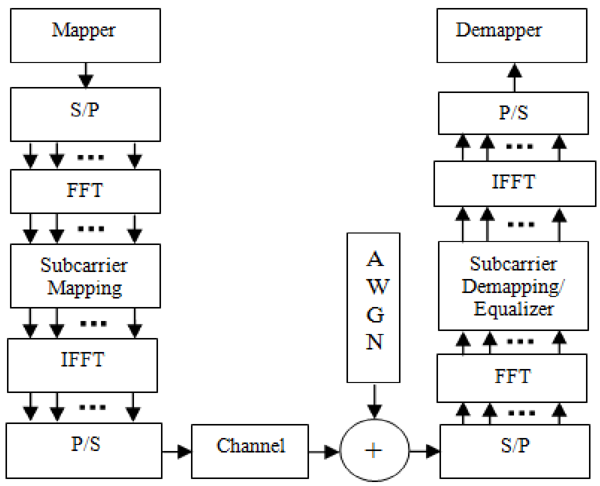

Fig.1. General Block diagram of Single Carrier System [7].

3. PROPOSED MODEL

Fig. 2 shows the block diagram of the proposed SLM-IFDMA uplink system. Suppose the data stream after S/P conversion is $X = [X_0, X_2 \ldots X_{M-1}]^T$, and each data block is multiplied by V dissimilar phase sequences, each length equal to M, $B^{(v)} = [b_{v,0}, b_{v,1}, \ldots, b_{v,M-1}]^T$, ($v$= 1, 2...$V$), which results in the altered data blocks. Let us denote the altered data block for the v^{th} phase sequence is given by $X^{(v)} = [\,X_0 b_{v,0},\, X_1 b_{v,1}, \ldots, X_{N-1} b_{v,M-1}]^T$, where $v = 1, 2, 3 \ldots V$.

Then, these altered data blocks are passed through the DFT precoder, which transforms this complex vector into new vector of same length L that can be written as $Y = PX = [Y_0, Y_2 \ldots Y_{L-1}]^T$ and the Y_m^v can be written as follows:-

$$Y_m^v = \sum_{l=0}^{L-1} p_{m,l} X_l^v \qquad m = 0,1, \ldots L-1 \qquad (2)$$

where, $p_{m,l}$ means DFT precoding matrix of m^{th} row and l^{th} column. Equation (2) represents the DFT precoded constellations signal. Then the sub-carrier mapping of this precoded signal is done in interleaved-mode. Mathematically the sub-carrier mapping in interleaved-mode for SLM-IFDMA uplink systems can be done as follows:-

$$\hat{Y}_m^v = \begin{cases} \frac{Y_m^v}{Q} & , m = Q.k \quad 0 \le k \le M-1 \\ 0 & otherwise \end{cases} \qquad (3)$$

where, N : System sub-carriers
M : User sub-carriers
Q : Sub-channels/Users ($Q = N/L$)

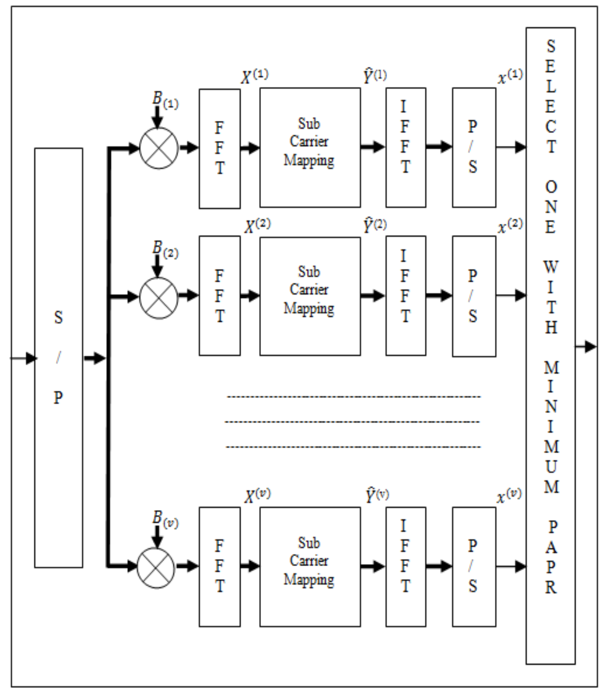

Fig. 2. Precoding based SLM-IFDMA uplink system.

The k^{th} subcarrier of each group is assigned to the k^{th} user with index set {(k), (Q+k) … ((M-1) Q+k)}, where $q = 0, 1, 2 \ldots Q-1$. Suppose the k^{th} user is assigned to subchannel (k) then the complex baseband SLM-IFDMA uplink signal for k^{th} user can be written as follows:-

$$x_n^{(k,v)} = \frac{1}{\sqrt{N}} \sum_{m=0}^{M-1} \left(\hat{Y}_m^{(k,v)} . e^{j2\pi \frac{(mQ+k)}{N} n}\right),$$

$$n = 0,1 \ldots N-1 \qquad (4)$$

$\hat{Y}_m^{(k,v)}$ is modulated signal on sub-carrier m for k^{th} user. The complex passband signal of the IFDMA uplink system in (4) after root-raised-cosine (RRC) pulse shaping can be written as follows:-

$$x(t) = e^{j\omega_c t} \sum_{n=0}^{N-1} x_n^{(k,v)} . r(t - n\check{T}) \qquad (5)$$

where ω_c is carrier frequency, $r(t)$ is baseband pulse, $\check{T} = \left(\frac{M}{N}\right)$, T is symbol duration is seconds.

T is compressed symbol duration after IFFT. The RRC pulse shaping filter can be defined as follows:-

$$r(t) = \frac{sin\left(\frac{\pi t}{T}(1-\alpha)\right)+4\alpha\frac{t}{T}.cos\left(\frac{\pi t}{T}(1+\alpha)\right)}{\frac{\pi t}{T}.\left(1-\frac{16\alpha^2 t^2}{T^2}\right)} \quad (6)$$

$0 \leq \alpha \leq 1$, where α is rolloff factor. The PAPR of IFDMA uplink signal in (5) with RRC pulse shaping can be written as:-

$$PAPR = \frac{\max_{0\leq t\leq N\tilde{T}} |x(t)|^2}{\frac{1}{N\tilde{T}}\int_0^{N\tilde{T}}|x(t)|^2 dt} \quad (7)$$

The SLM technique needs V (dissimilar phase sequences) IFFT operations and the information bits required as side information for each data block is $\lfloor log_2 V \rfloor$. 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.

4. SIMULATION RESULTS

Extensive simulations in MATLAB® version 7.6.0.324 (R2008a) have been carried out to evaluate the performance of the proposed SLM-IFDMA system. We evaluate the performance of the proposed system for $V = 4, 8$ and 16. To show the PAPR analysis of the proposed system, the data is generated randomly then modulated by QPSK or 16-QAM or 64-QAM respectively. We evaluate the PAPR statistically by using complementary cumulative distribution function (CCDF). The CCDF of the PAPR for IFDMA uplink signal is used to express the probability of exceeding a given threshold $PAPR_0$ ($CCDF = Prob\,(PAPR > PAPR_0)$).

We compare the simulation results of the proposed system with the conventional interleaved OFDMA uplink system, the conventional IFDMA 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 as:-

Table 1. System parameters.

Channel bandwidth	5 MHz
Oversampling factor	4
User sub-carriers	$M = 16$
System Sub-carriers	$N = 512$
Precoding	DFT
Modulation	QPSK, 16-QAM, 64-QAM
Data blocks/ dissimilar phase sequences	$V = 4$, 8 and 16
Subcarrier mapping mode of SC-FDMA	Interleaved
RRC Pulse shaping factor	$\alpha = 0.2$

Fig. 3 shows the CCDF comparisons of PAPR for the conventional interleaved OFDMA uplink system, the conventional IFDMA uplink system, the SLM based IFDMA uplink system with $V = 4$, the SLM based IFDMA uplink system with $V = 8$ and the SLM based IFDMA uplink system with $V = 16$ respectively. At clip rate of 10^{-3}, the PAPR of the conventional interleaved OFDMA uplink system, the conventional IFDMA uplink system, the SLM based IFDMA uplink system with $V = 4$, the SLM based IFDMA uplink system with $V = 8$ and the SLM based IFDMA uplink system with $V = 16$ is reduced to 9.9 dB, 5.4 dB, 4 dB, 3.5 dB and 3.1 dB respectively, for $M = 16$ and $N = 512$ using QPSK modulation.

Fig. 4 shows the CCDF comparisons of PAPR for the conventional interleaved OFDMA uplink system, the conventional IFDMA uplink system, the SLM based IFDMA uplink system with $V = 4$, the SLM based IFDMA uplink system with $V = 8$ and the SLM based IFDMA uplink system with $V = 16$ respectively. At clip rate of 10^{-3}, the PAPR of the conventional interleaved OFDMA uplink system, the conventional IFDMA uplink system, the SLM based IFDMA uplink system with $V = 4$, the SLM based IFDMA uplink system with $V = 8$ and the SLM based IFDMA uplink system with $V = 16$ is reduced to 9.9 dB, 5.4 dB, 4 dB, 3.5 dB and 3.1 dB respectively, for $M = 16$ and $N = 512$ using 16-QAM modulation.

Fig. 5 shows the CCDF comparisons of PAPR for the conventional interleaved OFDMA uplink system, the conventional IFDMA uplink system, the SLM based IFDMA uplink system with $V = 4$, the SLM based IFDMA uplink system with $V = 8$

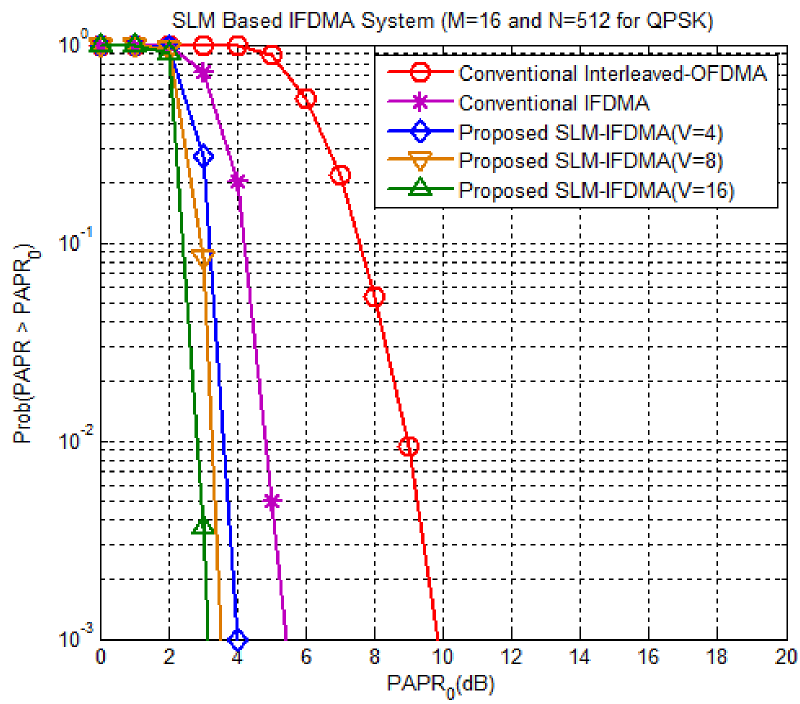

Fig. 3. CCDF comparison of PAPR of the conventional Interleaved OFDMA uplink system, the conventional IFDMA uplink system and the SLM based IFDMA uplink system with V = 4,8,16 respectively using QPSK modulation.

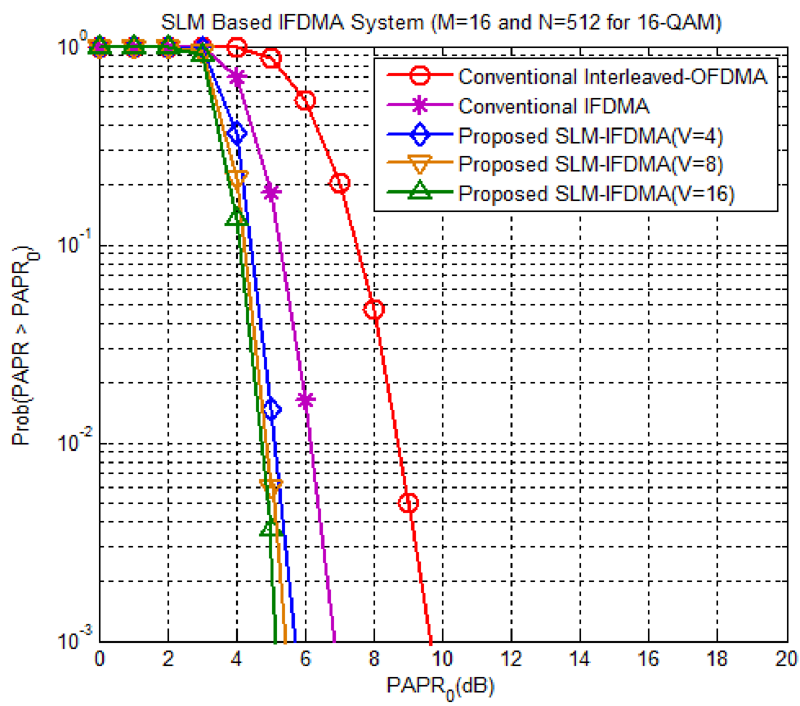

Fig. 4. CCDF comparison of PAPR of the conventional Interleaved OFDMA uplink system, the conventional IFDMA uplink system and the SLM based IFDMA uplink system with V = 4,8,16 respectively using 16-QAM modulation.

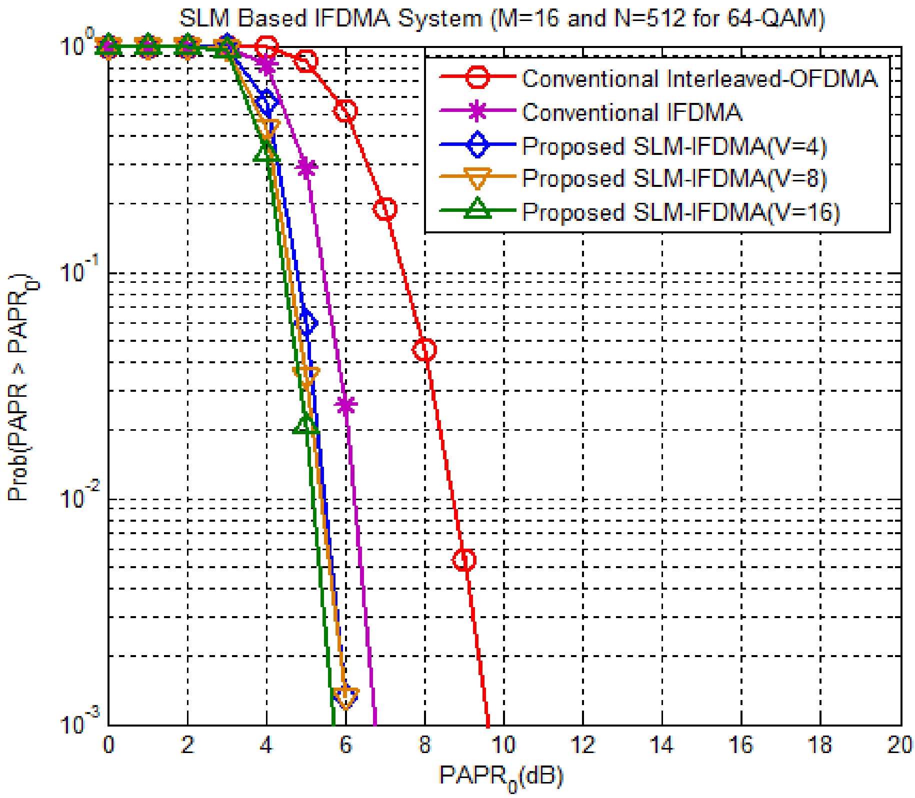

Fig. 5. CCDF comparison of PAPR of the conventional Interleaved OFDMA uplink system, the conventional IFDMA uplink system and the SLM based IFDMA uplink system with $V = 4,8,16$ respectively using 64-QAM modulation.

and the SLM based IFDMA uplink system with $V = 16$ respectively. At clip rate of 10^{-3}, the PAPR of the conventional interleaved OFDMA uplink system, the conventional IFDMA uplink system, the SLM based IFDMA uplink system with $V = 4$, the SLM based IFDMA uplink system with $V = 8$ and the SLM based IFDMA uplink system with $V = 16$ is reduced to 9.9 dB, 5.4 dB, 4 dB, 3.5 dB and 3.1 dB respectively, for $M = 16$ and $N = 512$ using 64-QAM modulation.

Table 2 summarizes the PAPR analysis of the proposed SLM-IFDMA uplink systems, the cconventional IFDMA uplink systems and the conventional interleaved OFDMA uplink systems respectively. At the clip rate of $10^{-3,}$ it is obvious from the Table II that the proposed uplink systems have lower PAPR as compare to those the conventional interleaved OFDMA uplink systems and the conventional IFDMA uplink systems respectively.

Table 2. At CCDF of 10^{-3}, the PAPR comparisons of the conventional interleaved OFDMA, the conventional IFDMA, the SLM-IFDMA (V = 4), the SLM-IFDMA (V = 8) And the SLM-IFDMA (V = 16) with RRC Pulse-Shaping factor α = 0.22.

Uplink Transmission Scheme	PAPR		
	QPSK	16-QAM	64-QAM
Conventional Interleaved OFDMA	9.9 dB	9.8 dB	9.8 dB
Conventional IFDMA	5.4 dB	6.9 dB	6.9 dB
SLM-IFDMA (V=4)	4.0 dB	5.7 dB	6.0 dB
SLM-IFDMA (V=8)	3.5 dB	5.4 dB	6.0 dB
SLM-IFDMA (V=16)	3.1 dB	5.1 dB	5.7 dB

5. CONCLUSIONS

In this paper, we present SLM based IFDMA uplink system for PAPR reduction. It is obvious from the Table II, that the proposed system has lower PAPR than the conventional interleaved OFDMA uplink systems and the conventional IFDMA uplink systems respectively. The PAPR of the proposed system can be further reduced if we increase the size of V but with the increase in size of V increases the complexity of the proposed system. So the values of V should be taken carefully. Hence, it is concluded that the proposed SLM based IFDMA uplink system is more suitable for the upcoming 4G cellular standard release 10 LTE-Advanced than the conventional IFDMA uplink system which is implemented in the release 8 LTE.

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