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Peak-to-Average Power Ratio Reduction of SFBC MIMO-OFDM Signals Using Unused Tones

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Abstract — Multiple input multiple output techniques combined with orthogonal frequency division multiplexing (MIMO-OFDM) provide a promising approach for wireless systems. However, a serious drawback of the OFDM system is the high peak-to-average power ratio (PAPR), which may severely affect the power efficiency of RF power amplifiers. In this paper, we propose a simple method to reduce the PAPR of MIMO-OFDM signals based on the use of unused subcarriers. Instead of processing the signals at each transmitter separately, a peak cancelling signal is generated at one antenna and is then applied to all the others with only simple modifications. Simulation has shown that a minimum 2 dB reduction in PAPR can be achieved for all transmit signals using this approach. As the signal processing is nearly all done at a single transmitter, repetition of the operations at each transmitter is avoided, and therefore the overall cost of the system can be significantly reduced.

Index terms — Clipping, Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Ratio (PAPR), Space Frequency Block Coding (SFBC).

I. INTRODUCTION

OFDM is a popular technology and has been adopted for many new and emerging broadband communication systems including wireless LAN, WiMAX, digital video broadcasting and 4G mobile systems. In this technique, the transmission frequency band is divided into a large number of subcarriers that are orthogonal to each other. The information is then divided onto multiple lower-speed signals that are transmitted simultaneously on different frequencies in parallel. MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance. OFDM combined with MIMO technology is an attractive candidate for modern mobile communication systems due to its ability to support high data rates, large capacity, and robustness to multipath fading [1].

As is also observed for single-input single-output (SISO) OFDM systems, MIMO-OFDM signals exhibit a high peak-to-average power ratio. High peak values cause saturation of power amplifiers and therefore introduce both in-band and out-of-band distortion. To prevent such phenomena, the power amplifier in the transmitters must be “backed off” into the linear region, which then severely impacts the power efficiency. To overcome this problem, a straightforward approach is to apply existing PAPR reduction techniques

proposed for SISO systems directly to the MIMO systems [2]. However, the system implementation complexity will be significantly increased when multiple antennas are employed.

Previously we reported an efficient PAPR reduction technique which exploits the use of a small number of the unused tones present in OFDM systems [3]. This technique can effectively reduce the PAPR by 2 to 4 dB. In this paper we extend this idea to MIMO-OFDM systems. The main concept is to generate a peak cancellation signal at only one of the transmit antennas in the MIMO system which is then applied to the other transmitters with a simple signal manipulation. This avoids repeating the same operation at each separate transmitter, and the overall cost of the system can thus be significantly reduced.

Space-frequency block coding (SFBC) has attracted increasing attention in MIMO systems because it is robust to time selective fading channels. In the paper, we employ 2x2 SFBC based MIMO-OFDM as an example to introduce our idea but the proposed approach is not limited to the 2x2 system, and it can be generally applied to any other similar systems.

II. OFDM AND PAPR

In OFDM modulation, a block of N symbols X_n ($n=0,1,2,\dots,N-1$) is transmitted in parallel, and each of them modulates a group of N subcarriers f_n ($n=0,1,2,\dots,N-1$). The subcarriers are orthogonal to each other, and $f_n = n\Delta f$, where $\Delta f = 1/T$ and T is the symbol period. The resulting baseband OFDM signal $x(t)$ can be written as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t}, 0 \leq t \leq T \quad (1)$$

In real implementation, the digital transmission signal may be generated by the Inverse Fast Fourier Transform (IFFT) in the transmitter and restored by Fast Fourier Transform (FFT) in the receiver. The PAPR of the OFDM signal can be defined as:

$$PAPR = \frac{\max_{0 \leq t \leq T} |x(t)|^2}{E \{ |x(t)|^2 \}} \quad (2)$$

where $E\{\cdot\}$ denotes the expectation operation. Because independent phases of subcarriers may align with each other, OFDM signals often exhibit a high PAPR, and the PAPR increases proportionally with the number of subcarriers.

The complementary cumulative distribution function (CCDF) is often used to characterize the probability that PAPR of an OFDM signal exceeds a given threshold ($PAPR_0$), which can be expressed as

$$CCDF = \Pr(PAPR > PAPR_0) \quad (3)$$

III. MIMO-OFDM SYSTEM

A 2X2 MIMO-OFDM based on space-frequency block coding that employs the Alamouti Scheme [4] is depicted in Fig.1,

Fig. 1. 2X2 MIMO-OFDM system

The sequences of data bits are first modulated using an M-ary modulation scheme and then the SFBC scheme is employed to spread the information data across the 2 antennas at the transmitter. Consider that, $\mathbf{X} = [X_1 \ X_2 \ \dots \ X_{N-1} \ X_N]$ is the data signal modulated. In a usual communication transmission, X_1 will be sent in the first time slot, X_2 in the second time slot, and so on. In a MIMO system, Alamouti scheme suggests an arrangement of the symbols into groups of two, which is usually represented by a matrix:

$$\begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \quad (4)$$

where each column represents the subcarrier position in the OFDM signal and each row corresponds to the symbols transmitted from different antennas. For example, the first subcarrier in the first antenna transmits symbol X_1 and the second antenna transmits X_2 , while on the second subcarrier, the first antenna transmits $-X_2^*$ and the second antenna transmits X_1^* , where $()^*$ denotes complex conjugate. The output of SFBC for antenna 1 can be expressed as $\mathbf{X}_1 = [X_1 \ -X_2^* \ \dots \ X_{N-1} \ -X_N^*]$ and the output of antenna 2 is $\mathbf{X}_2 = [X_2 \ X_1^* \ \dots \ X_N \ X_{N-1}^*]$. These signals are then modulated to a group of subcarriers using the IFFT in each transmitter, respectively. Since the signals are different in each transmission path, separated PAPR reduction must be conducted for each antenna, which increases the system complexity and implementation cost.

IV. PROPOSED TECHNIQUE

In order to avoid using complicated PAPR reduction for each transmitter separately, we propose here to generate the peak cancelling signal from only one transmitter and then apply it to all transmitters in the system.

Fig. 2. Block diagram of the proposed PAPR reduction technique

The proposed technique is based on the use of unused subcarriers. In practical OFDM systems, not all subcarriers are employed to transmit user data; some subcarriers are reserved and set to zero. For instance, in a WIMAX system with 256 IFFT/FFT size, 192 tones are used data subcarriers, 8 tones are pilot subcarriers and 56 are null subcarriers, while in a LTE system with FFT size of 2048, the number of used subcarriers are 1200 and 848 subcarriers are unused tones. In [3], a solution was proposed to use some of these unused tones to reduce the PAPR of OFDM signals. The idea is to absorb the distortion caused by PAPR reduction by setting small values on some of the unused tones instead of spreading the distortion on all data carriers or out-of-band frequencies. Although this results in a slight broadening of the original spectrum, it is possible for the spectrum to remain well inside the spectrum mask defined by the standards. Since these unused tones do not affect the original data carriers, they can be used to reduce the PAPR without increasing the BER or introducing out-of-band distortion. In this paper, we extend this idea to SFBC-based MIMO-OFDM systems.

We can see that if we know $\mathbf{X}_1$, we can easily generate $\mathbf{X}_2$ from $\mathbf{X}_1$ using the relationship defined by the matrix (4). In the same way, if we know the peak cancelling signal $\mathbf{C}_1$ for antenna 1, we could generate the peak cancelling signal $\mathbf{C}_2$ for antenna 2 from $\mathbf{C}_1$ by using the same relationship. For example, if $\mathbf{C}_1 = [C_1 \ -C_2^* \ \dots \ C_{N-1} \ -C_N^*]$, then $\mathbf{C}_2 = [C_2 \ C_1^* \ \dots \ C_N \ C_{N-1}^*]$. We present this idea in detail as follows:

- I). The signal from antenna 1 is first clipped in the time domain, which can be described as:

$$\bar{x}_1(n) = \begin{cases} A \cdot e^{j\theta(n)}, & |x_1(n)| > A \\ x_1(n), & |x_1(n)| \leq A \end{cases} \quad (5)$$

where $\bar{x}_1$ represents the output of the clipped time domain signal, A is the clipping threshold, and ϕ is the signal phase and $\|\cdot\|$ returns the magnitude value.

- II). Following an FFT transform, the data carriers are restored to their original value while a small, pre-selected number of unused tones retain their clipped values. These new values on the unused tones can be considered as the peak canceling signal, C1.
- III). The signal is then converted back into the time domain using IFFT to check for the presence of peaks. If the PAPR is below the desired threshold A , the signal is transmitted, otherwise the values of the unused subcarriers C1 are scaled by a factor α in the frequency domain to increase their absorption of the clipping effects so as to bring the time domain peak value down further. An optimal or near-optimal scaling factor can be found after 2 or 3 iterations. As a result, an optimum peak cancelling signal C1 is generated for antenna 1 transmitting the data signal X1.
- IV). The peak cancelling signal C2 then can be generated from C1 by using the matrix (4), and this may then be used directly to set the values on the unused tones in the data sequence transmitted by antenna 2, which can reduce the PAPR of X2 in the time domain.

The block diagram of this process is shown in Fig. 2. The advantage of this approach is that the process of finding an optimum peak cancelling signal, i.e., steps I) to III) above, needs only to be conducted once in one transmitter.

IV. RESULTS

In order to validate the proposed PAPR reduction technique, a test bench was set up with a WiMAX signal using 64-QAM as well as a 3GPP LTE signal with 16-QAM. The signal processing was conducted in MATLAB.

In the WiMAX signal, the IFFT/FFT size was 256 and 56 unused tones were employed. The peak cancelling signal was first generated for antenna 1 and then applied to antenna 2. Figs. 3 and 4 illustrate the CCDF plots of the WiMAX signals at antenna 1 and 2 respectively before and after PAPR reduction, where we can see that over 2.5 dB reduction at the 0.01% (1e-4) probability can be achieved for both antennas.

A 20MHz downlink LTE signal, containing 2048 subcarriers with 16-QAM modulation, was also used for further test purposes. In this signal, there were 1200 subcarriers for data transmission and 848 unused tones for peak reduction operation. The CCDF plots are shown in Figs. 5 and 6 for antenna 1 and antenna 2, respectively, where a 2

dB PAPR reduction at the 0.01% probability level was also achieved for both antennas.

Fig. 3 CCDF showing the PAPR reduction performance for antenna 1 for a WiMax signal

Fig. 4. CCDF showing the PAPR reduction performance for antenna 2 for a WiMax signal

Fig. 5. CCDF showing the PAPR reduction performance for antenna 1 for a LTE signal

Fig. 6. CCDF showing the PAPR reduction performance for antenna 1 for a LTE signal

IV. CONCLUSIONS

In this paper, we have introduced a novel technique to reduce the PAPR of MIMO-OFDM signals. The idea focuses on utilizing the unused subcarriers of OFDM signals to generate the peak cancelling signal only in one transmitter and then applying this to other transmitters with simple signal processing. This avoids repeating the same operation at each transmitter separately, which significantly reduces the overall complexity and the cost of the system. Although only a 2x2 MIMO system was tested in the paper, this technique can be readily extended to other systems that use a larger number of transmit and receive antennas.

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