BER and PAPR Analysis of DFT Precoded OFDM Multilayer IDMA (P-OFDM ML IDMA) Signals

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Abstract—In this paper, Discrete Fourier Transform Precoded Orthogonal Frequency Division Multiplexing Multilayer Interleave Division Multiple Access (DFT P OFDM ML IDMA) communication system has been proposed. Chip by Chip (CBC) iterative receiver is used to recover the data in each layer. Also, different precoding techniques has been applied with and without clipping in the proposed P OFDM ML IDMA. Simulation results confirm that the DFT precoder provides better PAPR reduction compared with other precoded methods with and without clipping. BER and PAPR simulation results shows that the proposed DFT P OFDM ML IDMA brings about 7 dB PAPR reduction and 0.5 dB BER improvement compred with OFDM ML IDMA. The Simulations for the proposed DFT P OFDM ML IDMA with 2 - 6 layers shows that the variation is 3.4 to 8.2 dB for the PAPR and 7.8 to 8.7 dB for the BER. So, the adaptive modulation can be simply realized by the proposed DFT P OFDM ML IDMA.

Index Terms—PAPR, DFT, precoding, OFDM and IDMA.

I. INTRODUCTION

Interleave-Division Multiple-Access (IDMA) was recently investigated. IDMA uses different chiplevel interleavers to distinguish different users, all adopting the same spreading sequence. The key principle of IDMA systems is that the chip-level interleavers should be different for different users. In addition, a low-cost CBC iterative detection can be utilized in the IDMA systems [1], [2]. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission scheme that has become the technology choice for next generation wireless and wire line digital communication systems [3].

IDMA can be combined with OFDM (OFDM-IDMA) integrates the advantages of both OFDM and IDMA in order to mitigate the intersymbol interference (ISI) and suppress the multiple access interference (MAI) simultaneously [4], [5]. OFDM-IDMA suffers PAPR problem. The transmitted signal of OFDM-IDMA has high PAPR, which may degrade the efficiency of power amplifier of the transmitters.

A number of PAPR reduction schemes have been proposed for OFDM systems, such as clipping [6], partial transmit sequence method (PTS) [7], and selected mapping method (SLM) [8]. In [9], clipping is adopted in OFDM-IDMA systems for PAPR reduction but interference from clipping noise will reduce BER performance.

To alleviate the above problem, precoding based

techniques, however, show great promise as they are simple linear techniques to implement without the need of any side information. Precoding improves PAPR without increasing much complexity and without destroying the orthogonality between subcarriers. The precoding also improves the BER in comparison to normal OFDM system because of diversity gain obtained due to the spreading of data symbol among more than one subcarrier.

In this paper, we present DFT precoder for clipped and Unclipped OFDM ML IDMA signals to reduce PAPR. Performance comparison is made with other transform-based precoders, namely Discrete Hartley Transform (DHT) and Zadoff-Chu Transform (ZCT) [7], [10].

This paper is organized as follows: Section II presents the proposed DFT P-OFDM ML IDMA system adopted in this paper; in Section III, computer simulation results are given and the system performance is also analyzed; the conclusions are given in Section IV.

II. PROPOSED DFT PC-OFDM ML IDMA

A. Transmitter

Fig. 1. Proposed DFT P-OFDM ML IDMA transmitter

The transmitter based on OFDM ML IDMA with K layers is shown in Fig. 1 binary data sequence d is first partitioned into K subsequences. For k -layer, the data sequence d_k is spread using a length- S spreading sequence S_k . we write the chip sequence obtained after spreading as $S_k = [s_k(1), \dots, s_k(j), \dots, s_k(J)]^T$, where J is the block length. Then S_k is permuted by an interleaver π_k , yielding $v_k = [v_k(1), \dots, v_k(j), \dots, v_k(J)]^T$. After interleaving, the sequence v_k is modulated to a sequence x_k by binary phase shift keying (BPSK) mapping. Then all the data of K layers are linearly superimposed to transmission. The output signal x is a linear superposition of independently symbol in (1).

$$x(j) = \sum_{k=1}^K x_k(j) \quad j = 0, 1, \dots, J-1 \quad (1)$$

After ML IDMA signal processing, x is passed to DFT precoder P yielding X in (2):

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$$X(v) = \sum_{m=0}^{M-1} x(m) \cdot e^{-j2\pi mv/M}, v = 0, 1 \dots M-1 \quad (2)$$

which have the same size as *IFFT* is used as a precoded spreading code. Thus, the OFDM system becomes equivalent to the Single Carrier (SC) system because the *DFT* and *IDFT* operations virtually cancel each other [11].

In this case, the transmit signal will have the same PAPR as in a single-carrier system which results in improvement in PAPR. We assume that the size of DFT is equal to the block length, namely $M=J$. The transmitted time domain channel symbol that is obtained from the inverse DFT (IDFT) of X is:

$$y(n) = \frac{1}{N} \sum_{l=0}^{N-1} X(l) \cdot e^{j2\pi nl/N}, n = 0, 1 \dots N-1 \quad (3)$$

B. Receiver

The received signal can be written as:

$$R = h \cdot y + n \quad (4)$$

where n is additive white Gaussian noise (AWGN) with variance σ^2 . We assume that the channel gains h are independent, identically distributed and perfectly known at transmitter and receiver. We consider the AWGN channel. The received data is first implemented by FFT and the IDFT precoder. For the sake of attaining the best possible performance, the structure of CBC iterative multiple user detection of IDMA is shown in Fig. 2.

Fig. 2. Proposed DFT P-OFDM ML IDMA receiver

This structure consists of a soft-in-soft-out (SISO) Elementary Signal Estimator (ESE) and a bank of K individual SISO Decoding for the de-spreading operation (DES), where the soft information exchanged between the receiver components is constituted by the extrinsic Log-Likelihood Ratios (LLRs).

We adopt the low complexity ESE algorithm derived in [11], [12]. This algorithm is derived through Gaussian approximation based on the assumption that the interfering symbols are independent of each other. This assumption is reasonable when the block is long enough because of the layer-specific random interleavers.

$$\bar{X}(v) = \sum_{n=0}^{N-1} R(n) e^{-j2\pi vn/N} \quad v = 0, 1, \dots, N-1 \quad (5)$$

Then implements De-precoding using IDFT, producing r

$$r(v) = \frac{1}{M} \sum_{m=0}^{M-1} \bar{X}(m) e^{j2\pi vm/M} \quad v = 0, 1, \dots, M-1 \quad (6)$$

In the process of IDMA detection, we reformulate the algorithm for BPSK signaling as:

$$r_k = h_k \sum_{m=0}^{M-1} x_m + n_k \quad (7)$$

$$r_k = h_k x_m + \zeta_k \quad (8)$$

where ζ_k is the interference in r_k with respect to layer m .

$$\zeta_k \equiv r_k - h_k x_m = h_k \sum_{m'=0, m' \neq m}^{M-1} x_{m'} + n_k \quad (9)$$

From the central limit theorem ζ_k can be approximated as Gaussian variable, and r_k can be characterized by conditional Gaussian probability function, e.g. BPSK is adopted $x_k \in \{+1, -1\}$.

$$p(r_k | x_m = \pm 1) = \frac{1}{\sqrt{2\pi \text{var}(\zeta_k)}} \exp \left[-\frac{(r_k - (\pm h_k + E(\zeta_k)))^2}{2 \text{var}(\zeta_k)} \right] \quad (10)$$

where $E(*)$ and $\text{Var}(*)$ are the mean and variance functions, respectively. The output Log Likelihood Rate (LLR) of $\hat{X}$ can be expressed as:

$$\text{llr}(\hat{X}_m) = \log \left[\frac{p(r_k | x_m = +1)}{p(r_k | x_m = -1)} \right] = 2h_k \frac{r_k - E(\zeta_k)}{\text{var}(\zeta_k)} \quad (11)$$

where

$$\begin{aligned} E(\zeta_k) &= E \left(h_k \sum_{m'=0, m' \neq m}^{M-1} x_{m'} + n_k \right) \\ &= h_k \sum_{m'=0, m' \neq m}^{M-1} E(x_{m'}) \\ &= E(r_k - h_k E(x_m)) \end{aligned} \quad (12)$$

$$\begin{aligned} \text{var}(\zeta_k) &= |h_k|^2 \sum_{\substack{k'=1 \\ k' \neq k}}^K \text{Var}(x_{m'}) + \sigma^2 \\ &= \text{Var}(r_k) - |h_k|^2 \text{Var}(x_m) \end{aligned} \quad (13)$$

$$\text{Ext}(x_m) = \log \left[\frac{p(x_m = +1)}{p(x_m = -1)} \right] \quad (14)$$

$E(x_m)$, $\text{Var}(x_m)$ both are determined by the input extrinsic information $\text{Ext}(x_m)$ defined in (14), given by re-interleaver module.

$$E(x_m) = \tanh \left(\frac{\text{Ext}(x_m)}{2} \right) \quad (15)$$

$$\text{Var}(x_m) = 1 - (E(x_m))^2 \quad (16)$$

Thus we can analyze and detect the signal of each layer through the mean and variance of the interlayer interference. And then the updated extrinsic LLR from ESE function goes through the layer-specific deinterleaver and gets into the DESs iteratively. After the last iteration, the DESs produce hard decisions towards information bits in each layer separately. Finally, the decision bits of each layer are parallel-to-serial converted to obtain the recovered data sequence.

III. SIMULATION RESULTS

In this subsection, simulations are carried out to evaluate the performance of P-OFDM ML IDMA system with and without clipping. In the simulations, the BPSK modulation and AWGN channel are employed. The spreading code length is $S=8$, and the spreading sequence $\{+1, -1, +1, -1, \dots\}$ is adopted for all layers and the subcarriers number is $N=128$ and the layers number is $L=2$, the number of iterations is 3.

Fig. 3 Shows the PARR comparisons of clipped OFDM ML

IDMA system at CRs (0.9, 1, 2) which improve PAPR performance but as shown in Fig. 4 the BER performance is degraded by 4 dB.

Fig. 5 shows the CCDF comparisons of the proposed DFT P-OFDM ML IDMA system (without clipping) which are better than original OFDM ML IDMA, ZCT P-OFDM ML IDMA and DHT P-OFDM ML IDMA, by about 7 dB, 3dB, 6 dB respectively.

As shown in Fig. 6 the proposed system (without clipping) using DFT precoder improves the BER performance by about 0.3 dB compared with original system.

Fig. 7 shows that the PAPR for both DFT P OFDM ML IDMA with and without clipping. It is shown that they have the same PAPR. The proposed DFT precoder improves the BER performance by about 0.3 dB compared with clipped system as shown in Fig. 8.

Fig. 9 shows the PAPR comparisons for different layers =2, 3, 4, 5 and 6 where the proposed DFT precoder system using 6 layers is better than original system using 2 layers by about 2 dB in addition to keep the BER performance as shown in Fig. 10.

The final simulated results for the proposal DFT P OFDM ML IDMA system is shown in Table I and II.

Fig. 3. PAPR of clipped OFDM ML IDMA

Fig. 4. BER for clipped OFDM ML IDMA

Fig. 5. PAPR of ZCT, DHT and DFT P-OFDM ML IDMA

Fig. 6. BER for ZCT, DHT and DFT P-OFDM ML IDMA

Fig. 7. PAPR of ZCT, DHT and DFT P Clipped systems

Fig. 8. BER for ZCT, DHT and DFT PC-OFDM ML IDMA

Fig. 9. PAPR DFT P-OFDM ML IDMA with layers = 2,3,4,5 and 6

Fig. 10. BER for DFT P-OFDM ML IDMA with layers = 2,3,4,5 and 6

TABLE I: PAPR REDUCTION AND BER PERFORMANCE ($CR=2$) PAPR AT $= 10^{-3}$ (dB), Eb/No AT BER $= 10^{-4}$ (dB)

Schemes	PAPR	Eb/No
OFDM ML IDMA	10.9	8.1
Clipped OFDM ML IDMA	6.37	8.6
ZCT OFDM ML IDMA	9.49	8.3
ZCT Clipped OFDM ML IDMA	6.5	8.5
DHT OFDM ML IDMA	6.47	8.8
DHT Clipped OFDM ML IDMA	4.28	9.2
DFT OFDM ML IDMA	3.46	7.8
DFT Clipped OFDM ML IDMA	3.44	8.7

TABLE II: ML PAPR AND BER PERFORMANCE ($CR=2$) PAPR AT $= 10^{-3}$ (dB), Eb/No AT BER $= 10^{-4}$ (dB)

Schemes	PAPR	Eb/No
DFT OFDM 2L IDMA	3.466	7.8
DFT OFDM 3L IDMA	5.246	8.4
DFT OFDM 4L IDMA	6.547	8.4
DFT OFDM 5L IDMA	7.345	8.5
DFT OFDM 6L IDMA	8.214	8.8

IV. CONCLUSIONS

In this paper, PAPR mitigation based on DFT, DHT and ZCT Precoding schemes has been applied to OFDM ML IDMA. CBC iterative receiver is indicated in this paper to recover the data of each layer. Simulation results confirm that the DFT precoder provides better PAPR reduction and improves the BER performance compared with DHT and ZCT precoder with and without clipping. Simulated results for the proposal DFT P OFDM ML IDMA system shows that the proposed system is an efficient bandwidth with increasing the number of layer.

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