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A NEW DISCRETE HARTLEY TRANSFORM PRECODING BASED INTERLEAVED-OFDMA UPLINK SYSTEM WITH REDUCED PAPR FOR 4G CELLULAR NETWORKS

IMRAN BAIG*, VARUN JEOTI

Electrical and Electronic Engineering Department,
Universiti Teknologi PETRONAS, Malaysia
*Corresponding Author: imran_baig_mirza@yahoo.com

Abstract

High peak-to-average power ratio (PAPR) reduction is one of the major challenges in orthogonal frequency division multiple access (OFDMA) systems since last decades. High PAPR increases the complexity of analogue-to-digital (A/D) and digital-to-analogue (D/A) convertors and also reduces the efficiency of RF high-power-amplifier (HPA). In this paper, we present a new Discrete- Hartley transform (DHT) precoding based interleaved-OFDMA uplink system for PAPR reduction in the upcoming 4G cellular networks. Extensive computer simulations have been performed to analyze the PAPR of the proposed system with root-raised-cosine (RRC) pulse shaping. We also compare simulation results of the proposed system with the conventional interleaved-OFDMA uplink systems and the Walsh-Hadamard transform (WHT) precoding based interleaved-OFDMA uplink systems. It is concluded from the computer simulations that the proposed system has low PAPR as compared to the conventional interleaved-OFDMA uplink systems and the WHT precoded interleaved-OFDMA uplink systems.

Keywords: Interleaved-OFDMA, Peak-to-average power ratio, Discrete-Hartley transform, High-power-amplifier.

1. Introduction

Orthogonal frequency division multiple access (OFDMA) is a multiple access version of the orthogonal-frequency-division-multiplexing (OFDM). The OFDMA system splits the high speed data stream into a number of parallel low data rate streams and these low rates data streams are transmitted simultaneously over a number of orthogonal subcarriers [1-4].

Nomenclatures

A	Precoding matrix
$a_{m,l}$	m^{th} row and l^{th} column of DHT precoder matrix A
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

ω_c	Carrier frequency

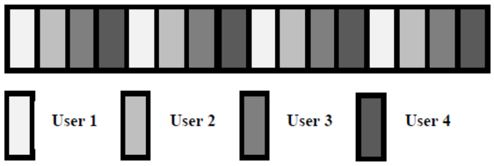
Abbreviations

A/D	Analogue-to- digital
CCDF	Complementary cumulative distribution function
DHT	Discrete- Hartley transform
D/A	Digital-to-analogue
HPA	High-power-amplifier
IFFT	Inverse fast Fourier transform
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
PAPR	Peak-to-average power ratio
RC	Raised-cosine
RRC	Root raised cosine
SNR	Signal-to-noise ratio
S/P	Serial-to-parallel
WHT	Walsh-Hadamard transform

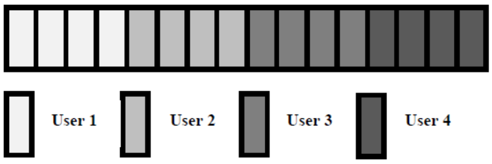
The key difference between OFDM and OFDMA is that instead of allocating all the available subcarriers to one user, the base station assigns one subset of carriers to one user and another subset to another user in order to accommodate several users at the same time. There are two different approaches to do subcarrier mapping to users in OFDMA systems: localized subcarrier mapping and distributed subcarrier mapping. In localized subcarrier mapping one group of locally adjacent subcarriers are mapped to one user and another to another. The distributed subcarrier mapping aims to allocate a distributed set of subcarriers to one user. It can be further divided in to interleaved subcarrier mapping mode and random interleaved subcarrier mapping mode. In interleaved subcarrier mapping, the mapped distributed subcarriers are equidistant to each other, while, in random interleaved subcarrier mapping, these subcarriers are distributed randomly.

Figure 1 further explains the concept of localized subcarrier mapping mode and interleaved subcarrier mapping mode of the OFDMA.

Moreover, the interleaved-OFDMA is one of the promising multiple access techniques for future mobile radio communication systems [5]. OFDMA is widely adopted in the various communication standards like Worldwide Interoperability for Microwave Access (WiMAX), Mobile Broadband Wireless Access (MBWA), Evolved UMTS Terrestrial Radio Access (E-UTRA), Ultra Mobile Broadband (UMB), OFDMA is also a strong candidate for the Wireless Regional Area Networks (WRAN) and Layered OFDMA of LTE-Advanced. However OFDMA has some drawbacks, among others, the peak-to-average power ratio (PAPR) is still one of the major drawbacks in the transmitted OFDMA signals.



(a)



(b)

Fig. 1. (a) Interleaved OFDMA and (b) Localized OFDMA.

Therefore, for zero distortion of the OFDMA signals, the high-power-amplifier (HPA) must not only operate in its linear region but also with sufficient back-off. Thus, HPA with a large dynamic range are required for OFDMA systems. These amplifiers are very expensive and are major cost component of the OFDMA systems. Thus, if we reduce the PAPR it not only means that we are reducing the cost of OFDMA systems and reducing the complexity of A/D and D/A converters, but also increasing the transmit power, thus, for same range improving received signal-to-noise ratio (SNR), or for the same SNR improving range.

A large number of PAPR reduction techniques have been proposed in the literature. Among them, schemes like constellation shaping [6], nonlinear companding transforms [7], clipping and filtering [8], partial transmit sequence (PTS) [9], selective mapping (SLM) [10-11] and precoding based techniques [12-14] are popular. The precoding based techniques, however, show great promise as they are simple linear techniques to implement without the need of any side information.

This paper presents a new DHT precoding based OFDMA uplink system for PAPR reduction in 4G cellular networks. This paper is organized as: section 2 describes the basics of the interleaved-OFDMA, in Section 3 we present the proposed system model for PAPR reduction, and Section 4 presents the computer simulation results and Section 5 concludes the paper.

2. Interleaved-OFDMA Uplink System

Figure 2 illustrates the block diagram of interleaved-OFDMA uplink system. In interleaved-OFDMA uplink system, the baseband modulated symbols are passed through serial-to-parallel (S/P) converter, which generates the complex vector of size M. We can write complex vector of size M as $X = [X_o, X_1, X_2, \ldots.., X_{M-1}]^T$. After this, the N subcarrier mapping is carried out to the vector X in interleaved mode, and we get $\hat{Y}_k = \left[\hat{Y}_0, \hat{Y}_1, \hat{Y}_2, \ldots\ldots, \hat{Y}_{N-1}\right]^T$. For k^{th} user, the complex baseband interleaved-OFDMA uplink signal with N system's subcarriers and M user's subcarriers can be written as follows

$$x_n^{(k)} = \frac{1}{N}\sum_{k=0}^{M-1} \hat{Y}_k^{(k)} . e^{j2\pi \frac{kQ+m}{N} n} \qquad (1)$$

where $n = 0, 1, 2, \ldots N$-1, $m = 0, 1, 2, \ldots Q$-1. $\hat{Y}_k$ we get after subcarrier mapping, $j = \sqrt{-1}$, and $\hat{Y}_k^{(k)}$ is modulated signal on subcarrier k for k^{th} user. The PAPR of the conventional interleaved-OFDMA signal in Eq. (1) can be written as follows

$$PAPR = \frac{\max\limits_{n=0,1,\ldots.N-1} \left|x_n^{(k)}\right|^2}{\frac{1}{M}\sum_{n=0}^{N-1} \left|x_n^{(k)}\right|^2} \qquad (2)$$

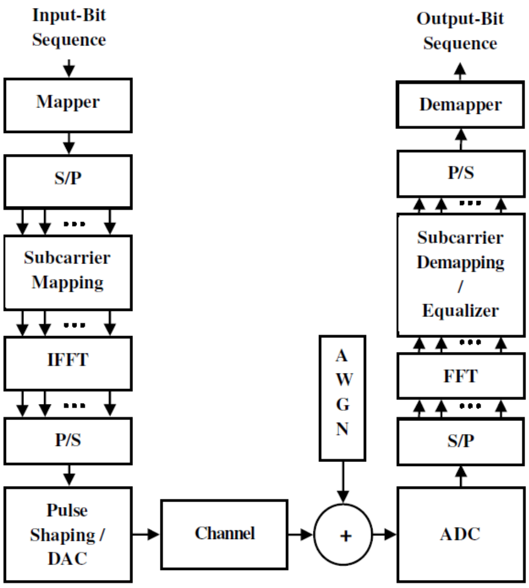


Fig. 2. Interleaved-OFDMA Uplink System.

3. Proposed Model

3.1. Discrete Hartley transform (DHT)

The DHT is a linear transform. In DHT, N real numbers x_o, x_1, ….., x_{N-1} are transformed into N real numbers H_o, H_1, ….., H_{N-1}. According to [15], the N-point DHT can be defined as follows

$$H_k = \sum_{n=0}^{N-1} x_n \left[\cos\left(\frac{2\pi nk}{N}\right) + \sin\left(\frac{2\pi nk}{N}\right) \right] = \sum_{n=0}^{N-1} x(n) \text{cas}\left(\frac{2\pi nk}{N}\right) \tag{3}$$

where cas $\theta = \cos\theta + \sin\theta$ and $k = 0, 1\ldots N\text{-}1$

$$a_{m,1} = \text{cas}\left(\frac{2\pi mn}{N}\right) \tag{4}$$

The precoding matrix A can be constructed as follows

$$A = \begin{bmatrix} a_{00} & a_{01} & \cdots & a_{0(L-1)} \\ a_{10} & a_{11} & \cdots & a_{1(L-1)} \\ \vdots & \vdots & \ddots & \vdots \\ a_{(L-1)0} & a_{(L-1)1} & \cdots & a_{(L-1)(L-1)} \end{bmatrix} \tag{5}$$

A is precoding matrix of size $L\times L$ shown in Eq. (5), m and l are integers from 0 to L-1. The DHT is also invertible transform which allows us to recover the x_n from H_k and inverse can be obtained by simply multiplying DHT of H_k by $1/N$.

3.2. DHT precoding based interleaved-OFDMA uplink system

Figure 3 shows a DHT precoding based interleaved-OFDMA uplink system. In DHT precoding based interleaved-OFDMA uplink system a precoding matrix A of dimension $L\times L$ is applied to constellations symbols before the subcarrier mapping and IFFT to reduce the PAPR. In the proposed system, the baseband modulated data is passed through the S/P converter which generates a complex vector of size M that can be written as: $X = [X_o, X_1, X_2, \ldots.., X_{M-1}]^T$. After that, the DHT precoding is applied to this complex vector which transforms this complex vector into new vector of length $L = M$ that can be written as: $Y=AX = [Y_o, Y_1, Y_2, \ldots.., X_{L-1}]^T$ and Y_M can be written as follows

$$Y_m = \sum_{l=0}^{L-1} a_{m,l}.X_l \text{ , } m = 0, 1, \ldots., L\text{-}1 \tag{6}$$

$a_{m,l}$ means m^{th} row and l^{th} column of precoder matrix. After the precoding, the subcarrier mapping is done in interleaved mode. Mathematically, the subcarrier mapping in interleaved mode can be done as follows

$$\hat{Y}_l = \begin{cases} Y_{\frac{l}{Q}}, & l = Q.k \quad 0 \le k \le M\text{-}1 \text{ otherwise} \\ 0 \end{cases} \tag{7}$$

where $0 \le l \le N$-1, $N = Q.M$, N is system subcarriers, M is user subcarriers, and Q is subchannels/users ($Q = N/M$).

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

$$x_n^{(k)} = \frac{1}{N}\sum_{l=0}^{M-1}\hat{Y}_l^{(k)}.e^{j2\pi\frac{lQ+k}{N}n}\ ,\ n = 0, 1, 2, \ldots N\text{-}1 \tag{8}$$

where, user index k = 0, 1, …, Q-1 and $\hat{Y}_l^{(k)}$ is modulated signal on subcarrier l for k^{th} user. The complex pass and signal of DHT precoded interleaved-OFDMA after RRC pulse shaping can be written as follows

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

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. The root raised cosine (RRC) pulse shaping filter can be defined as follows

$$r(t) = \frac{\sin\left(\frac{\pi t}{\breve{T}}(1-\alpha)\right) + 4\alpha\frac{t}{\breve{T}}\cos\left(\frac{\pi t}{\breve{T}}(1+\alpha)\right)}{\frac{\pi t}{\breve{T}}\left(1-\frac{16\alpha^2 t^2}{\breve{T}^2}\right)}, \qquad 0\le\alpha\le 1 \tag{10}$$

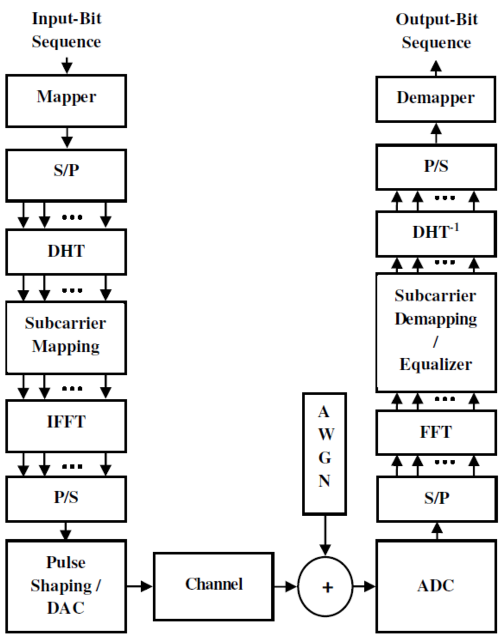


Fig. 3. DHT Precoding Based Localized-OFDMA System.

The PAPR of DHT precoded interleaved-OFDMA signal in Eq. (9) with pulse shaping can be written as follows

$$PAPR = \frac{\max_{0 \le t \le N\breve{T}} |x(t)|^2}{\frac{1}{N\breve{T}} \int_0^{N\breve{T}} |x(t)|^2 dt} \tag{11}$$

The PAPR of DHT precoded Interleaved-OFDMA signal in Eq. (8) without pulse shaping can be written as follows

$$PAPR = \frac{\max_{n=0,1,\ldots,N-1} \left|x_n^{(k)}\right|^2}{\frac{1}{M} \sum_{n=0}^{N-1} \left|x_n^{(k)}\right|^2} \tag{12}$$

4. Simulation Results

Extensive simulations in MATLAB® have been performed to analyse the PAPR of the proposed DHT precoding based interleaved-OFDMA uplink system. We evaluate the PAPR statistically by using complementary cumulative distribution function (CCDF). The CCDF of PAPR, for interleaved-OFDMA uplink signal, is used to express the probability of exceeding a given threshold $PAPR_0$ (i.e., CCDF = $Pr(PAPR>PAPR_0)$). We also compared our simulation results with the conventional interleaved-OFDMA uplink systems and WHT precoded interleaved-OFDMA uplink systems. Simulation parameters used in the simulation are chosen to reflect the LTE standard and are tabulated in the Table 1 as follows

Table1. System Parameters.

Channel Bandwidth	5MHz
User Subcarriers	16
System Subcarriers	512
Modulation	QPSK, 16-QAM and 64-QAm
Precoding	DHT and WHT
Pulse Shaping	Root Raised Cosine (RRC)
RRC Roll-off Factor	Alpha=0.22
CCDF Clip-Rate	10^{-3}

Figure 4 shows the CCDF comparison of PAPR of the DHT precoding based interleaved-OFDMA uplink system with the conventional interleaved-OFDMA uplink systems and the WHT precoding based interleaved-OFDMA uplink systems. At clip rate of 10^{-3}, with user subcarriers M = 16 and system subcarriers N =512, the PAPR is reduced to 9.9 dB, 8.8 dB and 7 dB respectively, for the conventional interleaved-OFDMA uplink system, WHT precoded interleaved-OFDMA uplink system and DHT precoded interleaved-OFDMA uplink system.

Figure 5 shows the CCDF comparison of PAPR of the DHT precoding based interleaved-OFDMA uplink system with the conventional interleaved-OFDMA uplink systems and the WHT precoding based interleaved-OFDMA uplink systems. At clip rate of 10^{-3}, with user subcarriers M = 16 and system subcarriers N =512, the PAPR is reduced to 9.9 dB, 8.9 dB and 7.9 dB respectively, for the conventional interleaved-OFDMA uplink system, WHT precoded interleaved-OFDMA uplink system and DHT precoded interleaved-OFDMA uplink system.

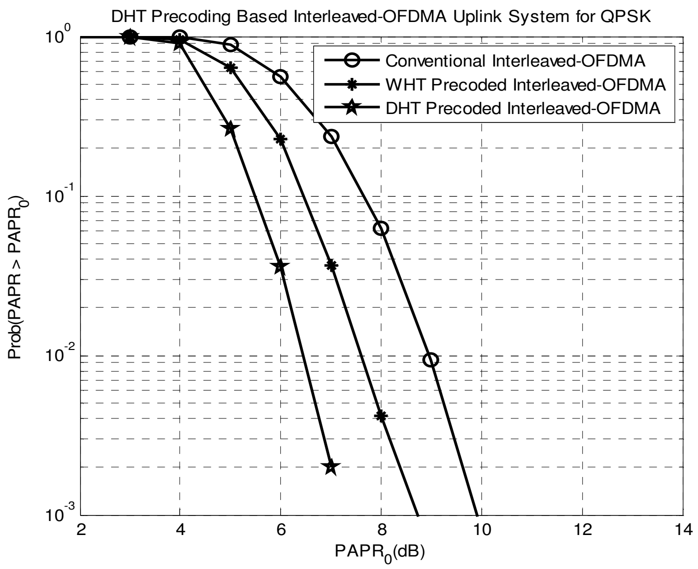


Fig. 4. CCDF Comparison of the PAPR of the DHT Precoded Interleaved-OFDMA Uplink with the Conventional Interleaved-OFDMA Uplink and the WHT Precoded Interleaved-OFDMA Uplink with *M*=16 (User Subcarriers) and *N*=512 (System Subcarriers) for QPSK Modulation.

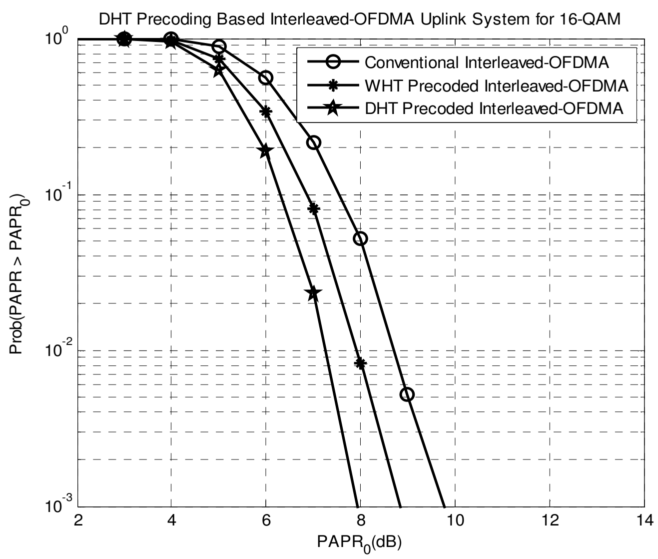


Fig. 5. CCDF Comparison of the PAPR of the DHT Precoded Interleaved-OFDMA Uplink with the Conventional Interleaved-OFDMA Uplink and the WHT Precoded Interleaved-OFDMA Uplink with *M*=16 (User Subcarriers) and *N*=512 (System Subcarriers) for 16-QAM Modulation.

Figure 6 shows the CCDF comparison of PAPR of the DHT precoding based interleaved-OFDMA uplink system with the conventional interleaved-OFDMA uplink systems and the WHT precoding based interleaved-OFDMA uplink systems. At clip rate of 10^{-3}, with user subcarriers M = 16 and system subcarriers N = 512, the PAPR is reduced to 9.9 dB, 9 dB and 8 dB respectively, for the conventional interleaved-OFDMA uplink system, WHT precoded interleaved-OFDMA uplink system and DHT precoded interleaved-OFDMA uplink system.

Thus, it can be seen that the PAPR performance of the DHT precoding based interleaved-OFDMA uplink system is better than the no-precoding or the popular WHT precoding based OFDMA systems. The improvement is most for QPSK constellation based system than for 16 QAM or 64 QAM based systems.

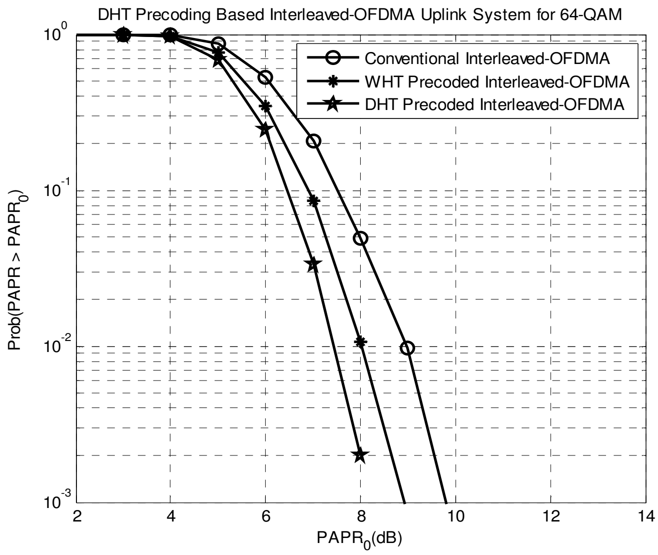


Fig. 6. CCDF Comparison of the PAPR of the DHT Precoded Interleaved-OFDMA Uplink with the Conventional Interleaved-OFDMA Uplink and the WHT Precoded Interleaved-OFDMA Uplink with *M*=16 (User Subcarriers) and *N*=512 (System Subcarriers) for 64-QAM Modulation.

5. Conclusions

In this paper, we proposed a new DHT precoded interleaved-OFDMA uplink system with improved PAPR for 4G cellular networks. MATLAB® simulation shows that DHT precoded interleaved-OFDMA uplink system shows better PAPR gain as compare to the conventional interleaved-OFDMA uplink systems and the WHT precoded interleaved-OFDMA uplink systems. Hence, it is concluded that the proposed DHT precoding based interleaved-OFDMA uplink system is more favourable than the conventional interleaved-OFDMA uplink systems and the WHT precoded interleaved-OFDMA uplink systems. The DHT precoded OFDMA uplink system also take the advantage of the frequency variations of the communication channel and can also offer substantial performance gain in fading multipath channels.

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