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PAPR Reduction Using Tone Reservation for NC-OQAM/OFDM Based CR System

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Abstract: This study examines PAPR (Peak-to-Average Power Ratio) reduction using TR (Tone Reservation) for NC-OQAM/OFDM (Non-Contiguous Offset Quadrature Amplitude Modulation based Orthogonal Frequency Division Multiplexing) transmissions which are used in DSA (Dynamic Spectrum Access) networks such as CR (Cognitive Radio). In the TR method, scaling of time-domain peak reduction kernel signal affects only reserved tones in a given frequency domain according to Fourier transform principles. Since, it does not interfere with PUs (Primary Users), it can be an optimal approach in CR network environment. In this study, a method was considered to reduce PAPR for NC-OQAM/OFDM based CR system by reserving some tones among tones available to SU (Secondary User) for NC-OQAM/OFDM based CR systems.

Key words: Active Constellation Extension (ACE), Peak Average Power Ratio (PAPR), Overlapping Smart Gradient Projection (OSGP), Adaptive Scaling (AS), modulation, peak

INTRODUCTION

Offset Quadrature Amplitude modulation based Orthogonal Frequency Division Multiplexing (OQAM/OFDM) has drawn significant attention recently because of its low narrow band interference, side lobe and high spectrum efficiency (Proakis, 2007). The wireless transmission based on Non-Contiguous OQAM/OFDM (NC-OQAM/OFDM) is a viable technology for Cognitive Radio (CR) transceivers operating in Dynamic Spectrum Access (DSA) networks. However, in spite of many advantages, NC-OQAM/OFDM based CR system still suffers from the problem of high Peak-to-Average Power Ratio (PAPR) of the transmitted NC-OQAM/OFDM signals of the Secondary User (SU) frequency band (Pischella and Ruyet, 2015).

Various methods have been proposed for the PAPR reduction of OQAM/OFDM signals, containing Partial Transmit Sequence (PTS), SeLective Mapping (SLM), Tone Reservation (TR) and clipping to name a few (Farhang, 2011; Zhang *et al*., 2009; Siohan *et al*., 2002; Jinfeng and Signell, 2007, Bellanger, 2010). However, these methods when applied directly to NC-OQAM/OFDM, they produce undesirable outcomes. For example, the clipping method affects the PU by distorting the SU signals which is not compatible with the basic principle of CR. Furthermore, the PTS and SLM methods cannot be simply considered in NC-OQAM/OFDM systems due to the presence of overhead and increased computational complexity as discussed by Pischella and Ruyet (2015a, b), Skrzypczak *et al*. (2006), Deng and Lin (2007), Wang *et al*. (1999) and Krongold *et al*. (2004).

In this letter, we consider the Tone Reservation (TR) method for the PAPR reduction in NC-OQAM/OFDM based CR. The TR causes no interference to data tones other than the tones reserved for peak reduction by the principle of Fourier transform. A CR user developed spectrum pooling enabling the access to white spaces under licensed spectral bands. These unused parts of the spectrum are usually available in chunks. SU signals that utilizes these chunks should not interfere with the PU signals in this perspective TR method is desirable to apply for its application in NC-OQAM/OFDM based CR. More particularly, a novel TR scheme is proposed to minimize the peak of NC-OQAM/OFDM signals by employing small percent of subcarriers as the peak reduction tones in relatively poor channel conditions among the available tones of SU.

NC-OFDM/OQAM signaling, PAPR and tone reservation

NC-OFDM/OQAM signaling and PAPR: In Fig. 1, the baseband modulated NCOFDM/OQAM system is considered with N subcarrier, real valued symbols

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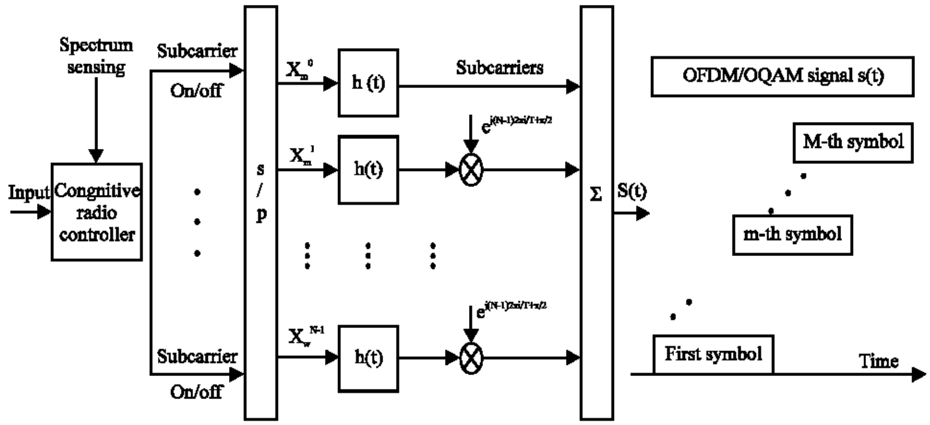

Fig. 1: OFDM/QAM signal model

modulated by Offset QAM are transmitted on each sub-carrier and then the transmitted signal can be written as Pischella and Ruyet (2015), Muller and Huber (1997), Lim and Rhee (2012) and Bauml *et al.* (1996):

$$S(n) = \sum_{m=0}^{M-1}\sum_{K=0}^{N-1} \underbrace{X_m^k h(n-mN) e^{jk(\frac{2m}{N}+\frac{\pi}{2})}}_{h_m^k(n)} \tag{1}$$

Where:

M = The number of input data block

X_m^k = A real valued symbol at the time frequency index (m, k) with N/2 as symbol interval

$X_{2\rho}^k$ and $X_{2\rho+1}^k$ ($\rho \epsilon z$) = The real and imaginary parts of the staggered complex QAM symbol

h(n) = The prototype filter impulse response with length LN ($L \epsilon z$)

Thus, the NC-OQAM/OFDM transmitted signal s(n) length is (M+L-1)N. Due to the overlapping nature in NC-OQAM/OFDM, data block length in time domain is much larger. To calculate PAPR, the NC-OQAM/OFDM signal s(n) is segmented into (M+L) intervals equally with the length N. Then, the PAPR of each interval is:

$$PAPR_q = \frac{qN \leq n \leq (q+1)N\text{-}1^{|s(n)|^2}}{e[|s(n)|^2]}, q = 0, 1, ..., M+L\text{-}1 \tag{2}$$

where, E[.] denotes the expected value operation.

NC-OFDM/OQAM system based on the tone reservation: For NC-OQAM/OFDM based CR system, the TR method uses N_p subcarriers among available N_c(-N) subcarriers to SU with $N_p \leq N_c$ for the PAPR reduction in NCOQAM/OFDM signals. The ordered set of PRTs indices are denoted as $\Re = \{k_0, k_1, ... k_{Np-1}\}$ where N_p denotes the size of the PRT set. The mth symbol on the kth tone of X_m^k consists of two parts, one is the peak reduction signal on the PRTs and the other one is the data signal on the unreserved tones, respectively, i.e.:

$$s_k^m = D_k^m + C_k^m = \{D_k^m, k \in \Re^c C_k^m, k \in \Re \tag{3}$$

Where:

$\Re^c$ = The complement set of R in $\delta = \{0, 1, ..., N_c\text{-}1\}$

D_k^m and C_k^m = The data and peak reduction signals on the kth tone of the mth data block, respectively:

$$D_k^m = 0, \text{ for } k \in \Re, C_k^m = 0, k \in \Re^c \tag{4}$$

Then, at the receiving end peak reduction subcarriers are discarded and the signal demodulation is performed only on the data subcarrier. If cancelling signal is superimposed on the transmission data subcarrier, the peak reduction signal is given as follows:

$$\hat{s}(n) = \sum_{m=0}^{M-1}\sum_{k=0}^{N-1} D_k^m + C_k^m h(n-\frac{mN}{2}) e^{jk(\frac{2\pi}{N}n+\frac{\pi}{2})}$$
$$\sum_{m=0}^{M-1}\sum_{k=0}^{N-1} D_k^m h_k^m(n) + \sum_{m=0}^{M-1}\sum_{k=0}^{N-1} C_k^m h_k^m(n) = S(n)+c(n) \tag{5}$$

where, c(n) is time domain peak cancelling signal, i.e.:

$$c(n) = \sum_{m=0}^{M-1}\sum_{k=0}^{N-1} C_k^m h(n-\frac{mN}{2}) e^{jk(\frac{2\pi}{N}n+\frac{\pi}{2})} \tag{6}$$

In this case, the peak to average power ratio is defined as:

$$PAPR_q = \frac{qN \leq n \leq (q+1)N\text{-}1^{|s(n)+c(n)|^2}}{e[|s(n)|^2]}, q = 0, 1, ..., M+L\text{-}1 \tag{7}$$

From Eq. 11, the peak cancelling signal c(n) determines the effect of PAPR reduction. Thus, C must be chosen to minimize the maximum of the time domain signal to achieve the optimal peak cancelling symbol C^{opt}, i.e.:

$$C^{opt} = \arg\min_{c} \max_{qN \le n \le (q+1)N} |s(n)+c(n)|^2,\ q = 1, 1, ..., M+L-1 \quad (8)$$

Since, the NC-OFDM/OQAM signals are overlapped with adjacent data blocks due to the bank of filters and the real and imaginary parts are time staggered by half a symbol period, the conventional definition of PAPR for NC-OFDM systems no longer match perfectly to the NC-OFDM/OQAM systems. Therefore, the optimal peak cancelling signal for PAPR reduction is obtained by jointly considering the multiple data blocks in NC-OFDM/OQAM systems. Moreover, a simple algorithm needed to be proposed to effectively obtain the optimum peak cancelling signalC^{opt} with much lower computational complexity.

MATERIALS AND METHODS

Proposed TR method in NC-OFDM/OQAM based CR system: Figure 1 shows the peak reduction approach for NCOQAM/OFDM based CR system by the proposed tone reservation method. It uses the reserved subcarriers to generate impulse like signal to eliminate the peak value of NCOQAM/OFDM signals.

In NC-OQAM/OFDM system the real input signal before and after IFFT operation need to enter pre-modulator and filter. We know that, if we run an IFFT operation on frequency domain data block containing 0 and 1, the IFFT output signal is a impulse like signal waveform and reaches its peak at n = 0 (Jinfeng and Signell, 2007; Sathananthan and Tellambusa, 2002; Ye *et al*., 2014; Skrzypczak *et al*., 2006a, b; Lu *et al*., 2012; Qu *et al*., 2013; Neut *et al*., 2014; Krongold and Jones, 2003; Tellado, 1999; Sandeep and Anuradha, 2016). Therefore, in a conventional NC-OFDM system the signal after the IFFT operation can be directly used as time domain signal to synthesize new peak cancellation signal. However, in the NC-OQAM/OFDM system, the signal after the IFFT operation must also pass through filter in order to generate peak cancelling signal. Hence, time domain peak cancelling pulse waveform of NC-OQAM/OFDM is entirely different from that of traditional NC-OFDM system.

The frequency domain peak cancelling kernel, Q is calculated by simply setting 1 for R of Np reserved tones as given by Eq. 3:

$$Q_K = \{1, k \in \Re \ \{k \in \Re^c \quad (9)$$

And the function q(n) is obtained by IFFT transform vector of Q, i.e.:

$$q(n) = \frac{1}{N}\sum_{K=0}^{N-1} Q_K e^{j\frac{2k\pi}{N}},\ n = 0, 1, ..., N-1 \quad (10)$$

Based on the Fourier transform cyclic shift characteristics, the signal q(n) is multiplied by Q_k cyclic shift corresponds to a linear phase i.e.:

$$q(n+v)N = \frac{1}{N}\sum_{k=0}^{N-1} Q_K e^{j\frac{2k\pi(n+v)}{N}} \quad (11)$$

Where:
q(n+v) = The signal q(n) left cyclic shifted by v
v = It may be any integer

If we pass Q frequency domain data blocks into NC-OQAM/OFDM system, the output signal, m = 0, 1, …, M-1 is expressed as:

$$q_m^0(n) = \sum_{k=0}^{N-1} Q_k h\left(n - \frac{mN}{2}\right) e^{jk(\frac{2\pi}{N}n + \frac{\pi}{2})} \frac{mN}{2} \le n \le \left(L + \frac{m}{2}\right)N = Nq(n + \frac{N}{4})N^{h(n - \frac{mN}{2})} \quad (12)$$

where, q(n+N/4) N is a pulse like signal with its peak position at n = 3N/4 and (n-mN/2) is symmetrical waveform having well localization time-frequency characteristics with its maximum value is much larger than the second largest value and reaches its peak value at n = (L+m)N/2, since, the signal $q_m^0(n)$ is obtained by multiplying q(n+N/4)N and h(n-mN/2) is still a similar impulse like signal. When m is even, $q_m^0(n)$ obtains maximum value n = (L+m-1/2)N/2, when m is odd, $q_m^0(n)$ obtains maximum value at n = (L+m-1/2)N/2. Similarly, if the input signal of NC-OQAM/OFDM is $Q^v = [Q_0 e^{jk\frac{2\pi v}{N}}, Qe^{jk\frac{2\pi v}{N}}, ..., Q_{N-1}e^{jk\frac{2\pi v}{N}}]$, then the output signal $q_m^v(n)$ is:

$$q_m^v(n) = Nq(n + v + \frac{N}{4})N^{h(n - \frac{mN}{2})},\ \frac{mN}{2} \le n \le (L + \frac{m}{2})N \quad (13)$$

When m is even, $q_m^v(n)$ obtain maximum at n = (L+m-1/2)N/2 when m is odd $q_m^v(n)$ is maximum at n = (L+m-1/2)N/2. Therefore, when v is any value, signal peak of $q_m^v(n)$ is always between n = L+m-1/2)N/2 and n = (L+m+1/2)N/2. And the peak of $q_m^v(n)$ is determined by v and we can control the $q_m^v(n)$ signal peak position by cyclically shifting q(n). Therefore, $q_m^v(n)$ signal in NC-OQAM/OFDM system is the time domain peak cancellation signal. It is worth noting that, due to the cyclic shift characteristics of the Fourier transform, cyclic shifted q(n) signal does not destroy the NC-OQAM/OFDM system orthogonality. In the following analysis, multiple signals that exceed the threshold A are simultaneously suppressed by applying multiple impulse like time domain kernels in a single iteration. This improves the time efficiency and accelerates the convergence rate.

The multiple adjacent data symbols need to be jointly considered for the proposed TR method, to obtain a series of clipping pulses f = [f [0], f [1], ..., f [(M+L-1)N]]T when |S(n)| exceeds A and it is given by:

$$f(n) = \{0, |S(n)| \leq A = s(n)\text{-}Ae^{j\theta(n)}, |S(n)| \leq A \tag{14}$$

where, $\theta(n)$ is the phase of s(n). Then the time domain kernel $q_m^v(n)$ is defined to construct the peak cancelling signal c(n). Since, s(n) signal length is much greater than the length of the signal $q_m^v(n)$, so, we segment s(n) in order to eliminate the peaks of each segment individually. Assuming each segment has v_m peaks with $n_m^0, n_m^1,...n_m^{v_m-1}$ can be obtained by $\delta_m = \{n \backslash f(n) > f(n\text{-}1), f(n+1), (L+m\text{-}1)N/2 \leq n \leq (L+m+1)N/2\}$, m = 0, 1, …, M-1. Then the time domain kernel $q_m^{u_m^v}$ is constructed by cyclically shifting $q_m^v(n)$ to the right by median u_m^v. The median u_m^v of the time domain kernel with peak positions is given by:

$$\begin{aligned} u_m^v &= \{n_m^v - \frac{(L+m-1/2)N}{2}, \text{ m is even} \\ &= n_m^v - \frac{(L+m+1/2)N}{2}, \text{ m is odd} \end{aligned} \tag{15}$$

After finding these peak positions, the peak cancellation signal c(n) is generated using the time domain kernel $q_m^{u_m^v}$. It is obvious that, if the peak cancelling signal amplitude approaches original clipping noise f (n) within single iteration, performance improves. Therefore, the time domain kernel of each segment $q_m^{u_m^v}$ is scaled to approximate the corresponding pulse in f(n) at the location s_m and then the peak reduction signal is generated. Defining a_m^v the scaling factor of vth peak of mth symbol, the time domain peak cancelling signal is given by:

$$c(n) = \sum_{m=0}^{M-1}\sum_{v=0}^{v_m-1} a_m^v q_m^{u_m^v}(n) = \sum_{m=0}^{M-1}\sum_{v=0}^{v_m-1} a_m^v q(n+\frac{N}{4}-u_m^v)h(n-\frac{mN}{2}) \tag{16}$$

where, $a_m^v = f(n_m^v)/q_m^{u_m^v}(n_m^v)$ is the scaling factor at the position of median, i.e., at n_m^v algorithm: as shown in Fig. 1, TR algorithm can be summarized as follows:

TR algorithm:

Step 1: Set the threshold to A, no of iterations to I and generate a set of N_P reserved tones among available N_c(<N) tones to SU

Step 2: The original input bit stream is encoded, interleaved and modulated to obtain the frequency domain data streams. According to NC-OFDM/OQAM tone reservation criteria, consider N_C-N_P frequency domain data on data subcarriers $\Re^c$ and calculate the corresponding time domain signal s(n)

Step 3: If max (|s(n)|)> A, set the number of iterations to i = 1, go to Step 4. Otherwise output the signal s(n) and terminate the algorithm

Step 4: According to Eq. 8 the time-domain signal s(n) is processed to get the time domain peak cancellation signal and find its peak position

Step 5: Accordingly calculate the complex scaling factor a_m^v and shift the median u_m^v then according to Eq. 10 calculate the peak cancellation signal c(n)

Step 6: The c(n) is superimposed on to the original time domain signal s(n) then the calculation of the reduced signal peak is given by:

$$\hat{S}(n) = s(n)+c(n) \tag{17}$$

Step 7: Calculating a current time domain signal peak max (|s(n)|)>A, then $\hat{s}(n)$ = s(n), i = i+1 and jump back to Step 4, otherwise output the current time domain signal s(n)

RESULTS AND DISCUSSION

The NC-OQAM/OFDM based CR system employs 64 subcarriers of which 54 are utilized by the SUs with N_p = 6, N_c = 48 subcarriers and the remaining 10 subcarriers are occupied by the PU. In the simulation, 104 data blocks are randomly generated and 4QAM modulated. Besides, this I = 2 and the length of prototype filter, i.e., Square-Root Raised Cosine (SRRC) filter is set as 4N with the roll off factor as 1. The PAPR reduction performance of NC-OQAM/OFDM based CR system with the proposed criterion is illustrated in Fig. 2. It is obvious that the proposed method provides better performance compared to the segmental PTS (S-PTS) and original signal without PAPR reduction. For example, at 10^{-3} clipping probability, the proposed method achieves 1.1dB more reduction in PAPR as compared with the SPTS method and 4.6 dB when compared with original. Figure 6 presents the BER curves of the proposed criterion over different channels. In this simulation, the Solid-State Power Amplifier (SSPA) (Wang *et al*., 1999) is adopted with input back off IBO = 2 dB. The curves labeled ideal, original and Fig. 3-4 proposed depict the BERs of NC-OFDM/OQAM signals without SSPA and PAPR

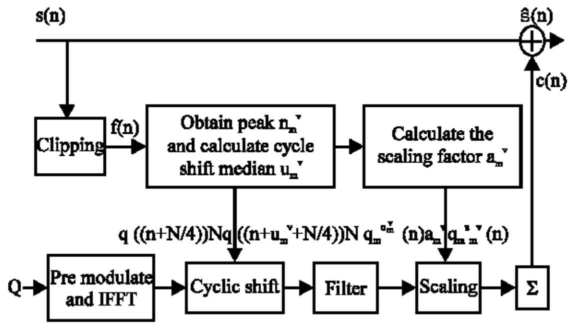

Fig. 2: Peak reduction approach by the proposed tone reservation method

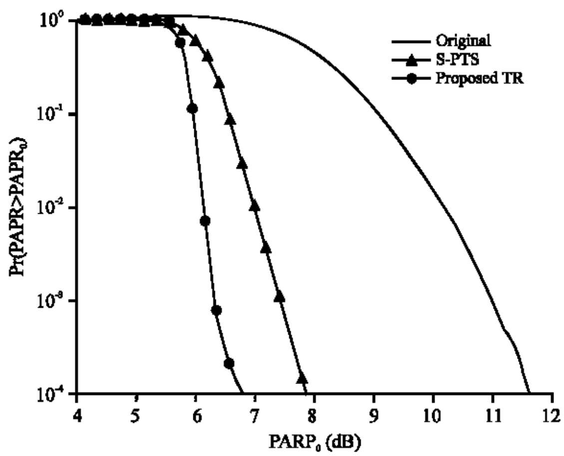

Fig. 3: PAPR reduction with the proposed criterion

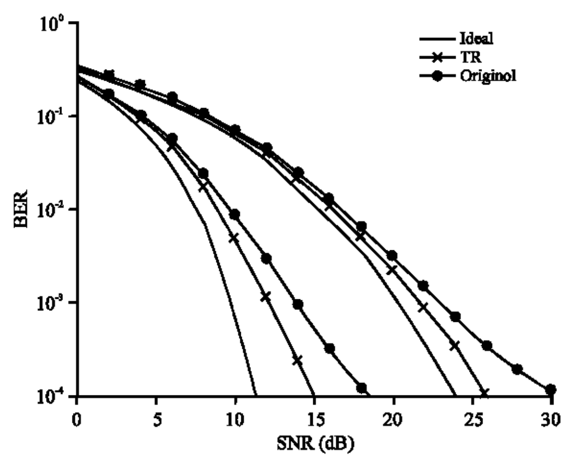

Fig. 4: PAPR reduction with the proposed criterion

reduction, original NC-OFDM/OQAM signals with SSPA the proposed criterion supplies much better BER performance than the original NC-OFDM/OQAM system. For example, over the Additive White Gaussian Noise (AWGN) channel, the Signal-to-Noise Ratios (SNRs) of the proposed criterion and the original NC-OFDM/OQAM system are 15 and 18 dB when BER = 10^{4}, respectively. In addition, over the Rayleigh fading channel when BER = 10^{4}, the SNRs are 21 and 30 dB for the proposed criterion and the original NC-OFDM/OQAM system, respectively.

CONCLUSION

In this study, we proposed Tone Reservation (TR) as a method to reduce the Peak-to-Average Power Ratio (PAPR) of noncontiguous orthogonal frequency division multiplexing with offset QAM (NC-OFDM/OQAM) based cognitive radio. The proposed scheme exploits the overlapping nature of the OQAM symbols in NC-OFDM/OQAM to allocate inactive subcarriers as Peak Reduction Tones (PRTs). We have shown that the proposed approach can eliminate the side information for dynamic PRT allocation and the data rate loss from using reserved subcarriers. Performance results were given which shown that the proposed method can significantly reduce the Out-of-Band (OOB) radiation within a Primary User (PU) band from the NC-OFDM signal due to the nonlinearity of the power amplifier. The proposed technique employs PRTs close to the Secondary User (SU) data bands to improve PAPR reduction and also the Bit Error Rate (BER) performance.

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