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PAPR REDUCTION IN LAYERED-OFDMA OF LTE-A: A NEW PRECODING BASED ADAPTIVE UPLINK RA SYSTEM

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Abstract

This paper presents a new precoding based adaptive multi-carrier/single-carrier (MC/SC) uplink radio-access (RA) system with improved peak-to-average power ratio (PAPR) for layered orthogonal frequency division multiple access (Layered-OFDMA) of long term evolution advanced (LTE-A). The Discrete-Cosine transform (DCT) precoding is applied before subcarrier mapping and IFFT to reduce the high PAPR of the MC uplink system. The conventional SC system is implemented to sustain all the functionalities offered by the release 8 LTE. Extensive computer simulations have been performed to analyze the PAPR of the proposed system. The computer simulation results show that, the PAPR of DCT precoded MC signals is approximately same as that of conventional SC signals.

Keywords: Multi-carrier/single-carrier (MC/SC), Long term evolution advanced (LTE-A), Layered-OFDMA, Discrete-cosine transform (DCT).

1. Introduction

Layered orthogonal frequency division multiple access (Layered-OFDMA) radio-access (RA) scheme has been proposed recently to achieve the higher level requirements of long term evolution advanced (LTE-A). The Layered-OFDMA will support all the functionalities provided in release 8 LTE including its enhancements. In the Layered OFDMA, layered transmission bandwidth is assigned according to the required data rate. Layered OFDMA has its own layered control signaling structure and layered environments in which adaptive multi-carrier/single-carrier (MC/SC) RA scheme is proposed to be used [1]. Single carrier frequency division multiple access (SC-FDMA) was adopted for

Nomenclatures

D	Precoding matrix
H	Real number
k	User index
L	Precoder Size = User subcarriers
M	User subcarriers
N	System subcarriers
Q	Subchannels/Users ($Q = N/M$)
$r(t)$	Baseband pulse
T	Symbol duration
$\breve{T}$	Compressed symbol duration after IFFT
X	A complex vector after *S/P* converter
$x_n^{(k)}$	A complex baseband interleaved-OFDMA uplink signal for k^{th} user
$\hat{Y}$	A complex vector after subcarrier-mapping

Greek Symbols

α	RRC roll-off factor.
ω_c	Carrier frequency

Abbreviations

CCDF	Complementary cumulative distribution function
DCT	Discrete-cosine transform
IFFT	Inverse fast Fourier transform
LTE	Long term evolution
MC	Multi-carrier
OFDMA	Orthogonal frequency division multiple access
PAPR	Peak-to-average power ratio
RRC	Root raised cosine
RA	Radio-access
SC	Single-carrier
S/P	Serial-to-parallel

the uplink communications in release 8 LTE. SC-FDMA utilizes single carrier modulation with frequency domain equalization at the receiver [2].

The main advantage of using SC-FDMA over the OFDMA is its low peak to average power ratio (PAPR). On the other hand, OFDMA was also selected for down link communications in the release 8 LTE [3]. In [4] LTE-A requirements were agreed but radio interface schemes are still debatable. OFDMA thwarts inter symbol interference (ISI) by inserting a guard interval using a cyclic prefix (CP) and moderates the frequency selectivity of the multi path channel with a simple equalizer. This leads to cheap hardware implementation and makes simpler the design of the receiver [5]. OFDMA is broadly implemented in a range of communication standards like ultra-mobile-broadband (UMB), mobile-broadband-wireless-access (MBWA), evolved-UMTS-terrestrial-radio-access (E-UTRA) and worldwide interoperability for microwave access (WiMAX). OFDMA is also a strong candidate for the wireless-regional-area-networks (WRAN) and LTE-A.

However OFDMA has some weaknesses, among others, the PAPR is still one of the key drawbacks in the transmitted OFDMA signals [6]. A large number of PAPR reduction techniques have been proposed in the literature. Among them, schemes like constellation shaping [7], clipping and filtering [8], partial-transmit-sequence (PTS) [9], selective-mapping (SLM) [10], precoding based selecting mapping [11, 12] and precoding based techniques [13] are popular.

Myung et al. [14] presented PAPR analysis of the SC-FDMA signals with pulse shaping. They showed through computer simulations that, that pulse shaping increases the PAPR of single carrier (SC) signals. They compared their results with the OFDMA conventional and found that SC-FDMA has low PAPR because of its single carrier structure than OFDMA conventional. They also compare the PAPR of interleaved SC-FDMA (IFDMA) and localized SC-FDMA (LFDMA) with and without pulse shaping. At the end, they conclude that IFDMA has lower PAPR then LFDMA.

This paper presents a new adaptive multi-carrier/single-carrier (MC/SC) RA system with reduced PAPR for Layered-OFDMA of LTE-A. This paper is organized as follows: Section 2 describes the basics of the MC system, SC system and PAPR, In Section 3 we present our proposed adaptive RA system with reduced PAPR, Section 4 presents the computer simulation results and section 5 concludes the paper.

2. MC System, SC System and PAPR

2.1. Multi carrier system (Localized-OFDMA)

Figure 1 shows the block diagram of localized-OFDMA uplink system. In localized subcarrier mapping the subcarriers are mapped in adjacent to each other. In localized-OFDMA uplink system, the baseband modulated symbols are passed through serial-to-parallel (S/P) converter which generates complex vector of size M. We can write the complex vector of size M as follows:

$$X = [X_o, X_1, X_2, \ldots.., X_{M-1}]^T \quad (1)$$

After N subcarrier mapping in localized mode to the X, we get

$$\hat{X}_l = \left[\hat{X}_0, \hat{X}_1, \hat{X}_2, \ldots\ldots, \hat{X}_{N-1}\right]^T \quad (2)$$

The complex baseband localized-OFDMA uplink signal with N system subcarriers and M user subcarriers can be written as follows:

$$x_n^{(k)} = \frac{1}{\sqrt{N}} \sum_{i=0}^{L-1} \left(\hat{X}_l^{(k)}\right) e^{j2\pi \frac{kL+l}{N} n}, \; n = 0, 1, \ldots.., N\text{-}1 \quad (3)$$

where $\hat{X}_l$ we get after subcarrier mapping, $j = \sqrt{-1}$, $n = 0, 1, 2, \ldots N\text{-}1$, $\hat{X}_l^{(k)}$ is modulated signal on subcarrier l for k^{th} user and users index $k = 1, 2, \ldots Q\text{-}1$. The complex passband signal of conventional localized-OFDMA after RRC pulse shaping can be written as follows:

$$x(t) = e^{j\omega_c t} \sum_{n=0}^{N-1} x_n^{(k)} . r\left(t - n\breve{T}\right) \quad (4)$$

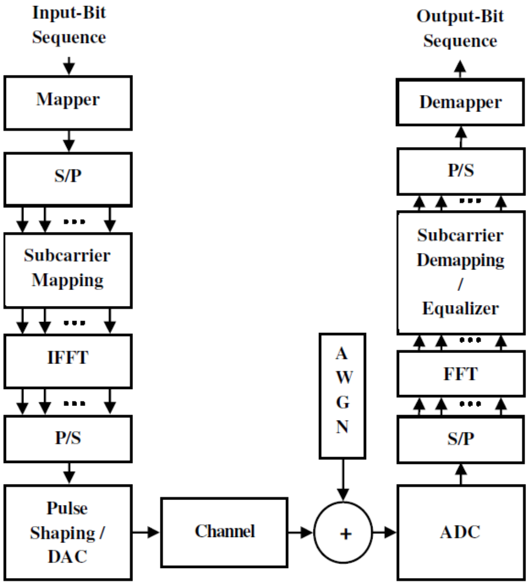

Fig. 1. General Block Diagram of MC System.

where ω_c is carrier frequency, *r(t)* is baseband pulse, $\breve{T} = (M / N)T$ is compressed symbol duration after IFFT and T is symbol duration in seconds. According to Theodore [15], the root raised cosine (RRC) pulse shaping filter can be defined as follows:

$$r(t) = \frac{\sin\left(\frac{\pi}{\breve{T}}(1-\alpha)\right) + 4\alpha\frac{t}{\breve{T}}\cos\left(\frac{\pi}{\breve{T}}(1+\alpha)\right)}{\frac{\pi}{\breve{T}}\left(1-\frac{16\alpha^2 t^2}{\breve{T}^2}\right)}, \qquad 0 \le \alpha \le 1 \tag{5}$$

2.2. Single carrier system (Localized SC-FDMA)

Figure 2 shows the block diagram of SC-FDMA system. In SC-FDMA system, baseband modulated data is passed through S/P converter which generates a complex vector of size M that can be written as $X = [X_0, X_1, X_2, \ldots.., X_{M-1}]^T$. Then DFT precoding is applied to this complex vector. The DFT precoded signal can be written as follows:

$$x_n = \frac{1}{\sqrt{M}}\sum_{l=0}^{M-1} X_l . e^{-j2\pi\frac{n}{M}l} \qquad , n = 0, 1, 2, M\text{-}1 \tag{6}$$

This DFT precoded signal is then mapped on to the N subcarriers and we get $\hat{Y}_k = \left[\hat{Y}_0, \hat{Y}_1, \hat{Y}_2, \ldots\ldots, \hat{Y}_{N-1}\right]^T$. The IDFT precoded signal with N subcarriers can be written as:

$$\hat{x}_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \hat{Y}_k . e^{j2\pi \frac{n}{N} k} \quad , n = 0, 1, 2, N\text{-}1 \tag{7}$$

$\hat{Y}_k$ we get after subcarrier mapping. Using Eqs. (6) and (7) we get complex baseband SC-FDMA signal with N subcarrier and can be written as follows:

$$\hat{x}_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \left(\frac{1}{\sqrt{M}} \sum_{l=0}^{M-1} X_l . e^{-j2\pi \frac{n}{M} l} \right) . e^{j2\pi \frac{n}{N} k} \tag{8}$$

The complex passband signal of localized SC-FDMA (LFDMA) after RRC pulse shaping can be written as follows:

$$x(t) = e^{j\omega_c t} \sum_{n=0}^{N-1} \hat{x}_n . r\left(t - n\breve{T}\right) \tag{9}$$

where ω_c is carrier frequency, $r(t)$ is baseband pulse, $\breve{T} = (M / N)T$ is compressed symbol duration after IFFT and T is symbol duration in seconds.

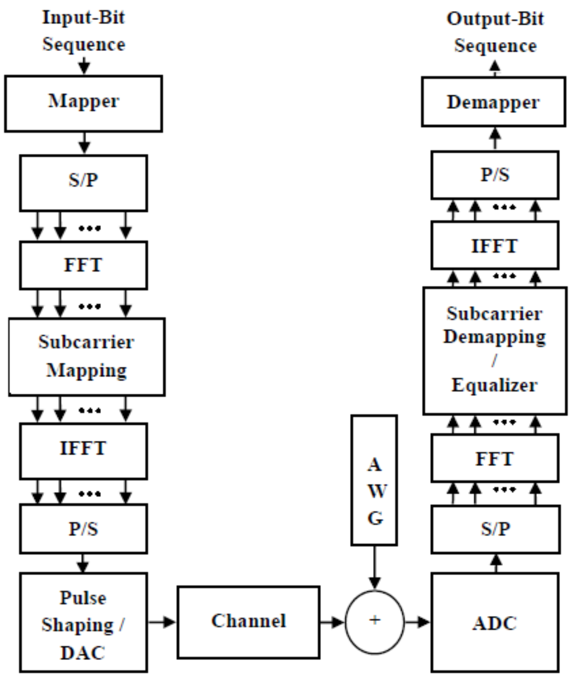

Fig. 2. General Block Diagram of SC System.

2.3. Peak to average power ratio (PAPR)

The PAPR of signals in Eqs. (4) and (9) with pulse shaping can be written as follows:

$$PAPR = \frac{\max_{0 \le t \le N\breve{T}} |x(t)|^2}{\frac{1}{N\breve{T}} \int_0^{N\breve{T}} |x(t)|^2 dt} \tag{10}$$

Complementary cumulative distribution function (CCDF) of the signals for the MC/SC systems can be written as follows

$$P(PAPR > PAPR_0) = 1 - \left(1 - e^{PAPR_0}\right)^N \tag{11}$$

where $PAPR_0$ is the clipping level and this equation can be interpreted as the probability that the $PAPR$ of a symbol block exceeds some clip level $PAPR_0$.

3. Proposed Model

3.1. Discrete cosine transform (DCT) and discrete cosine transform matrix

According to Nassir et al. [16], the DCT can be defined as follows:

$$X_k = \sum_{n=0}^{N-1} x_n \cos\left[\frac{\pi}{N}\left(n + \frac{1}{2}\right)k\right] \tag{12}$$

DCT Matrix D of size L-by-L can be created by using Eq. (13)

$$D_{ij} = \begin{cases} \frac{1}{\sqrt{N}} & i = 0, \quad 0 \le j \le N\text{-}1 \\ & 1 \le i \le N\text{-}1 \\ \sqrt{\frac{2}{N}} \cos\frac{\pi(2j+1)i}{2N} & 0 \le j \le N\text{-}1 \end{cases} \tag{13}$$

The DCT precoding matrix must fulfil the following criteria:

- All the elements of the precoding matrix must have the same magnitude.
- The magnitude must be equal to $D_{ij} = 1/\sqrt{N}$.
- The DCT precoding matrix must be non-singular.

The first requirement ensures that every output symbol has the same amount of information of every input data. The second requirement preserves the power at the precoder output. Finally, the third requirement ensures the recovery of the original data at the receiver. The kernel of the DCMT is defined in Eq. (14). For $N= L\times L$ and $j = \sqrt{-1}$, the DCT kernel D, of size $N= L\times L=L^2$ is obtained by using the Eq. (13) as hereunder:

$$D = \frac{1}{\sqrt{N}} \begin{bmatrix} d_{00} & d_{01} & \cdots & d_{0(L-1)} \\ d_{10} & d_{11} & \cdots & d_{1(L-1)} \\ \vdots & \vdots & \ddots & \vdots \\ d_{(L-1)0} & d_{(L-1)1} & \cdots & d_{(L-1)(L-1)} \end{bmatrix} \tag{14}$$

3.2. Adaptive Radio Access (RA) System

Figure 3 shows the adaptive MC/SC (localized OFDMA/localized SC-FDMA) RA system for uplink communications of LTE-A with improved PAPR. According to the transmission requirements, the switch is used to change the system from SC to MC and voice versa. In MC part, the DCT precoder is implemented before the subcarrier mapping and IFFT. This DCT precoder precodes the constellation symbols to reduce the PAPR. On the other hand, the DFT precoding is applied to make the system SC conventional. In the DCT precoding based uplink system, baseband modulated data is passed through S/P converter which generates a complex vector of size M that can be written as $X = [X_o, X_1, X_2, \ldots, X_{M-1}]^T$. Then DCT precoding is applied to this complex vector which transforms this complex vector into new vector of length L that can be written as $Y = DX = [Y_o, Y_1, Y_2, \ldots, Y_{L-1}]^T$, where D is a precoder matrix. The value of matrix D can be used from Eq. (14). With the use of proper sequence reshaping the precoding X gives rise to Y as follows

$$Y = DX \tag{15}$$

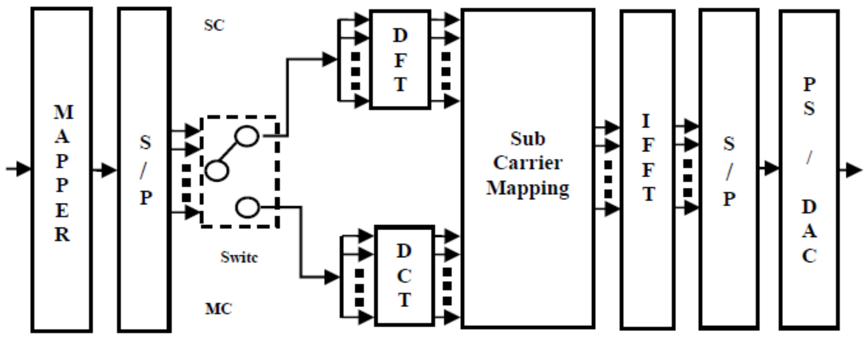

Fig. 3. Block Diagram of Adaptive Radio Access (RA) System.

$$Y_m = \sum_{l=0}^{N-1} d_{m,l}.X_m \text{ , } m = 0, 1, \ldots, L\text{-}1 \tag{16}$$

$d_{m,l}$ means m^{th} row and l^{th} column of precoder matrix. Then N subcarrier mapping is done in the localized mode. After subcarrier mapping, we get $\hat{Y}_l = [\hat{Y}_0, \hat{Y}_1, \hat{Y}_2, \ldots\ldots, \hat{Y}_{N-1}]^T$. The complex baseband DCT precoded localized OFDMA uplink signal for k^{th} user can be written as follows

$$x_n^{(k)} = \frac{1}{\sqrt{N}} \sum_{l=0}^{L-1} \hat{Y}_l^{(k)}.e^{j2\pi \frac{kL+l}{N} n} \text{ , } n = 0, 1, \ldots, N\text{-}1 \tag{17}$$

where users index k = 0, 1, Q-1 and $\hat{Y}_l^{(k)}$ is modulated signal on subcarrier m for k^{th} user, where $\hat{Y}_l$ we get after subcarrier mapping $j = \sqrt{-1}$, n=1, 2, …., N-1, $\hat{X}_l^{(k)}$ is modulated signal on subcarrier l for k^{th} user and users index k=1, 2, …., Q-1. The PAPR of signal in Eq. (17) can be calculated by using Eq. (10).

4. Simulation Results

Extensive simulations in MATLAB(R) have been performed to analyse the PAPR of the proposed adaptive MC/SC RA system for uplink communication of LTE-A. To show PAPR analysis of the proposed adaptive MC/SC RA system we considered QPSK, 16-QAM and 64-QAM modulation techniques with 10^3 random OFDMA blocks and the clipping probability (clip rate = 10^{-3}) is used. In MATLAB(R) simulation the parameters used are: 8-times oversampling, 20 MHz transmission bandwidth, user subcarriers M = 16, and system subcarriers N = 512. All the simulations have been performed, based on the 10^5 random data blocks.

Figure 4 shows the CCDF comparison of the PAPR of the DCT precoding based localized OFDMA uplink system with localized SC-FDMA (LFDMA) uplink systems and conventional localized OFDMA uplink systems respectively, for the user subcarriers (M = 16) and the system subcarriers (N = 512). At clip rate of 10^{-3}, the PAPR is reduced to 10 dB, 7 dB and 7 dB respectively, for the conventional localized OFDMA uplink systems, the conventional localized FDMA uplink systems and the DCT precoding based localized OFDMA uplink systems, for QPSK modulation.

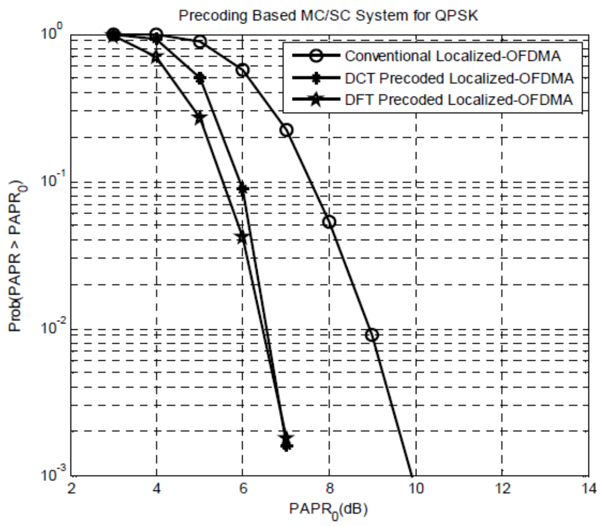

Fig. 4. CCDF Comparison of PAPR of DCT Precoding Based OFDMA (Multi-carrier System) with the LFDMA (Single-Carrier System) and Conventional Localized OFDMA Uplink Systems.

Figure 5 shows the CCDF comparison of the PAPR of the DCT precoding based localized OFDMA uplink system with localized SC-FDMA (LFDMA) uplink systems and conventional localized OFDMA uplink systems respectively, for the user subcarriers (M = 16) and the system subcarriers (N = 512). At clip rate of 10^{-3}, the PAPR is reduced to 9.9 dB, 8 dB and 8 dB respectively, for the conventional localized OFDMA uplink systems, the conventional localized FDMA uplink systems and the DCT precoding based localized OFDMA uplink systems, for 16-QAM modulation.

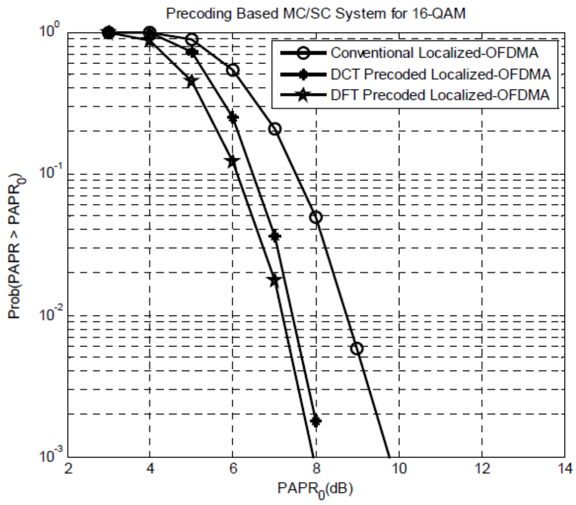

Fig. 5. CCDF Comparison of PAPR of DCT Precoding Based OFDMA (Multi-Carrier System) with the LFDMA (Single-Carrier System) and Conventional Localized OFDMA Uplink Systems.

Figure 6 shows the CCDF comparison of the PAPR of the DCT precoding based localized OFDMA uplink system with localized SC-FDMA (LFDMA) uplink systems and conventional localized OFDMA uplink systems respectively, for the user subcarriers (M = 16) and the system subcarriers (N = 512). At clip rate of 10^{-3}, the PAPR is reduced to 9.9 dB, 8 dB and 8 dB respectively, for the conventional localized OFDMA uplink systems, the conventional localized FDMA uplink systems and the DCT precoding based localized OFDMA uplink systems, for 64-QAM modulation.

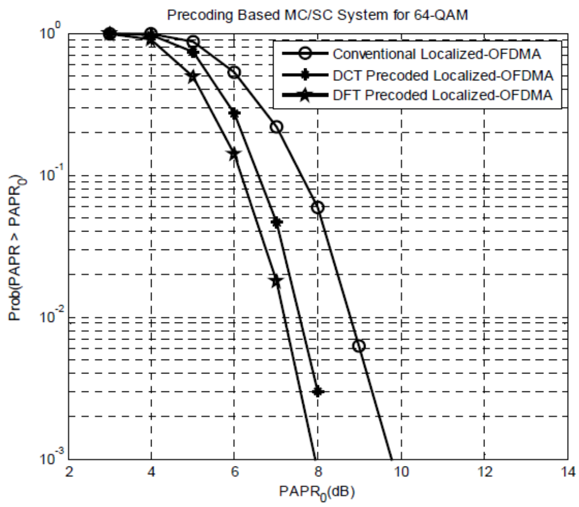

Fig. 6. CCDF Comparison of PAPR of DCT Precoding Based OFDMA (Multi-Carrier System) with the LFDMA (Single-Carrier System) and Conventional Localized OFDMA Uplink Systems.

5. Conclusions

In this paper, a new adaptive RA system with reduced PAPR is presented for the LTE-A. The PAPR of the proposed system is analyzed through the computer simulations. It is concluded from the computer simulation results that, the PAPR of the DCT precoded localized OFDMA (MC system) signals have almost equal to the localized SC-FDMA (conventional SC system) signals. Additionally, the DCT precoded MC system takes all the benefits of the multicarrier modulations. Hence, it is concluded that the DCT precoded localized OFDMA uplink system may be the one of best choice for MC part of Layered-OFDMA.

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