Improved Active Constellation Extension For The PAPR Reduction Of FBMC-OQAM Signals

Mounira Laabidi, Rafik Zayani , Ridha Bouallegue, Daniel Roviras

***Abstract*—** The Filter Bank multicarrier with Offset Quadrature Amplitude Modulation (FBMC-OQAM) has been introduced to overcome the poor spectral characteristics and the waste in both bandwidth and energy caused by the use of the cyclic prefix. However, the FBMC-OQAM signals suffer from the high Peak to Average Power Ratio (PAPR) problem. Due to the overlapping structure of the FBMC-OQAM signals, directly applying the PAPR reduction schemes conceived for the OFDM one turns out to be ineffective. In this paper, we address the problem of PAPR reduction for FBMC-OQAM systems by suggesting a new scheme based on an improved version of Active Constellation Extension scheme (ACE) of OFDM. The proposed scheme, named Rolling Window ACE, takes into consideration the overlapping naturally emanating from the FBMC-OQAM signals.

***Keywords*—**ACE, FBMC, OQAM, OFDM, PAPR, Rolling-Window.

I. Introduction

THE Filter Bank multicarrier with offset quadrature amplitude modulation (FBMC-OQAM) is an efficient transmission technique which has received an increasing attention [1]-[2]-[3]-[4] as an appropriate alternative to the cyclic prefix Orthogonal Frequency Division Multiplexing (CP-OFDM). Compared to the traditional OFDM, and since it operates without CP, FBMC-OQAM provides a higher useful bit rate. Using pulse shapes well localized in time and frequency guarantees more immunity to out-of-band radiation inter symbol interference (ISI), and inter-carrier interference (ICI).

Similar to the OFDM system, a major downside of the FBMC-OQAM system resides in the high Peak-to-Average Power Ratio (PAPR) of the transmitted signal, which is very sensitive to nonlinear distortions caused by the high power amplifier (HPA). Given this resemblance, it is normal to use the PAPR reduction schemes suggested for OFDM systems to reduce the PAPR of FBMC-OQAM signals. However, as the FBMC-OQAM signals have an overlapping structure, it follows that the direct application of the proposed methods of OFDM systems to FBMC-OQAM turns out to be ineffective.

There are some related works in the literature which have been concerned with the problem of PAPR reduction for the FBMC-OQAM systems. In [5], authors have employed the sliding window algorithm to improve the Tone Reservation (TR) PAPR reduction scheme and fit it for the PAPR reduction of FBMC-OQAM signal. The advanced scheme, called Sliding Window Tone Reservation (SW-TR), cancels the peaks of the FBMC-OQAM signal inside a window by using the PRTs (Peak Reduction Tones) of a number of successive data blocks. The SW-TR is appropriate in reducing the PAPR of FBMC-OQAM signal. In [6], the Selective Mapping scheme (SLM) has been improved as the authors suggested an Overlapped SLM for the PAPR reduction of OFDM-OQAM signal.

Building on these studies whose main purpose was to reduce the PAPR of FBMC-OQAM; there is strong reason here to take into consideration the ACE scheme. Such scheme qualifies as one of several techniques [7]-[8]-[9]-[10] which are purported to reduce the PAPR for OFDM systems. Our choice of this scheme is motivated by the number of benefits it offers. Among these merits is its transparence to receiver since no side information is needed and that we do not predict any loss of data rate. Additionally, the ACE scheme applies similar principle of reducing the PAPR as the TR method does seeing that these two schemes employ PRTs so as to reduce the peaks of the signal. Consistently with the TR scheme, it follows that the direct implementation of the ACE PAPR reduction scheme to the FBMC-OQAM signal is far from being efficient in light of the signal structure differential between the two MCMs systems.

In this investigation we put forward a new scheme based on the conventional ACE-POCS (Projection onto Convex Sets) namely, Rolling-Window ACE (RW-ACE) for reducing the PAPR of the FBMC-OQAM signals. The proposed scheme takes into consideration the overlapping obviously introduced by the FBMC-OQAM.

This paper is organized as follows. Section II gives a brief introduction to the FBMC-OQAM system by giving the signal model. The conventional ACE method for PAPR reduction proposed for OFDM system and the suggested RW-ACE for FBMC-OQAM one are investigated in Section III. Section IV

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displays the simulation results of the RW-ACE scheme. The conclusion part is given in Section V.

II. FBMC-OQAM SIGNAL MODEL AND PAPR DEFINITION

A. FBMC-OQAM Signal

The basic idea of the FBMC-OQAM system is transmitting Offset Quadrature Amplitude Modulation (OQAM) data instead of QAM ones, where the in-phase component and the quadrature one are separated in time by half a symbol period $T/2$. Thus, the baseband continuous-time model of the FBMC-OQAM transmitted signal can be defined as follows:

$$(t) = \sum_{m=0}^{N-1} \sum_{n=-\infty}^{+\infty} a_{m,n}\, h(t - n\tfrac{T}{2}) e^{j\frac{2\pi}{T}mt} e^{j\varphi_{m,n}} \qquad (1)$$

With:

- $h(t)$ the impulse response of filter,
- N refers to the number of sub channels,
- m refers to the sub channel index,
- n refers to the time index for the OQAM symbol.
- $a_{m,n}$ are real OQAM symbols.
- $\varphi_{m,n}$ is the phase term.

The phase term $\varphi_{m,n}$ is given by:

$$\varphi_{m,n} = \frac{\pi}{2}(m+n) - \pi mn \qquad (2)$$

Equation (3) introduces the shifted versions of $h[t]$ in time and frequency:

$$\tau_{m,n}(t) = h(t - n\tfrac{T}{2}) e^{j\frac{2\pi}{T}mt} e^{j\varphi_{m,n}} \qquad (3)$$

Equation (1) can be rewritten as follow:

$$x(t) = \sum_{m=0}^{N-1} \sum_{n=-\infty}^{+\infty} a_{m,n}\, \tau_{m,n}(t) \qquad (4)$$

B. PAPR Definition In FBMC-OQAM System

The PAPR is a significant factor to measure the sensitivity to non-linear amplification of the transmitted signal characterized by a non-constant envelope. In the OFDM case, the PAPR of the OFDM signal with N carriers in discrete time version is defined as follows:

$$\text{PAPR(dB)} = 10\log_{10} \frac{max_{k\in\{0,\ldots,N-1\}}\{|s_k|^2\}}{E\{|s_k|^2\}} \qquad (5)$$

Where, $E[.]$ is the expectation operator and s_k is the OFDM signal.

As both OFDM and FBMC-OQAM systems, at a rate of $1/T$, transmit the equivalent of one complex symbol even with the length of the FBMC-OQAM pulse shape longer than T, it is rather practical to use equation (5) so as to measure the PAPR of FBMC-OQAM signal but with some constraints based on the time period on which lie the most of energy of the symbol. The large part of energy of one symbol lies in the two succeeding symbol period intervals when compared with OFDM. In the present work we calculate the PAPR of any current symbol on its third symbol period.

As the PAPR being a random variable, an appropriate method to evaluate its comportment is the Complementary Cumulative Distribution Function (CCDF). The CCDF offers the probability that the maximum power level of a data block reaches or exceeds a given threshold $PAPR_0$ the CCDF can be described as follows:

$$CCDF = Pr[PAPR > PAPR_0] \qquad (6)$$

III. ROLLING-WINDOW ACTIVE CONSTELLATION EXTENSION

This section briefly introduces the conventional ACE POCS which was proposed for the OFDM system. As the OFDM signals of the adjacent data blocks do not overlap, ACE scheme for the OFDM signal independently determines the possible extension for each data block. Consequently, the direct application of the ACE scheme, implemented for the OFDM systems to the FBMC-OQAM one, appears as ineffective because of the overlapping signal structure of the FBMC-OQAM. Therefore, we suggest a new method which is called Rolling Window Active Constellation Extension (RW-ACE) for reducing the PAPR of FBMC-OQAM signals. The scheme being considered takes into account the overlapping unsurprisingly introduced by the FBMC-OQAM.

A. The Conventional ACE for OFDM

There is a great deal of methods which have been designed for the purpose of reducing the peak power of the OFDM signal. Among these methods for PAPR reduction is the Active Constellation Extension (ACE) proposed by Krongold and Jones in [7]. In its POCS variant, ACE is claimed to be a simple and refined method with promising results. Such scheme is similar to Tone Injection method [11].

ACE-POCS method requires both time-domain and frequency-domain signal processing. In this method, the time domain signal is clipped and filtered. The clipping and filtering noise moves the constellation points. The extension of each symbol must be within the allowable regions. If otherwise, the point is moved to its original position. These procedures are performed iteratively to achieve the target PAPR. The ACE principle is presented in the Fig. 1.

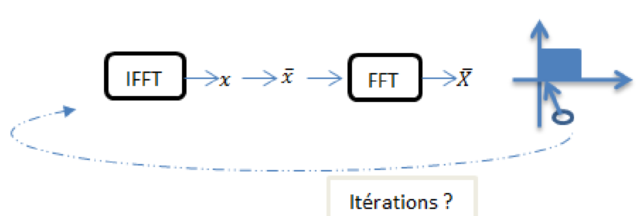

Fig. 1 POCS- Active Constellation Extension principle

As illustrated in Fig. 2 below, ACE allows the corner QAM constellation points (red circle) to be moved within the quarter planes outside their nominal values. In order to preserve the minimum distance between the constellation symbols, the interior points (magenta circle) are not adjusted. With respect to the other boundary points (black rectangle), their transfer along rays pointing towards the exterior of the constellation is tolerated. Such a constellation modification is represented in Fig. 2 for the 16-QAM constellation.

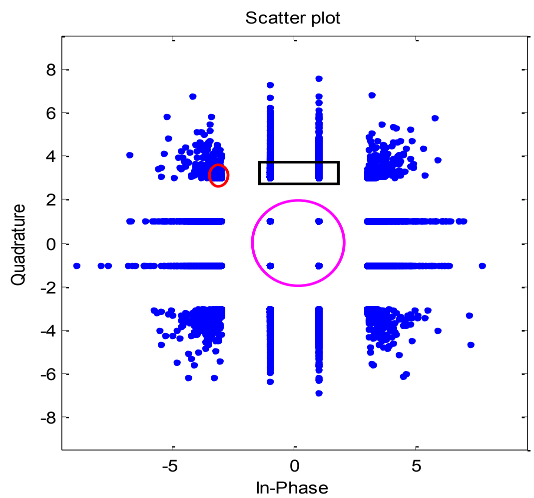

Fig. 2 Illustration of ACE scheme with 16-QAM encoding. The shaded regions represent the corner-point extension regions

The main advantage of ACE technique consists in the important reduction of PAPR without loss in data rate. Furthermore, ACE has the advantage that no side information is required at the receiver in order to recover the transmitted data.

In this investigation, we focus on ACE-POCS variant whose algorithm is described in [7]. Such scheme is based on both frequency and time-domain signal processing. An iterative clipping and filtering followed by the ACE decision, based on the position of the constellation points, can be a summary of the ACE-POCS algorithm.

The ACE-POCS algorithm is as follow:

1) Starting with the data symbols X in a given block, apply an IFFT to get x.
2) Clip any $|x[n]| \geq A$ in magnitude to obtain :
$$\overline{x}[n] = \begin{cases} x[n], & |x[n]| \leq A, \\ Ae^{j\theta[n]}, & |x[n]| > A \end{cases} \tag{7}$$
Where:
$$x[n] = |x[n]|e^{j\theta[n]} \tag{8}$$
Another way to look at step 2 is to consider $\bar{x}[n]$ as follows:
$$\bar{x}[n] = x[n] + C_{clip}[n] \tag{9}$$
Where:
$$C_{clip}[n] = \begin{cases} 0, & |x[n]| \leq A, \\ A - |x[n]|e^{j\theta[n]}, & |x[n]| > A \end{cases} \tag{10}$$
3) Obtain $\bar{X}$ via an FFT applied to $\bar{x}$.
4) Enforce all ACE constraintson $\bar{X}$ by restoring all interior points to their original values, while projecting exterior points into the region of increased margin.
5) Return to step 1 and iterate the algorithm until no points are clipped or the PAPR is essentially minimized.

Using the linearity, only the IFFT of $C_{clip}[n]$ needs to be computed since the $X[k]$ are already known.

B. Rolling-Window ACE for the FBMC-OQAM Signal

The present section gives an account of how the RW-ACE method reduces the PAPR of FBMC-OQAM signal. The principle of RW-ACE technique functions along two steps. Instead of reducing the PAPR of every data block independently, the key idea of the RW-ACE scheme is to operate inside a window (W) composed of a number of succeeding data blocks. As a first step, use the possible extension of several data blocks to cancel the peaks of FBMC-OQAM inside the window (W). As a second step, slide the window when the target PAPR or the maximum number of iterations is fulfilled.

The proposed method reflects the overlapping structure of the FBMC-OQAM signal by considering a common part between the succeeding windows. Accordingly, the present work refers to the window length by $lw = j * N$, where j is an integer used to adjust the window's length. The overlapping slice named $over$ is equal to $(j-1) * N$.

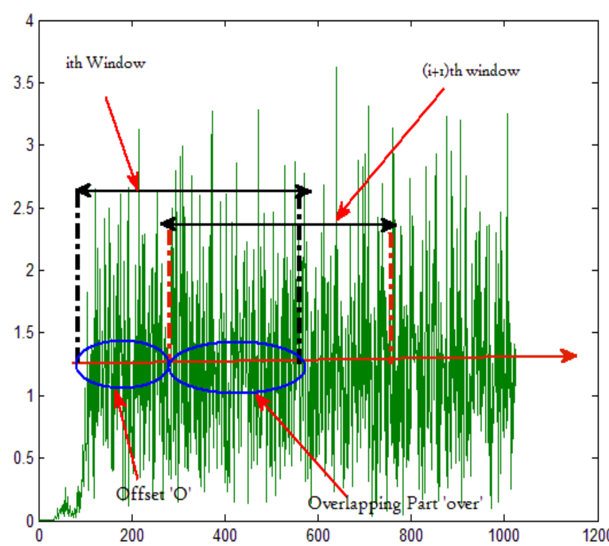

Fig. *3* Rolling Window scheme principle

As shown in Fig. 3, the proposed scheme highlights the overlapping structure of FBMC-OQAM signal by considering an overlapping portion between two succeeding windows.

The idea behind RW-ACE is to increase the block size by considering j blocks instead of one and then exploit the increased flexibility of ACE. The different steps of RW-ACE method are described below:

- Step 1: Once the $(i-1)th$ window is well treated, extract the signal in the ith window from $x[n]$ where an overlapping part with the previous window is considered and it is called $over$. The starting point of two contiguous rolling windows has an offset and it is entitled O, where $O = W - over$.The ith window signal can be given as:

$$w_i[n] = \begin{cases} x[n], (i-1)O \le n \le (i-1)O + W - 1 \\ 0, \quad else \end{cases} \quad (11)$$

- Step 2: Clip any $|w_i[n]| \ge A$ in magintude to obtain :

$$w\_clip_i[n] = \begin{cases} w_i[n], & |w_i[n]| \le A, \\ Ae^{j\theta(w_i[n])}, & |w_i[n]| > A \end{cases} \quad (12)$$

Where: A is the clipping threshold and $\theta(w_i[n])$ is the phase of $w_i[n]$.

- Step 3 : Apply FFT followed by the analysis filter to the signal result of clipping operation $w\_clip_i[n]$ in order to return to the frequency domain.
- Step 4:Apply the ACE constraint to the result of step 3
- Step 5: Return to step 1 and iterate the algorithm until no points are clipped or until the PAPR inside the window is principally minimized.

IV. PAPR REDUCTION PERFORMANCES

In this section, simulations are conducted to investigate the PAPR reduction performance of the proposed RW-ACE scheme. The FBMC-OQAM system employs 64 tones. All the data tones are 4-QAM modulated. We have used the PHYDYAS prototype filter (physical layer for dynamic access and cognitive radio) [1] with an overlapping factor $K = 4$. Thus, an FBMC-OQAM data block overlaps with four succeeding data blocks. The length of the Rolling Window is $lw = j * N$. For all simulations, the number of ACE-POCS iteration is fixed to 8 and $j = 3$.

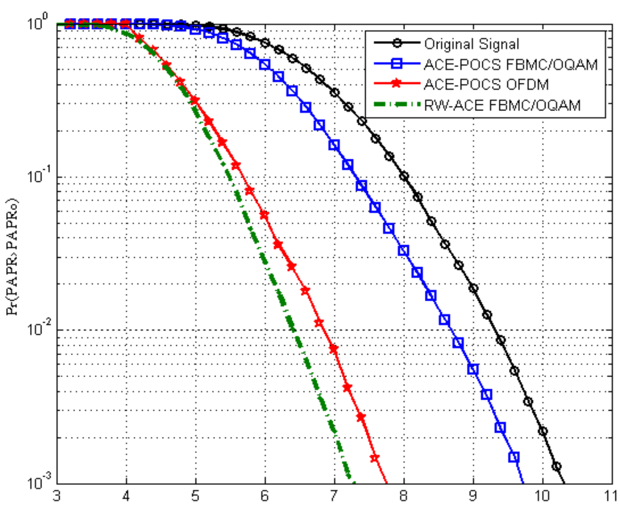

Fig. 4 CCDFs of the proposed RW-ACE, and the conventional ACE schemes applied for FBMC-OQAM signal with $N = 64$ carriers, $W = 3 * N$ and $over = 2 * N$

Fig. 3 shows the PAPR performance of the proposed PAPR reduction scheme RW-ACE in case of being compared with the conventional ACE-POCS when directly applied to the FBMC-OQAM signal and to the OFDM one. The number of carriers N is equal to $N = 64$.The length of the rolling window $lw = 3 * N$, and the length of the overlapping part is set as $over = 2 * N$. The clipping level is equal to$3.83\ dB$.

At a CCDF of 10^{-3} and compared with the PAPR performance of the original case, the conventional ACE-POCS scheme outperforms $0.5\ dB$ for FBMC-OQAM signal. The conclusion that we may draw from these simulation-based results is that the direct application of the conventional scheme ACE-POCS to the FBMC-OQAM system is not effective due to its overlapping structure.

Comparably with the PAPR performance of the conventional ACE-POCS scheme, at a CCDF of 10^{-3}, the expected RW-ACE outperforms $2.5\ dB$ and $0.4\ dB$ for respectively, FBMC-OQAM and OFDM. The anticipated RW-ACE performs better than the conventional ACE-POCS for OFDM signal. The explanation of this result is particularly associated with the common part between the succeeding windows. With Rolling Window ACE, the point of the overlapped part between succeeding windows will have many possible extensions which significantly decrease the PAPR.

A. Overlapping Part Effect

Fig. 5 compares the PAPR reduction of the proposed RW-ACE scheme with different overlapping part for the same window length $lw = 3 * N$. The length of the overlapping part is set as $over = 2 * N$ for the green curve and $over = N$ for the blue one. The clipping level is equal to $3.053\ dB$. It turns out from the simulation-based findings in Fig.5 that the larger the overlapping part $over$ gets the better the performances become.

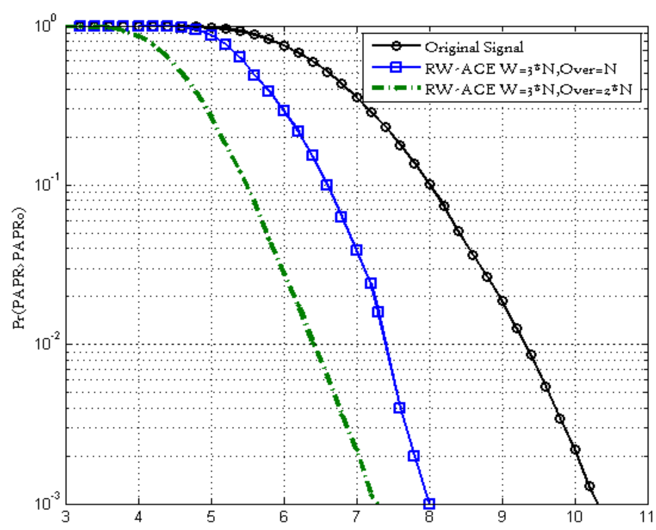

Fig. 5 CCDFs of the proposed RW-ACE applied for FBMC-OQAM signal with $N = 64$, $W = 3 * N$, $over = N$ and $over = 2 * N$

B. Constellation Effect

In this sub-section, the same simulation parameters as in Fig. 4 are used (The length of the rolling window $lw = 3 * N$, the length of the overlapping part is set as $over = 2 * N$ and the clipping level is equal to$3.83\ dB$). FBMC-OQAM systems with QPSK, 16-QAM and 64-QAM in each of $N = 64$ sub channels were simulated.

Based on the simulation results in Fig. 6, The RW-ACE 4 QAM curve outperforms the RW-ACE with 16-QAM and RW-ACE with 64-QAM. We can conclude that further increase of the QAM constellation size results in lower PAR performance gains as only the corner points can be extended.

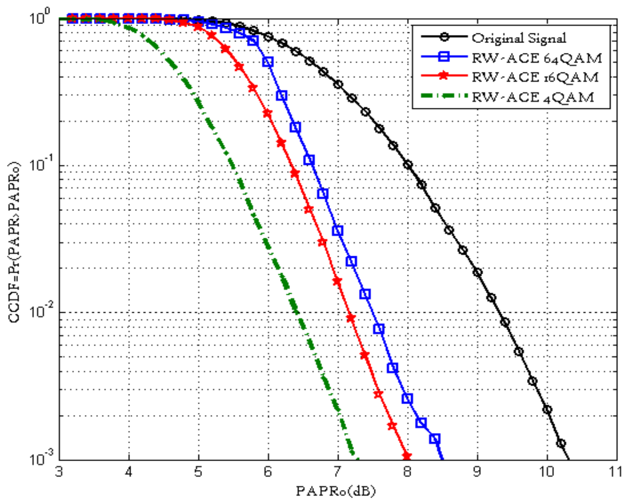

Fig. 6 CCDFs of the proposed RW-ACE scheme applied for FBMC-OQAM signal with $N = 64$ carriers, $= 3 * N, over = 2 * N$, QPSK, $16 - QAM$, and $64 - QAM$

From all the simulation-based results, we can conclude that the performance of the proposed RW-ACE scheme for the PAPR reduction of the FBMC-OQAM signals is even better than that of the conventional ACE-POCS method for the OFDM system.

V. Conclusion

In this paper, the improvement of the ACE-POCS scheme to reduce the PAPR for the FBMC-OQAM system has been addressed. A RW-ACE PAPR reduction scheme has been proposed in order to solve the PAPR problem of FBMC-OQAM signal. The method in question takes into account the overlapping naturally introduced by the FBMC-OQAM. The advantage here consists in the fact that the RW-ACE scheme does not require any side information to recover the transmitted data at the receiver.

The simulation results proved that the proposed RW-ACE scheme exhibits a better performance in reducing the PAPR of FBMC-OQAM signal than the conventional ACE one.

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