ALTERNATIVE LOW-COMPLEXITY APPROACHES FOR PAPR REDUCTION IN FBMC-OQAM SYSTEMS

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Abstract*: Recently, the Filter Bank Multi-Carrier with Offset-QAM modulation (FBMC-OQAM) system proved to be a strong candidate wave that can replace the conventional OFDM (Orthogonal Frequency Division Multiplexing) through several properties in future mobile generations (5G and 5G+). However, it faces a significant issue, which is high Peak-to-Average-Power-Ratio (PAPR) as all advanced waveforms. Many researchers have proposed either hybrid or non-hybrid techniques adapted to the FBMC-OQAM structure to minimize the PAPR parameter. Nevertheless, all of these techniques suffer from high complexity, which is a significant challenge in practical implementations. Therefore, in this paper, we propose two alternative low-complexity approaches, TD and TC, to effectively mitigate the PAPR problem in FBMC-OQAM systems. Both proposed hybrid schemes achieve superior PAPR performance compared to the conventional TR and very competitive results in comparison to the existing literature algorithms while requiring less computational complexity.*

1. INTRODUCTION

In recent times, the regular growth of collective needs has forced numerous technical challenges that need to be addressed to effectively realize the user requirements for wireless communication services, as well as high spectral, energy efficiency, and connectivity. For this reason, the physical layer of modern wireless communication systems has evolved a lot, which has allowed the development of this sector in a dizzying way. For example, in the 4G standard OFDM waveform is implemented [1]. It has been a popular choice among communication systems. Nevertheless, the OFDM waveform is not appropriate for highly developed radio systems due to a few limitations, such as high latency and low spectral efficiency. Consequently, it has become important to look for another alternative to the conventional OFDM for 5G and 5G+. Up to date, numerous new filtered waveforms, such as F-OFDM [2], FBMC [3], [4], GFDM [5], and UFMC [6], have been suggested for 5G and 5G+ [7]. Among these waveforms, Filter Bank Multicarrier modulation (FBMC-OQAM) is a strong candidate waveform for 5G and 5G+ applications, based on filter bank treatment to ensure better spectral efficiency than OFDM. However, as with all multicarrier systems, high PAPR is considered a serious problem in FBMC-OQAM [8]. This problem reduces the power efficiency of the high-power amplifier. To avoid this crucial issue, we need some PAPR reduction algorithms. In the literature, we can find several algorithms that are adopted for each waveform, whether for OFDM or FBMC. At present, a lot of interest is being given to the FBMC-OQAM PAPR mitigation issue since a large number of published papers are interested in PAPR reduction in FBMC-OQAM. In [9], the authors proposed a new TR scheme for the FBMC/OQAM structure. In [10], the authors recommended a joint solution founded on ACE and the Tone Reservation techniques for high peak power mitigation. H. Wang and al., in reference [11], offered a combined PAPR mitigation technique for FBMC/OQAM built on MDB-PTS and Tone Reservation scheme to ensure better PAPR reduction. In [12], the authors proposed a new approach for high peak power mitigation in FBMC/OQAM founded on SLM and MDB-PTS methods to achieve better PAPR reduction while maintaining good BER performance. Z. He in [13] has proposed a low complexity Partial Transmit Sequence (PTS) method for PAPR mitigation in FBMC-OQMA signals. S. Ren and al., in [14], suggested a low complexity algorithm that combines SPTS and TR to enhance the PAPR mitigation. D. Kong in [15] has introduced a novel Discrete Fourier Transform (DFT)-based PTS technique that effectively reduces the PAPR of the system while maintaining good BER performance. The authors in [16] and [17] recommended two hybrid schemes, TR&DC and TR&Compd for low PAPR in FBMC-OQAM systems. In [18], the authors suggested an optimized PTS technique using Discrete Swarm Optimization (DSO) to achieve better PAPR reduction performance. M. Ango and al., in [19] recommended an enhanced-PTS with a low complexity search algorithm to minimize the PAPR. In [20], the authors proposed a new SLM approach founded on a modified forest optimization algorithm for PAPR reduction in the FBMC system. M. Hussein and al., in reference [21], offered an improved harmony search optimization for hybrid Clipping-PTS PAPR reduction in the FBMC system. The authors in [22] recommended a new hybrid approach based on companding and PTS methods for PAPR reduction of 5G waveforms.

In this study, we shed light on the hybrid PAPR minimization class by presenting new alternative algorithms with the aim of decreasing the PAPR in FBMC-OQAM systems without added computational complexity. The paper is structured as: In Section 2, the FBMC-OQAM and PAPR are presented. In Section 3, the principle of Tone Reservation is addressed, and the suggested algorithms are outlined. In Section 4, the simulation results are discussed. The last part marks some conclusions.

2. FBMC SYSTEM

The FBMC-OQAM system has been the subject of extensive research. It is observed to be a potential wave in future wireless communication systems. Contrary to the CP-OFDM waveform, FBMC modulation is an efficient PHY-layer with inherent ability under spectral coexistence scenarios. This has led to the exploration of FBMC-OQAMA in various applications, including MIMO systems [23], 6G networks [24], and even indoor optical wireless communications using LIFI technology [25]. The FBMC-OQAM signal is formed by using a group of sub-carriers, which are filtered by a group of filters. The transmitted FBMC-OQAM [26], symbol and M transmitted symbols are written, respectively as:

$$u^{FBMC}(t) = \sum_{n=0}^{N-1} [\dot{R}_m^n \beta(t - mT) + j\dot{I}_m^n \beta(t - mT - \frac{T}{2})] e^{jn(\frac{2\pi}{T}t + \frac{\pi}{2})} \tag{1}$$

$$U(t) = \sum_{m=0}^{M-1} u^{FBMC}(t), \qquad 0 \le t \le \left(M + \varepsilon - \frac{1}{2}\right) T \tag{2}$$

Where: The imaginary and real parts of the m^{th} symbol on the n^{th} sub-carrier are represented by $\dot{R}_m^n$, $\dot{I}_m^n$. The PHYDYAS filter [4] is denoted by $\beta(t)$.

Figure 1 shows a schematic of FBMC/OQAM symbols repartition. Every symbol has a time delay that is distributed alternatively between the real and imaginary parts. Each data block spans over $4.5\,T$ because of the employment of OQAM modulation and filter bank technique. To estimate the peak to average power ratio (PAPR) of the filter bank signal, the stable part of the signal is considered, which is defined from $(\varepsilon + 1/2)N/2$ to $MN + (\varepsilon + 1/2)N/2$ (see *Fig. 1*). This part contains MN samples, which is then separated into M intervals of duration T. Consequently, the PAPR of every interval is estimated using equation (3). To analyze the dynamic of filter bank signals, we exploit the CCDF given by equation (4).

$$PAPR\ (dB) = 10 log_{10} \frac{max_{it \le t \le (i+1)T}(|U(t)|^2)}{E(|U(t)|^2)} \tag{3}$$

$$CCDF\ (PAPR) = Pr(PAPR > P_T) \tag{4}$$

3. ALTERNATIVE SCHEMES

3.1. Tone reservation

TR is a PAPR mitigation strategy [27], for any multicarrier design, such as FBMC and CP-OFDM waveforms. TR is based on canceling out high peaks through the use of some reserved tones that are orthogonal to the data tones and do not convey any useful data. The TR scheme subsists of adding a time-domain signal $Cr(t)$ to the initial signal $U(t)$to reduce the PAPR. Though the resulting PAPR of $\big(U(t) + Cr(t)\big)$ must be lower than the initial PAPR of $U(t)$. The foremost advantage of the tone reservation strategy is its effectiveness and simplicity in reducing the envelope fluctuation in filter bank symbols. On the other hand, various trade-offs must be considered, for example, the number of iterations, PRTs, and numerical complexity. The following describes the step-by-step process of the Tone Reservation mechanism for FBMC-OQAM data blocks:

Algorithm 1: TR algorithm

1. Indicate the amount of **PRT $\boldsymbol{Z}$,** and iteration $\boldsymbol{I}$ and the clipping level $\boldsymbol{\gamma}$, for **TR;**
2. Generate $\boldsymbol{U(t)}$ **FBMC-OQAM** signal by using Eq (1) and Eq (2)**;**
3. Clip $\boldsymbol{U(t)}$ signal at $\boldsymbol{\gamma}$ as :

$$\overline{\boldsymbol{U(t)}} = \begin{cases} \boldsymbol{U(t)} & |\boldsymbol{U(t)}| \leq \boldsymbol{\gamma} \\ \boldsymbol{\gamma e^{j\varphi_u}} & |\boldsymbol{U(t)}| > \boldsymbol{\gamma} \end{cases}$$

4. Compute the clipping noise as: $\boldsymbol{e(t)} = \overline{\boldsymbol{U(t)}} - \boldsymbol{U(t)}$**;**
5. Switch it to the frequency domain $\boldsymbol{E(f)}$;
6. Re-modulate $\boldsymbol{C(f)}$ to form $\boldsymbol{Cr(t)}$**;**
7. Add $\boldsymbol{Cr(t)}$ to $\boldsymbol{U(t)}$ to get the **TR-FBMC-OQAM;**
8. Compute the **PAPR** of $\boldsymbol{U_{TR}(t)}$ signal by using Eq (2)**;**

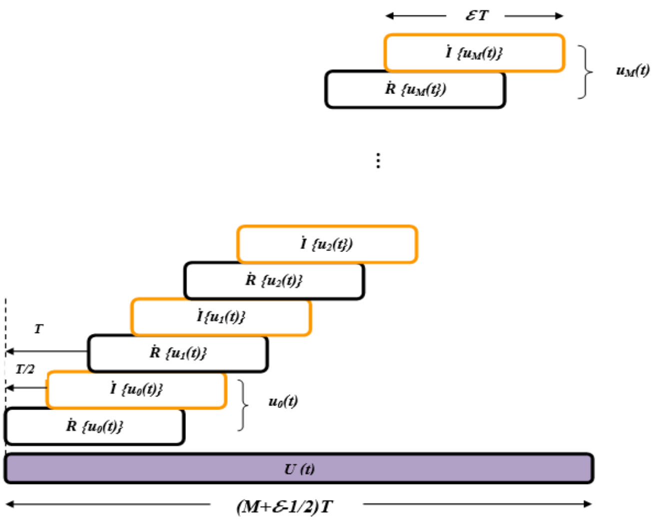

Fig. 1. FBMC-OQAM symbols repartitions.

3.2. TD and TC Schemes

The high peak to average power ratio (PAPR) in filter bank multicarrier symbols can present a major challenge in wireless systems. This issue has been tackled with various techniques of PAPR mitigation, but many of them entail increased complexity and cost. In general, higher numerical complexity requires higher energy consumption for signal processing. Therefore, optimizing this parameter is important for reducing power consumption and prolonging the battery life of mobile devices. The main spotlight of this study is to reduce the PAPR in FBMC-OQAM symbols in a simple and effective way without additional complexity and without BER degradation. For this, we present our proposed algorithms, TR&DC (TD) [16] and TR&Compd (TC) [17]. Both suggested schemes are based on TR method [11], [14] with two other boosters' techniques deep clipping (DC) [28], and Mu-Law [29] (see *Fig. 2*), to improve the PAPR reduction in filter bank systems. These two methods are very effective in reducing the dynamic range of multicarrier signals. Both methods TD and TC, (see *Fig. 3*), share the same first step, which is the tone reservation (TR) process, they differ in the second step. In the TD algorithm, TR-FBMC-OQAM symbols are clipped by deep clipping (DC) [28]. In a detailed way, we can say that TR can minimize the dynamic range of FBMC symbols but cannot cancel all peak power. For this, we recommend the use of the deep clipping function (DC) which is a simple and enhanced version of clipping to deeply clip high amplitudes, and to get better PAPR reduction. To control the depth of clipping, a parameter known as the clipping depth factor has been provided (see *Fig. 2*).This suggested TD technique for PAPR reduction combines the efficiency of the first stage (TR) with the reduced computational complexity of the second step (DC), providing improved PAPR reduction without added complexity. To not impact our signal, we used the optimal values of depth clipping and the clipping level for DC fonction to maintain the best BER performance (see Table 2). The main contributions of TD are: Firstly, compared to the TR algorithm, we use a small number of iterations and tones to have a relatively low PAPR FBMC signal. Then, adopt the deep clipping (DC) method to provide efficient PAPR minimization without added computational complexity and easy implementation. Secondly, compared to existing hybrid PAPR minimization algorithms in the literature, we find that the majority of works use very complex algorithms such as ACE-TR hybridization, PTS-TR, SLM-PTS and SLM-TR, which require a large number of operations (IFFT/FFT), as well as Side Informations 'SI' transmission for SLM and PTS. So in TD, we don't need to send SI, and we only need two operations (IFFT/FFT) to generate a correction signal (1 iteration), which could be advantageous for reducing algorithm complexity. Thirdly, we can adjust the depth factor, clipping threshold and TR parameters (Z, I) to achieve a compromise between computational complexity, PAPR reduction and BER perfomance.

On the other hand, in TC, as a second step after TR, we apply the Mu-Law [29] mechanism, which is a simple and effective companding technique to correct more all TR data blocks to ensure better PAPR reduction. Mu-law compandig is an amplitude limiting scheme that is easy to implement in any digital system.various forms of nonlinear companding, such as A-law and Mu-law are studied in the literature. Through the use of various functions, the companding technique reduces the PAPR by compressing high amplitudes and expanding lower ones. The contributions of TC are: Firstly, we run the TR with low iteration times and tones to obtain FBMC signals with low PAPR, then we apply the Mu-Law companding function to give a better reduction. Secondly, if we compare the scientific work based on the Mu-Law in the literature, we find that all the articles use very large ∂ values (Mu-law ratio), for example: ∂ = 255, which degrades the BER of the system due to the compression processes, so in our algorithm, we have proved that with a small value of ∂, we can have an excellent reduction, as in our case ∂ = 1. This benefits distortion reduction. Thirdly, the TC algorithm is remarkably flexible in terms of parameter adaptation (∂ parameters of the Mu-Law and other TR parameters such as (Z, I)) to achieve a compromise between PAPR reduction, reduced complexity, and BER quality. Finaly, we can say that to achieve the best results for both TD and TC schemes, we have to select the optimal combination of parameters because if we increase I, the complexity will increase, and if we use a large number of Z we will lose the bit rate, and if we use large values of clipping level and compandig parameter, we will degrade the BER performance.

The proposed schemes TD and TC for FBMC-OQAM symbols PAPR mitigation follow algorithm 2. In the following section, we estimate the performance of the three algorithms (TR, TD, and TC) and compare them.

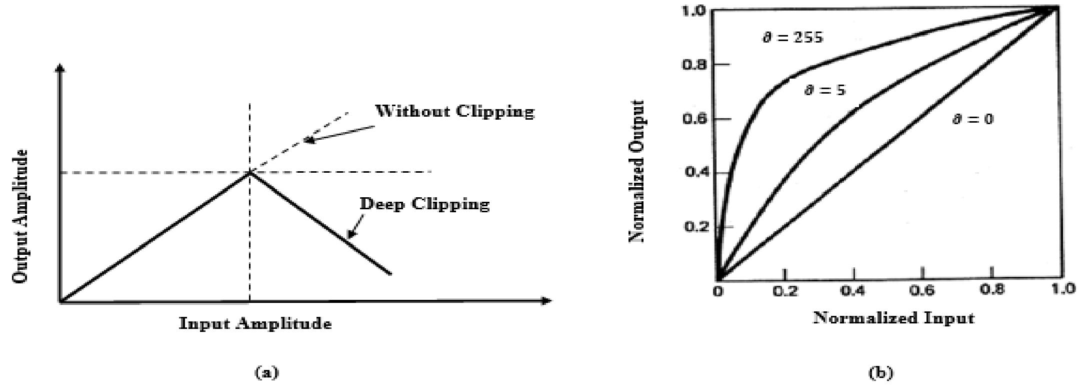

Fig. 2. (a) Deep clipping and (b) Mu-law companding.

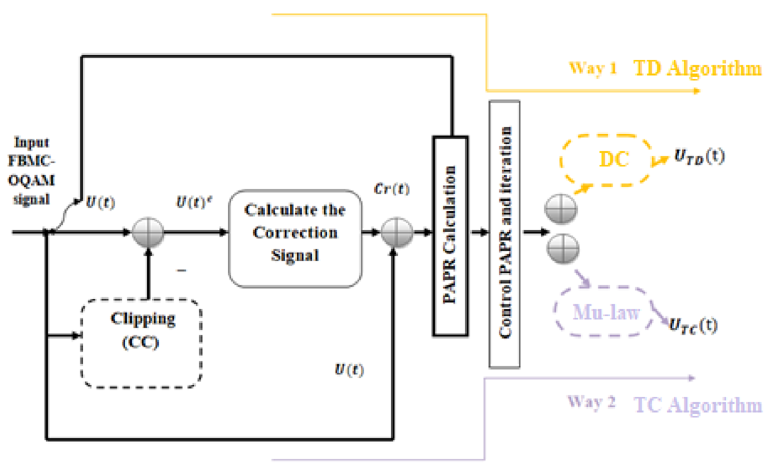

Fig. 3. TD and TC PAPR mitigation treatments.

Algorithm 2: Alternative Algorithms

1. **STEP I:TR**
2. Indicate the clipping level $\boldsymbol{\gamma}$, the number of reserved tones **Z** and iteration **I** for TR;
3. Generate $\boldsymbol{U(t)}$ FBMC-OQAM signal by using Eq(1) and Eq(2);
4. Clip $\boldsymbol{U(t)}$ signal at $\boldsymbol{\gamma}$:

$$\widehat{\boldsymbol{U(t)}} = \begin{cases} \boldsymbol{U(t)} & |\boldsymbol{U(t)}| \leq \boldsymbol{\gamma} \\ \boldsymbol{\gamma e^{j\varphi_u}} & |\boldsymbol{U(t)}| > \boldsymbol{\gamma} \end{cases}$$

5. Generate $\boldsymbol{Cr(t)}$ signal by :
   - Compute the clipping noise $\boldsymbol{e(t)} = \widehat{\boldsymbol{U(t)}} - \boldsymbol{U(t)}$**;**
   - Switch it to the frequency domain $\boldsymbol{E(f)}$;
   - Re-modulate $\boldsymbol{C(f)}$ to get $\boldsymbol{Cr(t)}$;
6. Add $\boldsymbol{Cr(t)}$ to $\boldsymbol{U(t)}$ to get $\boldsymbol{U_{TR}(t)}$**;**
7. **STEP II:**
   - **For TD**
8. Clip $\boldsymbol{U_{TR}(t)}$ by **DC** mechanism at a clipping level $\boldsymbol{D}$ and the clipping-depth factor$\boldsymbol{\mu}$.

$$\widetilde{\boldsymbol{U(t)}}_{\boldsymbol{TD}} = \begin{cases} \boldsymbol{U_{TR}(t)} & |\boldsymbol{U_{TR}(t)}| \leq \boldsymbol{D} \\ \boldsymbol{D} - \boldsymbol{\mu}(\boldsymbol{U_{TR}(t)} - \boldsymbol{D}) & \boldsymbol{D} < |\boldsymbol{U_{TR}(t)}| \leq \frac{\boldsymbol{1+\mu}}{\boldsymbol{\mu}}\boldsymbol{D} \\ \boldsymbol{0} & |\boldsymbol{U_{TR}(t)}| > \frac{\boldsymbol{1+\mu}}{\boldsymbol{\mu}}\boldsymbol{D} \end{cases}, \boldsymbol{0} \leq \left(\boldsymbol{M} + \boldsymbol{\varepsilon} - \frac{\boldsymbol{1}}{\boldsymbol{2}}\right)\boldsymbol{T}$$

   - **For TC**
9. Apply **Mu-Law** to the$\boldsymbol{U_{TR}(t)}$ signal as:

$$\boldsymbol{U_{TC}(t)} = \frac{\boldsymbol{J}\,\mathbf{log}\left(\boldsymbol{1} + \frac{\boldsymbol{\partial}|\boldsymbol{U_{TR}(t)}|}{\boldsymbol{J}}\right)}{\mathbf{log}(\boldsymbol{1}+\boldsymbol{\partial})}\boldsymbol{sgn}\big(\boldsymbol{U_{TR}(t)}\big)$$

10. **STEP III:PAPR CALCULATION**
11. Determine the PAPR of **TD&TC-FBMC-OQAM** using equation (4).

3.3. Complexity analysis

The numerical complexity was the main priority for both proposed TD and TC techniques due to the importance of this parameter in the energy consumption of FBMC systems. In this work, the complexity is evaluated in terms of the complex multiplications required for all M data blocks in an FBMC-OQAM frame. The compared systems use the same structure for Modulation and Demodulation. We consider that the complexity of an IFFT/FFT of N-point is $Nlog2N$, and the complexity of PPN is εN (ε is the overlap factor for PHYDYAS filter). Both algorithms are essentially based on TR treatment, so we can say that the complexity of TD and TC depends on the calculation of the attenuation signal in the time (c) and frequency (C) domains. More clearly, in each iteration of TR, the estimation of C and c requires two IFFT/FFT operations and two PPNs in order to compute the correction signal. The complexity of the TR for one iteration and M data blocks is reported in Table 1.

Moreover, in TD and TC, the deep clipping and Mu-law function (no iterations) do not add complexity to the TR algorithm. However, the complexity of TD and TC presents the same complexity as TR, which unfortunately increases with the number of iterations of this technique.

Table 1. Complexity of the proposed algorithms.

Algorithms	Majors operations in 1 iteration TR	Temporal complexity
TR	2 x (IFFT/FFT) et 2 x (PPN)	MI[2 x O (N $\log_2$ N)+2εN]
TD	2 x (IFFT/FFT) et 2 x (PPN)	MI[2 x O (N $\log_2$ N)+2εN]
TC	2 x (IFFT/FFT) et 2 x (PPN)	MI[2 x O (N $\log_2$ N)+2εN]

4. SIMULATION RESULTS

In this section, we present some numerical results for the three methods (TD, TC, and TR) using the most merit criteria for PAPR reduction methods in literature, which are CCDF, PSD, BER, complexity, SI and debit loss. Simulations are guided for an FBMC-OQAM system based on 4-OQAM modulation, 64 subcarriers, 16 data blocks, and a prototype filter named PHYDYAS with ($\varepsilon = 4$) is used. The simulation environment is shown in Table 2.

Table 2. Simulation parameters for TR, DC and Mu-law.

Parameters	*Values*
Reserved tones	*Z=8*
Iteration times	*I=8*
Clipping level for TR	*γ=2.1*
Clipping level for DC	*D=3*
Depth factor for DC	*μ=0.6*
Mu-law ratio	*∂ =1*

4.1. CCDF

The CCDFs comparison of TD, TC, and TR is shown in *Figure 4,* with a fixed threshold for the three algorithms equal to 2.1 dB and a fixed number of iterations, PRTs ($I = 8, Z = 8$). From the CCDFs curves, we can observe that when the CCDF is 10^{-3}, among three mechanisms TD, TC and TR, TC algorithm decreases by a gain equal to $4dB$, TD decreases by 3.5dB, while TR decreases the PAPR by $3dB$. It can be noted that the TC performs better than the TD and TR in terms of PAPR reduction. *Figure 5* presents the CCDFs of the TD with $I = 12$ iterations, TC with $I = 6$ iterations, TR with $I = 12$ iterations and the original FBMC-OQAM signal. We can notice that TC reduces the PAPR by 3.8 dB with only six iterations. Closer gain is reached with TD method however, with $I = 12$. We can notice that TC with a small number of iterations (6) has a superior gain compared to TD. This means that using the

TC algorithm with only 6 iterations resulted in a larger improvement in terms of numerical complexity compared to using the TD algorithm. Therefore, it is always recommended to thoroughly evaluate the performance of different algorithms with different parameter settings on a given task before making a final decision on which algorithm to use in practice.

4.2. BER

Figure 6 illustrates the BER performance of the proposed techniques TD and TC in an AWGN channel in the case of absence of HPA and by using the same simulation parameters as in Table 2. From the figure, we find that the proposed algorithms present good results in terms of BER, which are close to each other and to the BER of the original FBMC signal. In other words, we can say that our algorithms do not degrade the BER performance before the non-linear amplification.

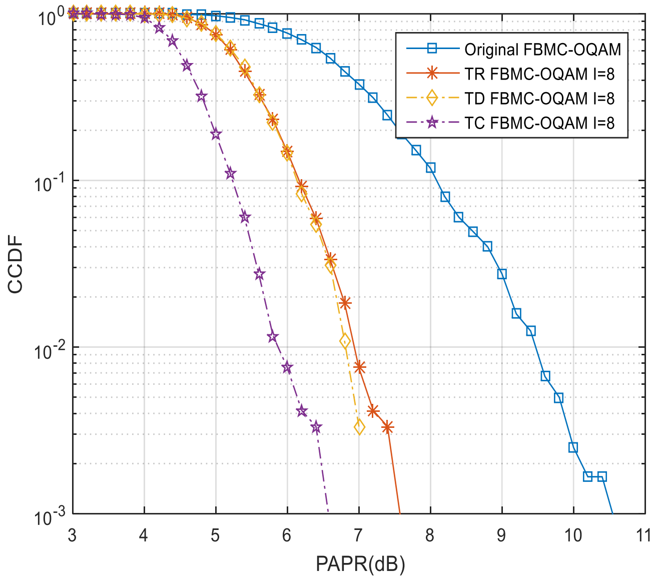

Fig. 4. CCDF measurements of the TD, TC and TR methods with eight iterations.

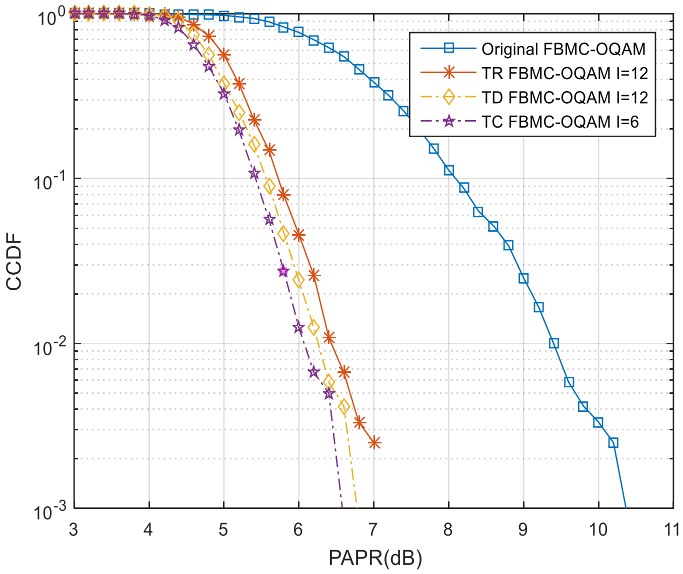

Fig. 5. CCDF measurements of the TD, TC and TR methods with different iteration time.

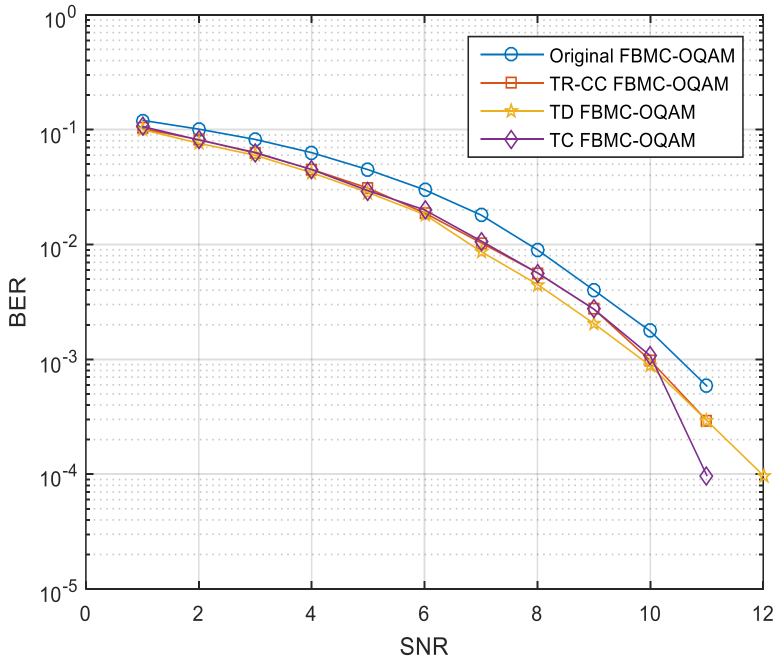

Fig. 6. BER performance of the TD, TC and TR methods in AWGN channel.

4.3. PSD

In our investigation, we also carried out simulations in terms of PSD for TD, TC, TR, and FBMC-OQAM original without the presence of an HPA. From *figure 7*, we can clearly see that the PSD of TC and TD coincide with the FBMC-OQAM signal without PAPR reduction. We can note that our suggested methods for PAPR reduction do not increase the PSD for the FBMC-OQAM symbols in the case of absence of non-linear HPA.

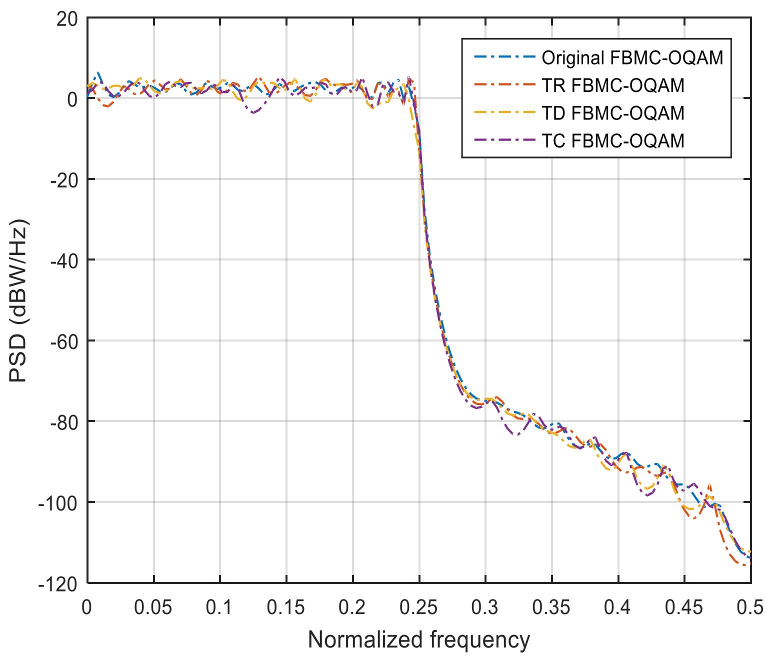

Fig.7. PSD performance of the TD, TC and TR methods.

4.4. Discussion

To complete our investigation, we have introduced a comparative table (see Table 3) of the CCDF, BER performances, and complexity of TD and TC and three cited methods, Hybrid PTS/TR [11], M-Hybrid [11] and Sparse PTS/TR [14]. From the table, we can say that in the case of an FBMC system with 4-OQAM modulation, 64 subcarriers, 16 data blocks and a prototype filter of size $4T$, the Hybrid PTS/TR, M-Hybrid, and Sparse PTS/TR can achieve a significant reduction of PAPR. Also, the proposed TD and TC methods can reduce PAPR considerably. It is clear that TC outperforms Sparse PTS/TR by $0.01dB$, Hybrid PTS/TR by $0.15dB$ and M-Hybrid by $0.05dB$. According to references [11] and [14] and Table 3, we recall that the proposed and cited algorithms do not cause any BER distortions. We have already demonstrated that the complexity of our algorithms TD and TC is always equal to the complexity of TR (see Table 1). According to reference [14] and Table 4, both PTS techniques have high complexities, and in the hybrid case, the complexity will increase. Therefore, we can say that the cited algorithms have very high complexity. The results of this study demonstrate that the proposed TD and TC algorithms are effective techniques for PAPR reduction in FBMC systems. Our finding proved that these algorithms outperform the existing methods in terms of complexity and PAPR reduction while not introducing any BER distortions or requiring additional information 'SI' transmission.

Table 3. Comparative PAPR values, BER loss at 10^{-3} and complexity of proposed and cited methods.

Algorithms	**Parameters**	**Performances PAPR [dB] (CCDF=10^{-3})**		**BER loss [dB]**	**Complexity**
TR	Z=8, γ=2.2	**I=8** 7.77	**I=4** 8.75	**0**	C_{TR}
TD	Z=8, γ=2.2, D=3, μ =0.6	**I=8** 7.00	**I=4** /	**0**	C_{TR}
TC	Z=8, γ=2.2, ∂=1	**I=8** 6.36	**I=4** 7.15	**0**	C_{TR}
Sparse PTS/TR [14]	Z=8, γ=2.2, K=8, S=4	**I=8** 6.46	**I=4** /	**0**	$C_{SPTS}+C_{TR}$
Hybrid PTS/TR [11]	Z=8, γ=2.2, S=4	**I=8** /	**I=4** 7.30	**0**	$C_{PTS}+C_{TR}$
M-Hybrid [11]	Z=8, γ=2.2, S=4	**I=8** /	**I=4** 7.20	**0**	$C_{PTS}+C_{TR}$

Table 4. Complexity of sparse PTS and segmental PTS.

Methods	**Real-Multiplications**	**Real-Additions**
Sparse PTS	$KS(2^S+1)$	$2KS(S-1)(2^S+1)$
Segmental PTS	$MNS(2^S+1)$	$2NM(S-1)(2^S+1)$

Where S is the number of sub-blocks, M is the number of data blocks, N is the number of subcarriers, and K is the number of iterations of Sparse PTS.

In the end, to recap our investigation, we propose a comparative table. Table 5 compares the performance of various PAPR mitigation algorithms in the FBMC structure. The algorithms are compared on five criteria: SI, BER, PAPR, complexity, and debit loss. From Table 5, we note that our suggested TD and TC algorithms are less complex, and do not require supplementary information (SI) compared to the cited techniques. They are very competitive with hybrid algorithms in the literature in terms of PAPR reduction and do not degrade the BER. However, they introduce bit rate loss like all probabilistic techniques (PTS and SLM).

Table 5. Comparative study of proposed and cited algorithms.

Algorithms	**SI**	**BER Destruction**	**PAPR Reduction**	**Complexity**	**Debit loss**
TR	No	No	Moderate	Moderate	Yes
TD	No	No	High	Moderate	Yes
TC	No	No	Very high	Moderate	Yes
Hybrid PTS/TR [11]	Yes	No	High	Very high	Yes
Sparse PTS/TR [14]	Yes	No	Very high	Very high	Yes
M-Hybrid [11]	Yes	No	High	Very high	Yes

5. CONCLUSION

In this paper, two alternative algorithms TD and TC, for PAPR mitigation in FBMC-OQAM systems were suggested. Simulation results demonstrated that the proposed algorithms present a good compromise between the capacity of PAPR reduction, complexity, BER performance and other metric criteria. In addition, for both methods, we can adjust the simulation paramters to get the optimal performance. Moreover, the numerical results are very competitive in terms of PAPR reduction with the cited algorithms in the literature and without additional complexity. The proposed algorithms are expected to be suitable for various communication systems, including 5G and beyond, where high-speed data rate and low latency are required. As a future work, we will involve testing TD and TC algorithms in practical scenarios and exploring their potential for integration with other methods for improved performance.

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