Joint spectrum access scheme for peak power control in Cognitive Radios

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1 Abstract

High Peak to Average Power Ratio (PAPR) is a parameter commonly associated to the multi-carrier signals like Orthogonal Frequency Division Multiplexing (OFDM). SoftWare Radio (SWR) is another example of multi-carrier signals and inherits high PAPR. Also, as SWR is an enabling technology for Cognitive Radio (CR) systems, therefore signals also demonstrate high power fluctuations in CR context. Upon opportunistic spectrum access in CR, the situation regarding PAPR becomes even grave as more carriers (secondary carriers) are added in an already large numbered multi-carrier signal (primary signal). This paper explores the PAPR variations on spectrum access in CR context. Also, the reduction of PAPR in CR is performed using a PAPR reduction method called Tone Reservation (TR). In TR, certain carriers of the data signal are reserved to create a peak reducing signal which on addition to the data signal reduces its peak power. These carriers are called peak reducing carriers (*PRC*). CR PAPR is reduced by presenting a joint spectrum access scheme which implies a part of secondary carriers as *PRC* to reduce CR PAPR.

2 Introduction

High speed applications have brought in new standards along with the need of efficient spectrum utilization. CR [1] with SWR [2] technology at its heart promises the solution to this mingling standard scenario with intelligent spectrum access for all sorts of signals. In CR the spectrum is accessed in opportunistic manner by unlicensed (secondary) users such that it should not affect the performance of licensed (primary) users. But the spectrum access can result in out of band distortions as larger number of carriers are being amplified by the transmitter non-linear component, the power amplifier (PA). This element is particularly sensitive to high fluctuating signals (multi-carrier signals). Signal fluctuations are normally described by power ratio between maximum and mean powers of the signal termed as Peak to Average Power Ratio (PAPR). As a consequence, a spectrum sensor should take into account the PAPR value of the transmitted signal on the available bandwidth to keep the PAPR value under an acceptable level which does not imply any changes to power amplifier design.

There are several methods developed to reduce OFDM signal PAPR. But all the existing PAPR reduction methods come at some cost. In case of some methods the price is BER degradation as in Clipping[3], Tone Injection[4] etc. While some methods suffer receiver modifications like coding methods[5]. On the other hand some methods need SI transmission to recover the data like PTS[6].The focus in this paper is on a method that does not change the standard specifications and the receiver design. Also no data-rate loss and no BER degradation occurs on PAPR reduction. The methods [4, 7] fall under the Tone Reservation (TR) class of PAPR reduction methods and satisfy our requirements. In TR methodology, a subset of carriers is reserved to generate the peak reducing signal. Accordingly these reserved carriers are called peak reducing carriers (*PRC*). As the reserved tones are orthogonal to the data tones, thus no BER degradation occurs. In [8], a very basic study on TR application for SWR signals is performed where the PAPR of a SWR system containing two hypothetical standards is reduced.

In this paper TR is used to reduce the PAPR of SWR signal[1] in CR context. In fact, secondary user detects the free band and transmits its data on it along with primary data and thus a mean PAPR increase due to spectrum access is observed. Consequently, PAPR reduction is performed in the CR context by proposing a new spectrum access scheme. In this scheme the spectrum is accessed for two purposes, firstly for secondary data transmission and secondly for *PRC* transmission in order to keep the PAPR of the signal under a certain level after spectrum access.

This paper is organized as follows. Section III describes the SWR signal after spectrum access and PAPR. Section IV is about TR methodology and in Section V simulation and results are presented. Paper is concluded in Section VI.

[1]At SWR transmitter, the signal is made to be a multiplex of multi carrier/standard signals to be amplified by a single power amplifier.

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3 SWR signal and PAPR

SWR can be defined as a system able of modulating and demodulating any kind of signal, anywhere, on any network.Consequently any received SWR signal $x(t)$ is a composite signal and this signal is modified after spectrum access. Thus SWR in CR context would be

$$x(t) = \sum_{i=1}^{S}\sum_{p=1}^{P_i} r_{i,p}(t)e^{2i\pi f_{i,p}t} + \sum_{u=1}^{U} r_{i,p}(t)e^{2i\pi f_u t}, \tag{1}$$

where *S* is the number of standards contained in primary signal signal and S_i represents i^{th} standard with P_i carriers. U are the unlicensed carriers. Also $r_{i,p}(t)$ represents the modulated and filtered signal associated to carrier *p* of the standard *i*.

Because of the addition of multiple carriers, the power fluctuations of the SWR are very high. The power fluctuations are defined by the term Peak to Average Power Ratio (PAPR). PAPR for the discrete form of $x(t)$ given in Eq. 1 can be formulated as,

$$PAPR\{\mathbf{x}\} = \frac{\max \|\mathbf{x}\|^2}{E\{\|\mathbf{x}\|^2\}}, \tag{2}$$

where $E\{.\}$ and $||.||$ denote the expectation and norm respectively. Also, $\mathbf{x} = (x(t_0), x(t_1), ..., x(t_{N-1}))$ where N is the number of samples over which PAPR is calculated. In this paper, the PAPR reduction performance is evaluated in terms of its Complementary Cumulative Distribution Density Function (CCDF), that is, the probability that the PAPR exceeds a given threshold i-e CCDF(λ)=Pr(PAPR >λ).

With an oversampling factor of $L = 4$, which is basically used to better approximate the analog PAPR [10], CCDF expression for continuous OFDM signal follows central limit theorem and is given by [11],

$$Pr\Big[PAPR\{\mathbf{x}\} > \gamma\Big] \approx 1 - (1 - e^{-\gamma})^{\tau N^{1.07}}. \tag{3}$$

where $\tau = (\frac{5.12}{\sqrt{e}})^{1.07} e^{-\zeta}$ and ζ is the Euler constant ($\zeta = 0.577$).

4 Tone Reservation: A PAPR reduction method

TR technique is about reserving specific tones *PRC*s for PAPR reduction such that the PAPR after adding *PRC*s is reduced compared to initial PAPR. *PRC*s must be optimized in order to create a signal which on addition to the original signal results in reduced PAPR. The problem of optimizing tones is resolved using Second Order Cone Programing (SOCP)[12]. Care should be taken about the mean power increase in the signal after *PRC* addition. Also the spectrum mask constraints should also be respected. The final SOCP formulation of the problem of minimizing signal peak with constraints on mean power and spectrum mask is given by,

$$\begin{gathered} \text{minimize} \quad \beta \\ \text{subject to} \\ \Big| x_k + \mathbf{q}_{k,L}^{row}\mathbf{C} \Big| \leq \beta, 0 \leq k \leq NL - 1 \\ E\left\{ |\mathbf{x} + \mathbf{c}|^2 \right\} \leq \lambda E\left\{ |\mathbf{x}|^2 \right\} \\ |C_k| \leq \delta_k, k \in R. \end{gathered} \tag{4}$$

where **X** and **C** are the data and *PRC* vectors respectively while $\mathbf{q}_{k,L}^{row}$ is the k-th row of $\mathbf{Q}_L$ and $\mathbf{Q}_L$ is the IFFT matrix of size NL. λ constrains the average power increase. R is the index set of all the reserved carriers and δ_k are the instantaneous values of the transmission mask.

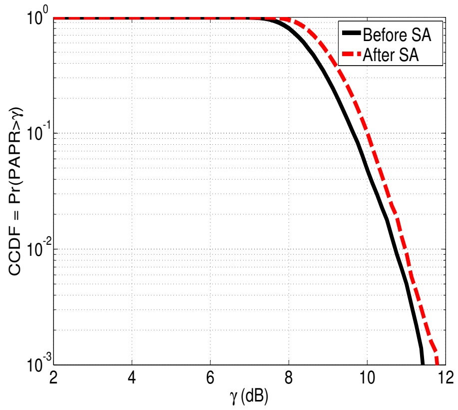

Figure 1: CCDF before and after spectrum access with random primary data.

5 Simulation and Results

In this section SWR signal PAPR variations in CR context due to spectrum access are considered. To keep the power fluctuations under control a new joint spectrum access scheme is introduced where a minor share of accessed spectrum is used to decrease CR PAPR.

5.1 PAPR variations due to spectrum access in CR

We shall first see the effects on PAPR due to spectrum access. A bi-standard SWR system containing two hypothetical standards, Standard A and Standard B, is considered here as a primary data source and a secondary user accesses the free spectrum in opportunistic manner. We study the practical scenario where both primary and secondary data are varied in time. Fig. 1 shows the CCDF before and after spectrum access.

We see that increase in PAPR is observed and therefore PAPR reduction must be performed to keep the peak power under control and avoid PA non-linearity.

5.2 Cognitive Radio PAPR reduction using joint spectrum access scheme

In this section we shall present a novel spectrum access methodology which not only permits to transmit secondary data but also keeps the PAPR under control. The basic ideology is shown in Fig. 2. Generally spectrum is accessed dynamically using opportunistic approach for non-licensed users' data transmission. We reserve here, a very small percentage of that accessed spectrum for PAPR reduction of the overall signal.

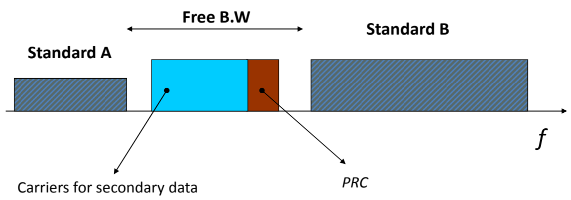

Figure 2: Joint spectrum access methodology for PAPR reduction.

For a bi-standard SWR system whose inter-standard band is accessed dynamically, we transmit secondary data on a considerably high percentage of accessed band. The rest of the band is used to generate *PRC*'s. Fig. 3 shows that original PAPR was varied on spectrum access but it was reduced using TR-SOCP. In our case we use 90% of the free spectrum for secondary data transmission while the rest of 10% is used for PAPR reduction.

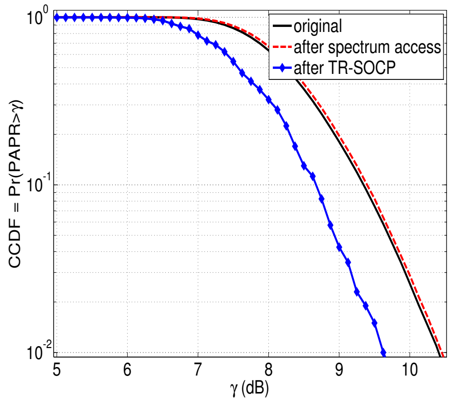

Figure 3: PAPR reduction using joint spectrum access methodology.

6 Conclusion

This paper explores the non-linear distortions issue in SWR based CR systems because of high PAPR these systems possess. High PAPR being a major problem in multi-carrier communications and should be reduced before power amplification otherwise non-linear distortions may occur. Using a PAPR reduction method called TR, PAPR of SWR signal in CR context is observed and reduced using a novel joint spectrum access scheme.

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