Peak to Average Power Ratio Reduction for Multi-band OFDM System using Tone Reservation

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1 Abstract

OFDM and its extension Multi-band OFDM (MB-OFDM) are considered as the modulation schemes for many future communications systems. But these schemes cause high PAPR which should be reduced before power amplification otherwise non-linearities can occur. In this paper Tone Reservation method is used for OFDM PAPR reduction where a corrective signal is added to the original signal to reduce its PAPR. The effect of some corrective signal properties which influence the PAPR reduction performance are discussed. It is revealed that corrective signal's bandwidth and power are proportional to PAPR reduction gain while the bandwidth gap between useful and corrective carriers is inversely proportional to the PAPR reduction gain. Finally MB-OFDM PAPR reduction is performed and it is demonstrated that PAPR reduction performed with corrective tones optimization over all OFDM symbols is more efficient but computationally more complex at the same time. This MB-OFDM PAPR reduction method can also be generalized for PAPR reduction of a Software Radio signal.

2 Introduction

MB-OFDM is perceived for Ultra Wide Band (UWB) system designed under IEEE 802.15.3a Task Group proposal for Wireless Personal Area Network (WPAN) communications where OFDM bands of 500 MHz each are used for multi-banding and the data is hopped across these multi-bands [1]. Likewise OFDM is used in many communication systems like DAB, IEEE 802.11a, etc. due to its strong immunity to multi-path fading. However, one of the main disadvantages of OFDM is its high PAPR that demands the transmitter power amplifier operation in a low efficiency zone. Otherwise this high power fluctuating signal when passed through a nonlinear device, such as a power amplifier, causes in-band and out-of-band distortions. Several solutions have been proposed to decrease the PAPR of OFDM.

The simplest approach is to clip the OFDM signal but clipping itself is a nonlinear process and causes in-band distortions that results in the Bit Error Rate (BER) performance degradation [2]. Some other techniques use coding, in which a data sequence is embedded in a larger sequence and only a subset of all the possible sequences are used to exclude patterns with high PAPR [3]. Also some multiple signal representation techniques have been proposed which include Partial Transmit Sequence (PTS) technique [4], Selective Mapping Technique (SLM) [5], and interleaving technique [6]. These techniques require side information to be transmitted to recover the original data from the received signal. Another kind of method [7] uses the reserved tones to generate the reducing signal. Wang [8] proposes a method with low complexity also based on the concept of Tones Reservation. Unfortunately, this method uses a trial-and-error approach without a deep theoretical justification. Recently, a method using convex optimization subject to constraints on the allowed constellation error to reduce PAPR has been presented [9]. Contrary to Tones Reservation (TR) methods, it reduces PAPR by adding a corrective signal to all data carriers that degrades the BER. Also [10] proposed the improvements of the methods proposed in [7] and [8] by modeling them as a Second Order Cone Program (SOCP). Sticking to the same TR methodology, the impact of the added tones' specific parameters on PAPR are observed. These parameters include added signal's bandwidth, position and its average power. Finally MB-OFDM case is considered and its PAPR reduction is performed using TR. Computational complexity aspects are detailed for MB-OFDM underlying the fact that MB-OFDM PAPR reduction scenario can be extended for Software Radio signals.

The paper is organized as follows. In section 3, OFDM, MB-OFDM signal model and PAPR notion are defined. Also the basic concept of Tone Reservation is discussed. In section 4, PAPR reduction is performed with different specifications of the added signal to see their effect on PAPR reduction performance. MB-OFDM PAPR reduction is performed in section 5 along with the discussion about complexity issues related to MB-OFDM PAPR reduction. Simulation and results are presented inside section 4 and 5. Finally, conclusions are drawn in section 6.

3 MB-OFDM Signal and PAPR Description

Let us denote the OFDM data of length N as a vector $X = [X_0, X_1, ..., X_{N-1}]$ where N is equal to the number of sub-carriers. Each OFDM symbol modulates each of the N subcarriers,$[f_n; n = 0, 1, ..., N-1]$ which are orthogonal

to each other. The complex envelop of the transmitted OFDM signal can be expressed as,

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}, 0 \leq t \leq T_S. \tag{1}$$

MB-OFDM is the transmission of these OFDM symbols over different frequency bands. As complex time-domain samples of MB-OFDM signals are approximately Gaussian distributed due to the statistical independence of carriers. This results in the generations of some very high peaks in the signal which can be quantified by the PAPR value. The PAPR, for a given OFDM symbol can be written as,

$$PAPR = \frac{\max_{t \in [0,T_S]} |x(t)|^2}{\frac{1}{T_S} \int_0^{T_S} |x(t)|^2 dt}, \tag{2}$$

where T_S is the OFDM symbol duration. As PAPR is a random variable thus it is evaluated in terms of its Complementary Cumulative Distribution Density Function (CCDF), that is, the probability that the PAPR exceeds a given threshold.

One approach for PAPR reduction is to search an additive corrective signal $\mathbf{c}$ in order to have $PAPR(\mathbf{x}+\mathbf{c}) < PAPR(\mathbf{x})$. One way to find $\mathbf{c}$ is to use optimization approaches. The signal addition is achieved in frequency domain as we can see in Fig 1 where corrective carriers are added in between the useful data carriers. Thus, the PAPR of the resulting signal $(\mathbf{x}+\mathbf{c})$ is given by:

$$PAPR = \frac{\max_{0 \leq k \leq N-1} |x_k + c_k|^2}{E[|\mathbf{x}+\mathbf{c}|^2]}. \tag{3}$$

In reality the ideal method to reduce PAPR would be to minimize the peak of the combined signal $(\mathbf{x}+\mathbf{c}$ while keeping the average power constant.

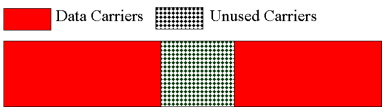

Figure 1: Unused carriers are used to reduce PAPR in Tone Reservation.

4 Corrective Signal's Parameter Influence on PAPR

4.1 BW Effect

Bandwidth of the added signal affects the performance of PAPR reduction scheme. More the bandwidth allocated for added signal more will be the PAPR reduction as more tones can be used to reduce PAPR but at the same time the average power of the added signal increases. Also it is not easy to find free bandwidth to transmit adding tones. Contrary if transmitted over useful band, the out of band interference shall be produced. Fig 2 testifies this fact where 2,4 and 6 tones are used to reduce PAPR of a 64 carrier OFDM signal.

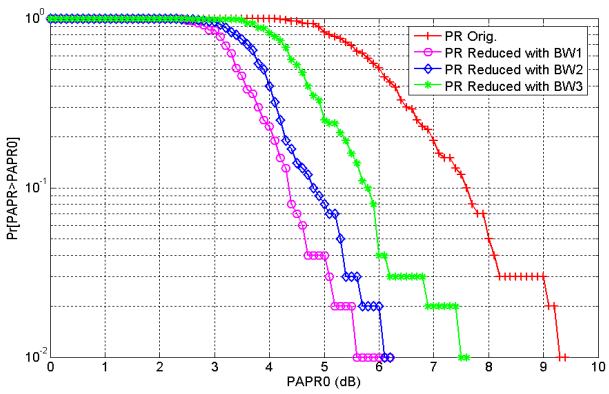

Figure 2: PAPR reduction with different BWs allocated for added signal.

4.2 Position Effect

Adding tones' position affects a lot the PAPR reduction performance. The tones nearer to the useful carriers reduce more PAPR than the farther tones. Let d be the frequency gap between useful OFDM carriers and corrective carriers. Fig 3 shows that 4 added tones at $d_1 = 4MHz$ reduce less PAPR than those at $d_1 = 2MHz$ and $d_3 = 0MHz$.

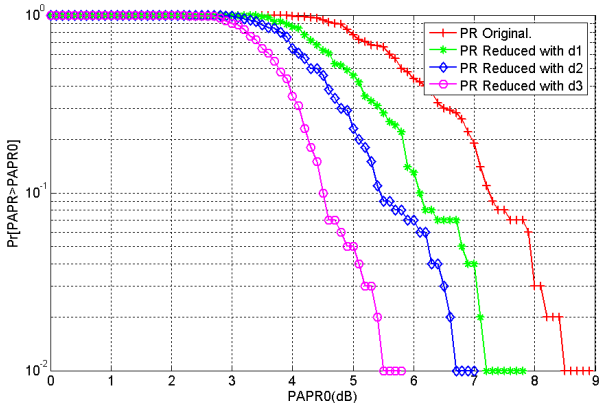

Figure 3: PAPR reduction with different frequency gaps between useful and added carriers.

4.3 Power Effect

It is not always possible to use the bandwidth closer to the useful band. Thus in order to achieve the same performance as with the closer tones, the power of the tones at larger distances must be increased. To have almost the same performance, mean power of the signal at d_2 ($P_{m_2} = 3.3dB$) must be almost doubled to $P_{m_1} = 6.4dB$ if corrective signal is placed at d_1 instead. Fig 4 highlights this mean power comparison.

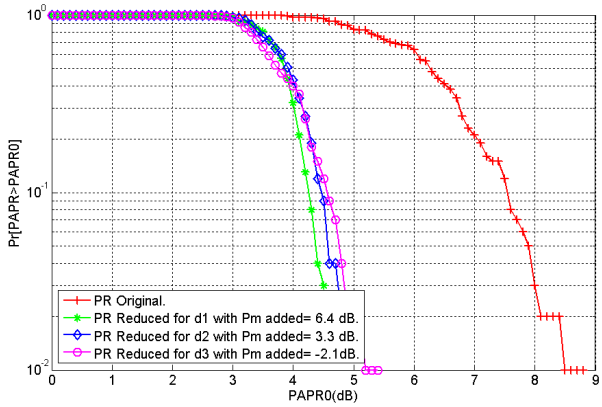

Figure 4: PAPR reduction with different mean power used for added signal to get same performance.

5 MB-OFDM PAPR Reduction and Complexity Issues

After dealing with the parameters affecting the PAPR reduction method we head towards the implementation of this scheme for MB-OFDM signal. For simplicity two OFDM symbols are considered which are separated by $25MHz$ as shown in Fig 5. Then 2 tones are added at d_3 for each of the two OFDM symbols. Initially optimization of the tones was performed over the whole spectrum reducing the PAPR of the overall signal. This process is more complex as minimization process is performed for a large FFT size. To reduce the complexity, Tone Reservation was performed for individual OFDM symbols separately but the PAPR reduction gain in this case is less than that in the former case as depicted in Fig 6. Thus appears the complexity vs performance compromise to be taken care of.

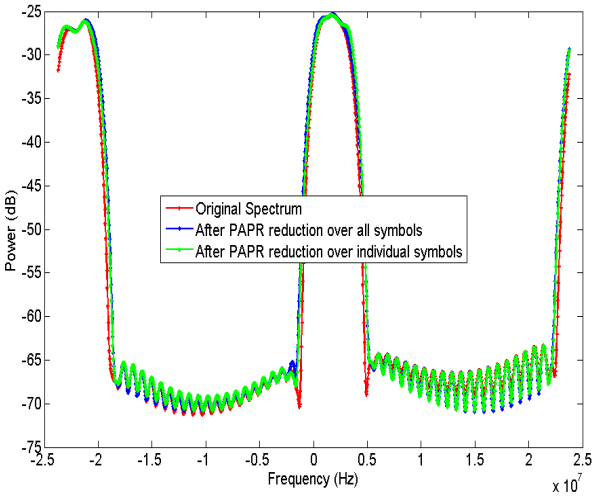

Figure 5: MB-OFDM Spectrum.

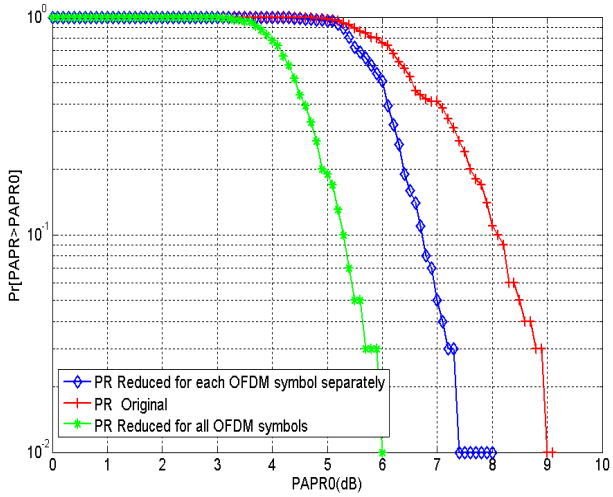

Figure 6: MB-OFDM PAPR reduction.

6 Conclusion

Tone Reservation is used for PAPR reduction of OFDM and MB-OFDM systems. Effect of corrective signal's parameters on PAPR reduction performance is discussed. These parameters include corrective signal's bandwidth, its distance from original data spectrum and its mean power. Finally PAPR reduction of a two OFDM symbol scheme is performed. It is shown that the optimization of the corrective tones performed over whole OFDM spectrum results in more PAPR reduction compared to the optimization performed over individual symbols but this gain is achieved at the cost of greater computational complexity. Further, the process can be generalized for more than two OFDM symbols scenario and eventually for a Software Radio system containing different standard signals.

References

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