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PAPR Reduction Method for the Localized and Distributed DFTS-OFDM System Using the Companding Technique

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Abstract— **Orthogonal Frequency Division Multiplexing (OFDM) is an efficient scheme for high speed data transmission in communication systems. However, this scheme has inherent problem of a High Peak to Average Power Ratio (PAPR), which causes significant reduction in performance and power efficiency of this scheme. In this paper, we propose a PAPR reduction method based on companding technique for the localized and Distributed Discrete Fourier Transform-Spread OFDM (DFTS-OFDM) systems. The simulation results indicate that the proposed method obtains about 10 dB PAPR reduction compared with simple OFDM systems.**

Keywords- OFDM; PAPR Reduction; Pre-coding; Companding method; LTE

I. INTRODUCTION

ORTHOGONAL Frequency Division Multiplexing (OFDM) is an attractive system that is used for high speed data transmission in wireless communications. In OFDM system the available spectrum is divided into subcarriers, which each subcarrier contains a low rate data stream. One of the major issues of OFDM is the high Peak to Average Power Ratio (PAPR is also known as PAR) value of transmitted signals. Due to high PAPR, the High Power Amplifiers must be operated in nonlinear region, which is not desirable. In addition, High PAPR would restrict OFDM system performance.

Recently, different techniques have been proposed to reduce the high PAPR problem, such as clipping [1], pre-coding [2], companding [3], partial transmit sequence (PTS), selected mapping [4], active constellation extension (ACE) [5], tone reservation (TR) and tone injection (TI) [6].

Each method has some advantages and disadvantages. Clipping is the simplest method for PAPR reduction in OFDM system, but it results in out-of-band radiation and in-band distortion. Companding method is a very good, but large PAPR reduction results in a high bit error rate (BER). The PTS and SLM are distortion-less, while suffering from high computational complexity. The TR, TI and ACE methods require a power increase in the transmit signal. The pre-coding technique does not require any power increment neither needs complex optimization nor submission of side information to the receiver. Moreover, pre-coding method can reduce the PAPR more than other methods [7].

This work studies the combination of pre-coding and companding methods with different techniques for adding a zero matrix to the pre-coded matrix in order to minimize the PAPR in OFDM systems.

II. OFDM SYSTEM AND PAPR DEFINITION

A. OFDM System

In OFDM system set of N baseband modulated data symbols are first passed through serial to parallel convertor, which generates a complex vector of length N. this vector is defined as:

$$X = [X_0, X_1, \dots, X_{N-1}]^T \quad (1)$$

where $[.]^T$ denotes the matrix transpose after IFFT. The OFDM signal can be written as equation (2):

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \,.\, e^{j2\pi n \Delta f t}, \quad 0 \le t \le NT \quad (2)$$

where $j = \sqrt{-1}$, $\Delta f = 1/(NT)$, T is the original bit period and $x(t)$ is the transmitted OFDM signal.

B. Definition of PAPR in OFDM system

The PAPR of OFDM signal can be written as:

$$\text{PAPR} = \frac{\max|x(t)|^2}{E[|x(t)|^2]} \quad (3)$$

where $E[.]$ is expectation.

PAPR is measured in terms of complementary cumulative distribution function (CCDF), which can be written as:

$$\Pr\{PAPR > \lambda\} = 1 - (1 - e^{-\lambda})^N \quad (4)$$

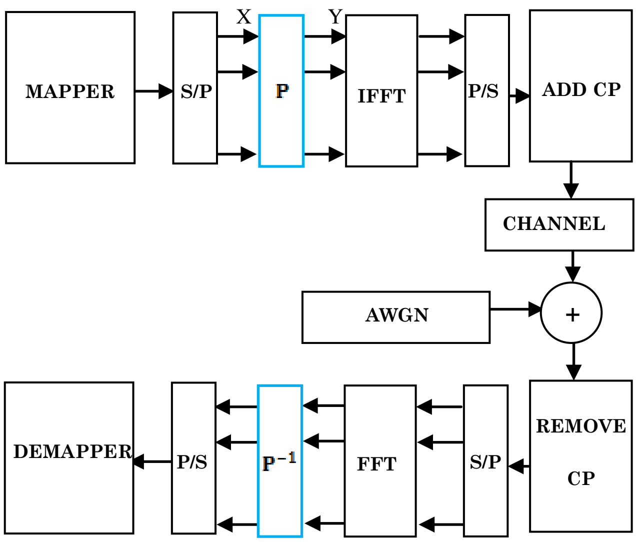


Fig.1 Block diagram of pre-coding based OFDM system

III. Proposed Method

A. *Pre-coding based, OFDM SYSTEM*

Figure 1 shows the block diagram of pre-coding based OFDM system. The pre-coding process is implemented with the pre-coding matrix P before the IFFT transform. In [7] described that the DFT-Pre-coding is better than other pre-coding techniques because it produces lowest PAPR.

DFT-Pre-coded OFDM system or DFT based OFDM system is also called DFTS-OFDM. DFTS-OFDM is a transmission scheme that can combine desired properties that are:

- Small variation in instantaneous power of transmitted signal ("single-carrier" property);
- Possibility for low-complexity high-quality equalization in the frequency domain;
- Possibility for FDMA with flexible bandwidth assignment.

Due to these properties, DFTS-OFDM is, for example, used for uplink data transmission in LTE.

In DFTS-OFDM systems the size of FFT pre-coder is smaller than size of IFFT transform, because if the FFT pre-coder size equals the IFFT size, the cascade FFT/IFFT processing would obviously completely cancel each other out. However, enlarging size of pre-coder length to the same size of IFFT block output by use of intentional zeros would not cause any data loss or requires additional power.

There are different techniques for adding a zero vector to the pre-coded vector. Zero vector padding and interleaving are two techniques that can be used. The modified block diagrams of DFTS-OFDM system are shown in Figures 2a and 2b.

In both Figures 2a and 2b set of N baseband modulated data symbols X_i are passed through serial to parallel convertor, which generate a complex vector X of size N as:

$$X = [X_0, X_1, \dots, X_{N-1}]^T \quad (5)$$

Then, the DFT pre-coding is applied to the X, to generate a new vector Y of length L that can be written as:

$$Y = P \cdot X = [Y_0, Y_1, \dots, Y_{L-1}]^T \quad (6)$$

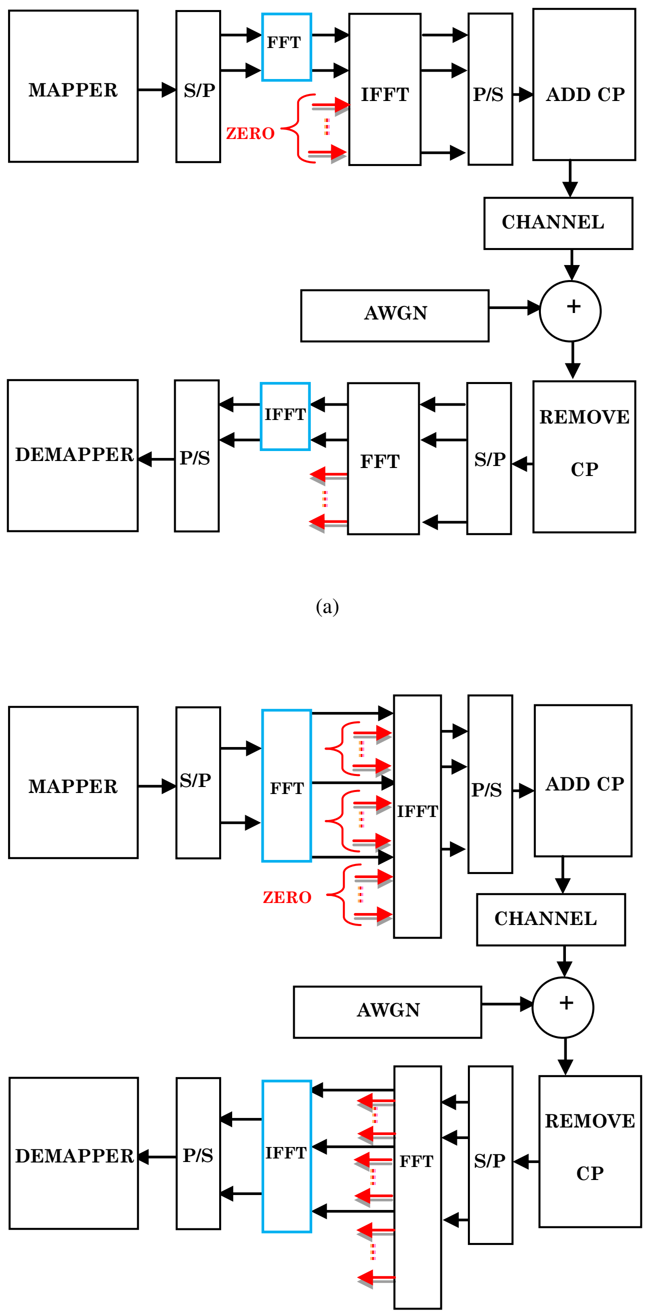
where P is a DFT precoder matrix of size $L \times N$. The value of matrix P in [2] is described as:

$$P = \begin{bmatrix} P_{0,0} & \cdots & P_{0,(N-1)} \\ \vdots & \ddots & \vdots \\ P_{(L-1),0} & \cdots & P_{(L-1),(N-1)} \end{bmatrix} \quad (7)$$

$$P_{i,m} = P_{i,0} e^{-j2\pi \frac{im}{N}} \quad (8)$$

where $P_{i,0}$ in this equation is defined as:

$$P_{i,0} = \begin{cases} \frac{(-1)^i}{\sqrt{N}} \sin\left(\frac{\pi i}{2N_P}\right) & 0 \le i < N_P \\ \frac{(-1)^i}{\sqrt{N}} & N_P \le i < N \\ \frac{(-1)^i}{\sqrt{N}} \cos\left(\frac{\pi(i-N)}{2N_P}\right) & N \le i < L-1 \end{cases} \quad (9)$$



(a)

(b)

Fig.2 Block diagram of DFTS-OFDM system with (a) zero padding technique and, (b) zero interleaving technique

Next, a zero vector of length N_P is added to the pre-coded vector Y.

After the DFT-pre-coding, we can use Zero padding or Zero interleaving techniques in order to zero insertion to the pre-coded vector. The Figure 3 shows an example of zero insertion techniques in the frequency domain for N=4 subcarriers.

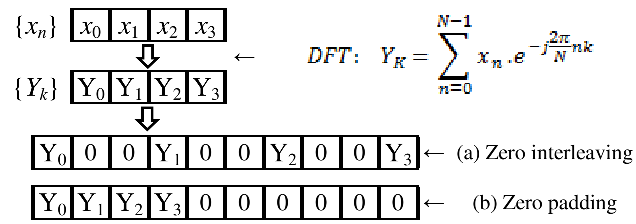


Fig.3 Example of zero insertion techniques in the frequency domain for N = 4 subcarriers with (a) zero interleaving, (b) zero padding

In this paper we consider three models for the zero insertion as equation (10a), (10b) and (10c).

$$B = \begin{bmatrix} b_0 & b_1 & b_{\left(\frac{L}{2}-1\right)} & \overbrace{0 \ldots 0}^{N-L} & b_{\left(\frac{L}{2}\right)} & b_{L-1} \end{bmatrix}^T \quad (10a)$$

$$B = \begin{bmatrix} b_0 & b_1 & b_{L-1} & \overbrace{0 \ldots 0}^{N-L} \end{bmatrix}^T \quad (10b)$$

$$B = [b_0 \quad b_1 \quad 0 \quad \ldots \; b_{L-2} \quad b_{L-1} \quad 0]^T \quad (10c)$$

Then the generated vector with zeros is passed through the IFFT block to produce a time domain signal $x(t)$ that can be written as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} b_n . e^{j\frac{2\pi n}{T}t} \quad ; \quad 0 \leq t < T \quad (11)$$

where T is the OFDM symbol duration.

For effectively PAPR reduction, the μ-law companding method is applied after the parallel to serial convertor and before cyclic prefix (CP) insertion. Inversely at receiver, the Expander should be employed between CP remover and serial to parallel converter. Hence, the compressed signal is defined as:

$$x_u(t) = \frac{\ln\left[1 + \frac{\mu|x(t)|}{x_{max}(t)}\right]}{\ln[1+\mu]} . x_{max}(t). \mathrm{Sgn}(x(t)) \quad (12)$$

where:

$x(\cdot)$: input signal;

$x_u(\cdot)$: output signal;

$\text{Sgn}(\cdot)$: sign of the input (+1 or –1);

$x_{max}(\cdot)$: Maximum uncompressed analog input;

μ :Parameter used to define the amount of compression & standard value taken is 255.

I. Simulation Results

In this section, the PAPR of conventional OFDM, companded Localized and Distributed DFTS-OFDM systems have been evaluated and compared using Simulink toolbox of MATLAB. The μ-law companding technique with μ=255 employed in new systems. Data symbols were generated randomly with the Bernoulli Binary bit generator. The bit stream vector length is 80 bits and modulated by QPSK baseband modulator. The length of FFT pre-coder is 40 and a zero vector with the length of 13 is added to it. Also IFFT size N and CP in OFDM modulator are 64 and 16, respectively.

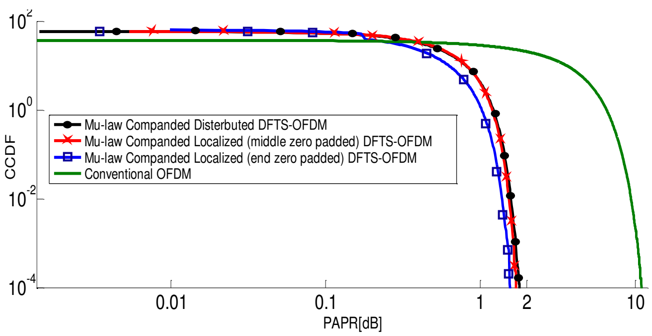


Fig.4 CCDF of various types of OFDM systems

The power spectral density (PSD) of various OFDM systems are provided in Figures 5 to 8 for further comparison and study the effect of conducted processes on OFDM signal.

Figure 4 compares the CCDF of the PAPR curves of conventional and other types of discussed OFDM systems. Generally, the Companded Localized DFTS-OFDM system which uses zero padding in the end of bit stream has the lowest PAPR value in same CCDF value. The second minimum PAPR achieved for Companded Localized DFTS-OFDM system which uses zero padding in the middle of bit stream. Third record belongs to the Companded Distributed DFTS-OFDM system. It can be observed from the Figure 4 that at a clip rate of 0.0001, the PAPR gains of 11.1 dB, 1.57 dB, 1.72 dB and 1.79 dB are achieved for conventional, Companded Localized DFTS (zero padded at end and middle of bit stream) and Companded Distributed DFTS systems, respectively.

The power spectral density (PSD) of various OFDM systems are provided in Figures 5 to 8 for further comparison and study the effect of conducted processes on OFDM signal.

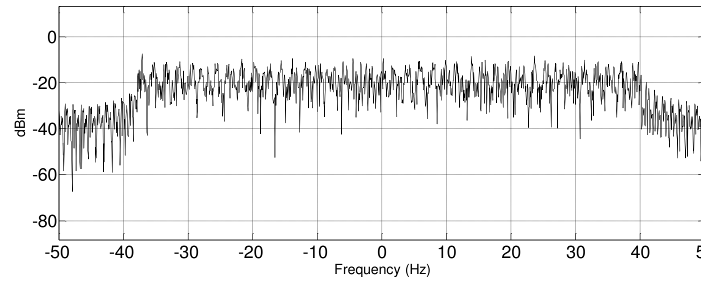


Fig.5 PSD of conventional OFDM system

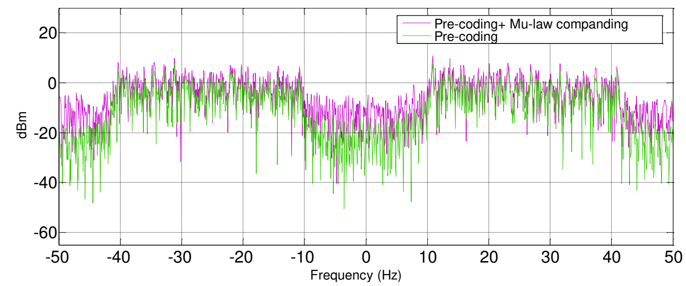


Fig.6 PSD of μ-law companded Localized DFTS-OFDM which used zero padding in the middle bit stream (with μ=255)

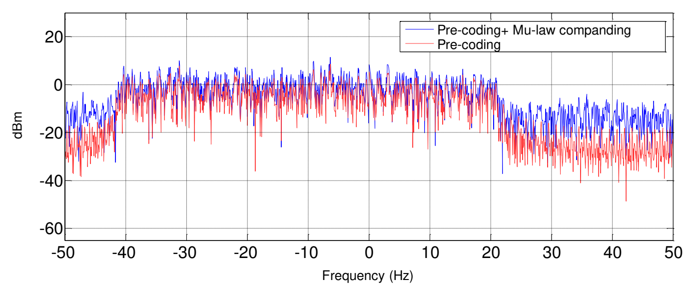


Fig.7 PSD of μ-law companded Localized DFTS-OFDM which used zero padding in the end of bit stream (with μ=255)

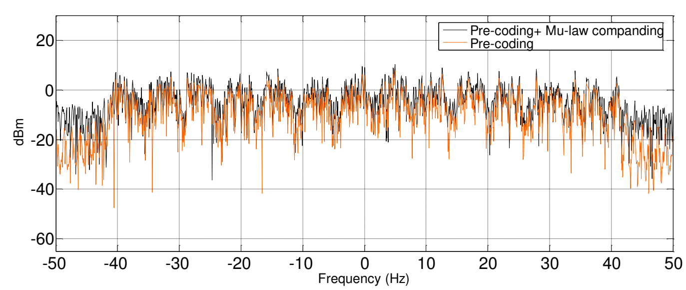


Fig.8 PSD of μ-law companded Distributed DFTS-OFDM (with μ=255)

CONCLUSION

In this paper, we propose a companding method for the Distributed and Localized DFT-Spread (DFTS) OFDM systems to reduce the high PAPR. Simulation results show that the proposed method have better PAPR performance than the conventional OFDM system and the developed scheme, which has been based on pre-coding and companding methods, has better ability of PAPR reduction in OFDM systems. Moreover, the hybrid companded and pre-coded scheme is reduced the PAPR by about 10 dB.

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Authors Profile

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