PAPR Reduction Technique Using Unused Subcarriers for SFBC-based MIMO-OFDM Systems

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***Abstract*— Orthogonal frequency division multiplexing based multiple input multiple output techniques (MIMO-OFDM) tend to achieve high data rate transmission targets for 4G wireless communication systems. However, due to its inherent drawback of high peak-to-average power ratio (PAPR), the OFDM based transmission may severely affect the power efficiency of RF power amplifiers. In this paper, we propose a simple approach to reduce the PAPR of MIMO-OFDM signals based on the use of unused subcarriers. In order to avoid processing the signals at each transmitter separately, a peak cancelling signal is only generated at one antenna and then employed to all the others with only simple modifications. Simulation has shown that by using this proposed approach, a minimum 2 dB reduction in PAPR can be achieved for all transmit signals. Since the generation of the peak cancellation signal for each transmitter separately is avoid, the overall cost of the system can be significantly reduced.**

I. Introduction

As a special case of multi-carrier transmission techniques, OFDM has been applied to many new and emerging broadband communication systems including WLAN, WiMAX, DVB and 4G LTE mobile communication systems. To increase the robustness against the frequency selective fading, in this technique, a large number of subcarriers, which are orthogonal to each other, are used to simultaneously transmit the multiple lower-speed signals, which carry the original information on different frequencies in parallel. MIMO system 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 observed for single-input single-output (SISO) OFDM systems, MIMO-OFDM signals also exhibit a high peak-to-average power ratio, which causes saturation of power amplifiers and consequently introduces both in-band and out-of band distortion. To avoid suffering from such distortions, the power amplifier in the transmitters must be "backed off" into its linear operating region, which then severely impacts the power efficiency. In order to overcome this problem, a straightforward approach is to apply existing PAPR reduction techniques proposed for SISO systems directly to the MIMO systems. Unfortunately, the system implementation complexity will be significantly increased when multiple antennas are employed.

Previously we proposed an efficient PAPR reduction technique for SISO-OFDM system which exploits the use of a small number of the unused subcarriers present in the transmission band [2]. This approach can effectively reduce the PAPR by 2 to 4 dB. We extended this idea to MIMO-OFDM systems in [3]. In this paper we further explain this idea and give more simulation results. The main concept of this solution is to generate a peak cancellation signal at only one of the transmit antennas in the MIMO system and then applied to the other transmitters with a simple signal manipulation. This avoids repeating the same PAPR reduction operation at each separate transmitter, and the overall cost of the system can thus be significantly reduced.

Due to its robustness to time selective fading channels, space-frequency block coding (SFBC) has attracted increasing attention in MIMO systems. 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. MIMO-OFDM And PAPR

In OFDM modulation, a block of N symbols X_n (n=0,1,2,…N-1) is transmitted in parallel, and each of them modulates a group of N subcarriers f_n (n=0,1,2…,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 expressed as follow:

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

Practically, the digital transmission signal may be generated by the Inverse Fast Fourier Transform (IFFT) in the transmitter and restored by the Fast Fourier Transform (FFT) in the receiver.

MIMO uses multiple antennas to enable data to travel along multiple independent paths. This technology effectively places more data into the available airwaves to increase throughput and/or coverage. It is particularly beneficial in high interference environments like urban areas. An example of 2x2 MIMO-OFDM based on space-frequency block coding that employs the Alamouti Scheme [4] is depicted in Fig.1.

The sequences of data bits are first modulated using an M-ary modulation scheme and then the SFBC encoder 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 modulated data signal. 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 SFBC-based MIMO system, Alamouti scheme suggests an arrangement of the symbols into groups of two, which is usually represented by a matrix:

$$\begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \tag{2}$$

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 encoder for antenna 1 can be expressed as $\mathbf{X}1= [X_1\ -X_2^* \dots\ X_{N-1}\ -X_N^*]$ and the output for 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, and demodulated using the FFT in the receiver, respectively.

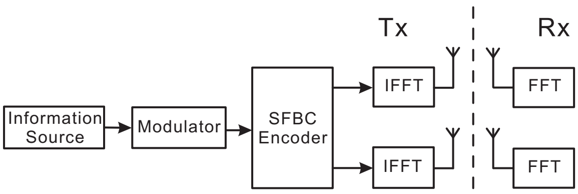

Fig. 1 Block diagram of a 2x2 MIMO-OFDM system

Due to the statistical independence of the subcarriers and the summation of orthogonal subcarriers, the time domain OFDM signal exhibits a high peak-to-average power ratio, which can be defined as:

$$\text{PAPR} = 10\log_{10}\left(\frac{\max\limits_{0\le t\le T}[|x(t)|^2]}{E[|x(t)|^2]}\right) \tag{3}$$

where $E[\cdot]$ denotes the expectation operation. The PAPR of the OFDM signal increases proportionally with the number of subcarriers. Since the signals are different in each transmission path, separated PAPR reduction must be conducted for each antenna for MIMO-OFDM systems, which increases the system complexity and implementation cost.

III. Proposed Technique

In order to avoid using complicated PAPR reduction for each transmitter separately, in this work we propose an approach in which the peak cancelling signal is only generated from one transmitter and then applied to all transmitters in the system with an 'encoder'.

The proposed technique is based on the use of unused subcarriers. In a practical system, not all the subcarriers of OFDM systems 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 data subcarriers, 8 tones are pilot subcarriers and 56 are null subcarriers, while in a LTE system with IFFT/FFT size of 2048, the number of used subcarriers are 1201 and 847 subcarriers are unused tones. In [2], a solution was proposed to use some of these unused subcarriers 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. 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.

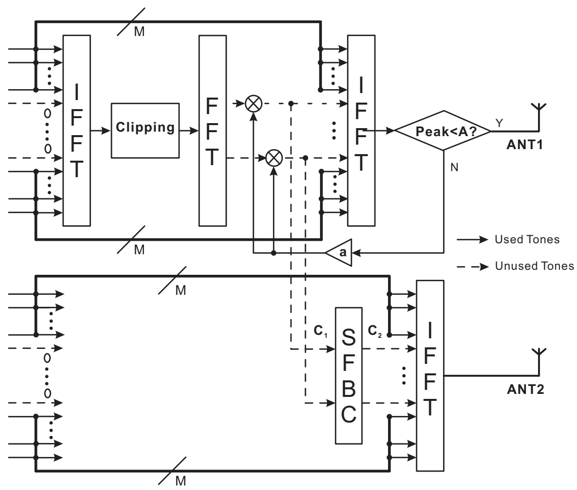

Fig. 2 Block diagram of the proposed PAPR reduction technique

From (2), we can see that if $\mathbf{X}1$ is given, we can easily generate $\mathbf{X}2$ from $\mathbf{X}1$ using the relationship defined by the SFBC encoding matrix. 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 $\mathbf{C}2= [C_2\ C_1^*\ \dots\ C_N\ C_{N-1}^*]$. This leads that we only need to conduct the PAPR reduction algorithm, namely, peak cancelling signal searching, in one transmitter, and then apply to the other transmitters using the above relationship. The detailed operation is presented as follows:

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

$$\overline{x}_1(n) = \begin{cases} A\cdot e^{j\theta(n)}, & |x_1(n)| > A \\ x_1(n), & |x_1(n)| \le A \end{cases} \tag{4}$$

where $\overline{x}_1$ represents the output of the clipped time domain signal, A is the clipping threshold, and ϕ is the signal phase and $|.|$ 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, **C**1.

III). The signal is then converted back into the time domain using IFFT transform 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 **C**1 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 **C**1 is generated for antenna 1 transmitting the data signal **X**1.

IV). The peak cancelling signal **C**2 then can be generated from **C**1 by using the relationship shown in 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 **X**2 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 to be conducted only once in one transmitter.

IV. Results

In order to validate the proposed PAPR reduction technique for the MIMO-OFDM system, a WiMAX signal with 64-QAM and a 3GPP LTE signal with 16-QAM were used. The signal processing was conducted in a simulation tool MATLAB.

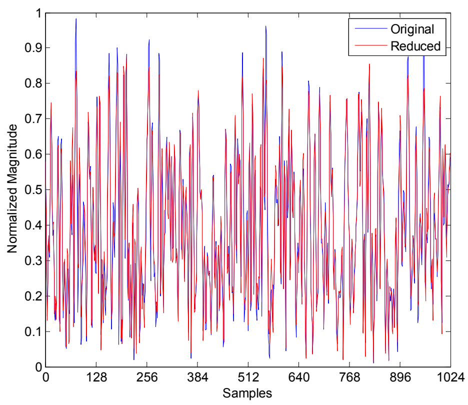

Fig. 3 Time domain signal of antenna 1 before and after PAPR reduction for a WiMAX signal.

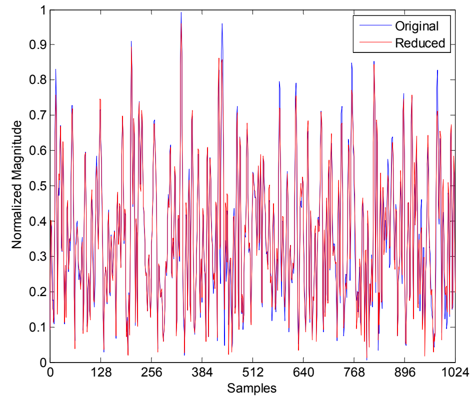

Fig. 4 Time domain signal of antenna 2 before and after PAPR reduction for a WiMAX signal.

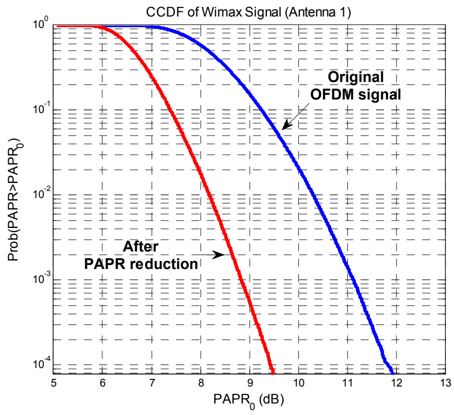

Fig. 5 CCDF showing the PAPR reduction performance of antenna 1 for a WiMAX signal

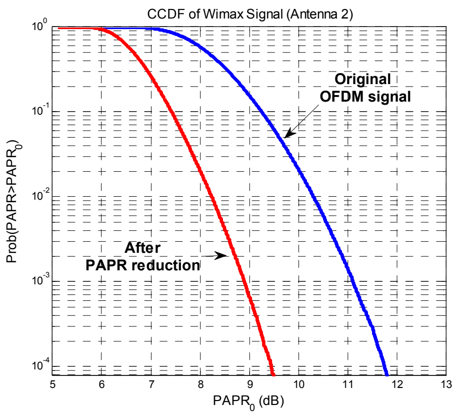

Fig. 6 CCDF showing the PAPR reduction performance of antenna 2 for a WiMAX signal

For 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. Fig. 3 and Fig. 4 show the waveforms before and after PAPR reduction in the time domain. Figs. 5 and 6 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.

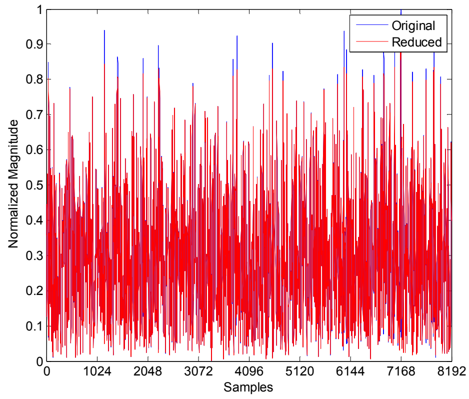

Fig. 7 Time domain signal of antenna 1 before and after PAPR reduction for a LTE signal.

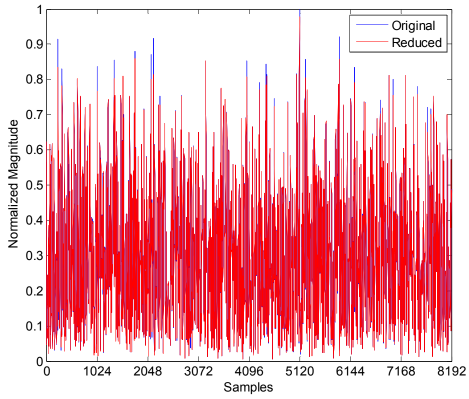

Fig. 8 Time domain signal of antenna 2 before and after PAPR reduction for a LTE signal.

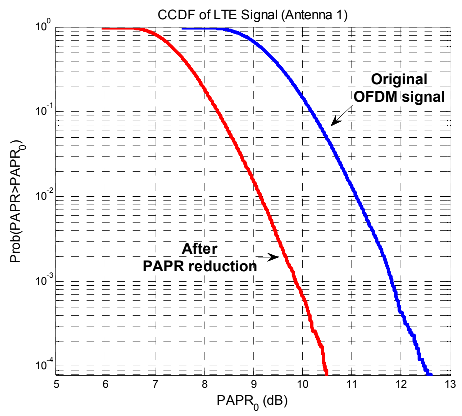

Fig. 9 CCDF showing the PAPR reduction performance of antenna 1 for a LTE signal.

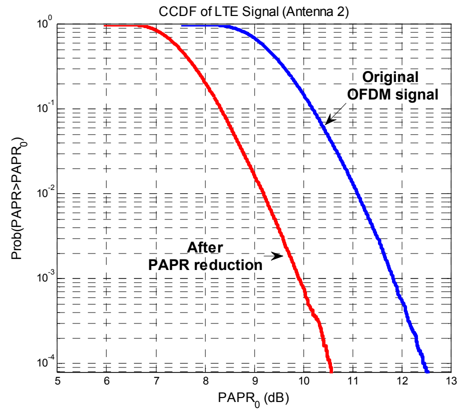

Fig. 10 CCDF showing the PAPR reduction performance of antenna 2 for a LTE signal.

A 20MHz downlink LTE signal, containing 2048 subcarriers with 16-QAM modulation, was also used for further test purposes. In this signal, there were 1201 subcarriers for data transmission and 847 unused tones for peak reduction operation. The time domain waveforms are shown in Fig. 7 and Fig. 8, while the CCDF plots are shown in Figs. 9 and 10 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.

V. Conclusions

In this paper, we have introduced a novel technique to reduce the PAPR of SFBC-based 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 apply it 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.

Acknowledgment

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References

[1] M. Jankiraman, *Space-Time Codes and MIMO Systems*, Artech House, Boston, 2004.

[2] C. Devlin, A. Zhu, and T. J. Brazil, "Peak to average power ratio reduction technique for OFDM using pilot tones and unused carriers," *The IEEE Radio and Wireless Symposium*, Orlando, FL, USA, Jan. 2008.

[3] I. Braz, L. Guan, A. Zhu, and T. J. Brazil, "Peak-to-average power ratio reduction of SFBC MIMO-OFDM signals using unused tones," *The IEEE International Microwave Workshop Series on RF Front-ends for Software Defined and Cognitive Radio Solutions* (*IMWS*), Aveiro, Portugal, Feb. 2010.

[4] K. Lee and D. Williams, "A space-frequency transmitter diversity technique for OFDM systems," in *Proc. IEEE GLOBECOM*, pp.1473–1477, San Francisco, USA, Nov. 2000.