Novel Repeating Clipping and Filter with Partial Transmit Sequence Technique for Reducing PAPR in FBMC/OQAM System

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Abstract: In this paper, a novel approach which merges two recognized signal processing techniques with repeating clipping filtering (RCF) and conventional partial transmit sequence (PTS) techniques has been proposed and analyzed. The key objective is to damp and set the ratio between peak and average powers of the filter bank multicarrier (FBMC) recently used in the 5G mobile systems. The hybrid proposed peak-to-average power ratio (PAPR) scheme is referred to as RCF-PTS technique. Simulation results show that our proposed PAPR reduction technique achieves better power reduction factor compared the clipping and filter (CF) scheme (around 4 dB) and to the PTS technique (around 3 dB).

Key–Words: FBMC/OQAM , PTS , iterative clipping & filtering.

1 Introduction

Filter bank multicarrier (FBMC) has been introduced as a promising alternative for orthogonal frequency-division multiplexing (OFDM) in 5G systems. However, being a multicarrier based technique, FBMC is inherently susceptible to high peak-to-average power ratio (PAPR) that must be mitigated. Moreover, the benefits of FBMC over OFDM in terms of spectral efficiency and the immunity from synchronization issues, has been obtained at the cost of higher PAPR, that the PAPR in FBMC is higher than that of OFDM systems with the same number of subcarriers [1, 2, 3].

The penetration of multicarrier modulation techniques in a diversity of telecommunication standards, with the inherent PAPR problem with the well-known consequences on system performance, led to lots of proposed solutions for that problem. The proposed algorithms in literature for mitigating PAPR in OFDM systems, are much less efficient in FBMC, i.e., the PAPR reduction capability is reduced [4].

Partial transmit sequence (PTS) had proved a great effectiveness in reducing PAPR in OFDM systems, and thus it is normal to be proposed either uniquely or joined with other techniques to mitigate PAPR of FBMC systems. A PTS-built methodologies are suggested in [5, 6, 7] inspired by of the overlapping feature of the prototype filter for FBMC symbols. A hybrid PTS and tone reservation (TR) PAPR reduction scheme is proposed in [8] for FBMC/offset quadrature amplitude modulation (OQAM) system, the reduction in PAPR is achieved with hybrid scheme instead of using each of them solely, numerical results show that higher PAPR reduction is achieved with hybrid schemes.

The use of clipping was the first thing to think about in order to reduce the PAPR in multicarrier systems, though it degrades the link performance, in terms of bit error rate (BER) and increased out-of-band radiation. Usually clipping is used along with some manipulations to mitigate its effects. The use of iterative clipping tries to mitigate the above mentioned effects at the cost of increased propagation delay, while filtering is introduced to cancel out the resulting out-of-band radiation [9, 10, 11].

The use of iterative processing for PAPR reduction has been proposed extensively in literature. An iterative processing is combined with spreading codes is introduced in [12] to reduce PAPR of an OFDM signal while minimizing the BER degradation in addition to reduced out-of-band interference. It is found that the use of spreading codes reduce the number of iterations to obtain threshold PAPR value, while increasing the number of iterations increases the PAPR reduction capability.

A segment based optimization PTS technique is combined with clipping in [13]. The PTS phase factors are assigned for all data blocks. All data blocks are divided into segments, and one data block is used to optimize each segment for PAPR reduction. Then the clipping is used for further PAPR reduction. The effect of clipping is mitigated by compressed sensing at the receiver.

PAPR reduction techniques in muticarrier systems proposed in literature, can be categorized into two main categories, these are signal scrambling techniques or called (linear methods) and signal distortion techniques or called (nonlinear methods)[14]. Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR and Signal distortion techniques minimize high peak dramatically by distorting signal before amplification. Usually, linear methods lead to an increase in computational complexity of communication system. On the other hand, non-linear methods increase the overall system bit error rate (BER). In fact, a good PAPR reduction technique is the one that compromises complexity and BER obtained at receiving end [15].

In this paper, a novel approach combining nonlinear (signal distortion) and linear (signal scrambling) methods, has been proposed, and referred to as clipping and filtering with partial transmit sequence denoted by RCF-PTS. The motivation behind this assumption is to reduce the peak-to-average power ratio (PAPR) and to keep an acceptable BER of the FBMC system. The proposed technique has achieved a significant reduction in PAPR as compared to the original FBMC system.

The major concept of the proposed PAPR method RCF-PTS is to use three leading signal processing steps to reduce the PAPR value. First, the merit of nonlinear iterative clipping method is used to cut the high power value of these minority symbols. second , a filter module is added after each clipping process to reject the out-of band signals. Finally, a conventional PTS module is applied to the clipped and filtered symbols to more optimize the PAPR reduction.

This paper consists of five sections organized as follows: In Section II, a brief description of FBMC/OQAM signal and system model and PAPR concept in FBMC system is explained. The new hybrid from clipping and filtering and PTS algorithm is introduced in section III. Simulation results of our proposed PAPR technique and performance evaluation and analysis of FBMC system with and without the proposed RCF-PTS technique are presented in section IV. Finally, the paper is concluded in section V.

2 FBMC/OQAM SYSTEM and PAPR Problem

2.1 2.1 FBMC /OQAM System Principle

FBMC system is adding generalized pulse shaping filters which produce a well localized sub-channel in both time and frequency domain. Filter banks can be defined as an array of N filters that processes N input signals to produce N outputs. If the inputs of these N filters are joined together, the system in an analogous mode can be considered as an analyzer to the input signal based on each filter characteristics. Hence, this type of filter bank is called analysis filter bank (AFB). While on the other hand, by adding the outputs of the filter array, a new signal is synthesized and hence this type of filter bank is called synthesis filter bank (SFB). The synthesis-analysis configuration is called trans multiplexer and is applied in the multicarrier communication systems. The basic principles of FBMC/OQAM modulator block diagram for are explained in Figure 1.The block diagram shows that synthesis filter bank (SFB) which includes the poly phase network (PPN) after the inverse fast fourier transform (IFFT) and the analysis filter bank (AFB) which includes the poly phase network (PPN) before the fast fourier transform (FFT) [1, 2, 3].

The data is QAM modulated into $A_m, A_m = [a_{m,1}, a_{m,2} ... a_{m,N-1}, a_{m,N}]$, the QAM symbols, then through serial to parallel, the real and imaginary part of each symbol are transmitted on a subcarrier, respectively. After the phase modulation and prototype filter, the transmission FBMC/OQAM data blocks can be obtained by equation (1) The FBMC/OQAM data block signal in time domain can be expressed as [8].

$$\begin{aligned} s_m(t) = \sum_{n=1}^{N} \{ & \Re(a_{m,n}) h(t - mT) \\ & + j\Im(a_{m,n}) h(t - mT - \frac{T}{2})\} e^{j\Phi_{m,n}} \\ & , mT \leq (m + \beta + \frac{1}{2})T \end{aligned} \tag{1}$$

Where $a_{m,n}$ denotes the m^{th} QAM symbol on the n^{th} subcarrier, the real and imaginary parts of $a_{m,n}$, are denoted by $\Re(.)$ and $\Im(.)$ respectively. The symbol period is denoted by T, and $h(t)$ is the response of the prototype filter with βT length, β is the overlapping factor. $\Phi_{m,n}$ is an additional phase term with $\Phi_{m,n} = n(2\pi t/T + \pi/2)$, and $s_m(t)$ is a single FBMC/OQAM signal data block formula.

The FBMC/OQAM [8] successive symbol overlapping is shown in Figure 2:

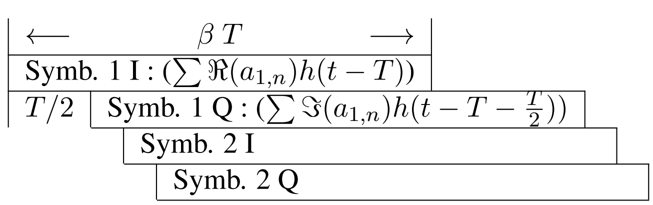

Figure 2: The FBMC/OQAM symbol overlapping.

The transmitter consists of N subcarriers, the M

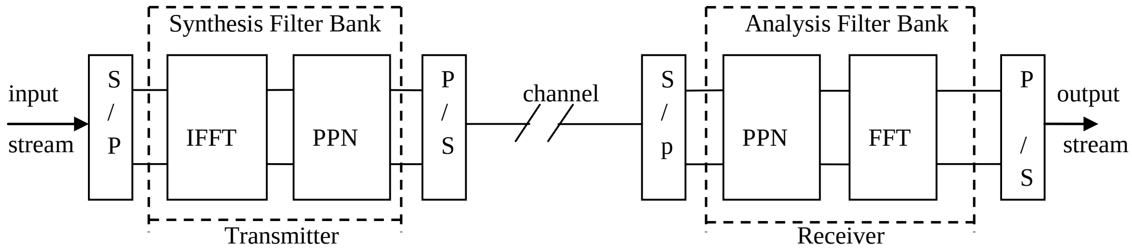

Figure 1: Modulator block diagram of FBMC system model with PPN.

consecutive data block is written as equation (2)

$$s(t) = \sum_{m=1}^{M} s_m(t) \quad , 0 \le t \le (M + \beta - \frac{1}{2})T \quad (2)$$

As we mentioned before, PPN is in the SFB that has N subcarriers with frequency spacing Δf , a signal bandwidth as result of $Bw = N \cdot \Delta f$. According to the sampling theorem, the sampling interval equals $T_s = 1/Bw = T/N$. The length of the symbol period is T, so the corresponding number of signal samples within each symbol period is $T/T_s = N$.

The modulation and demodulation of signal though filter banks, which are the frequency shift of the prototype filter are realized in FBMC system. The Nyquist filter (such as classical raised cosine filter) is chosen in FBMC system to reduce the out-of-band radiation. Actually, modulation and demodulation are coupled in the network. Consider the normalization of data, we often use half-Nyquist filter (such as the square root raised cosine filter). The frequency coefficients of prototype filter when overlapping factor $\beta = 4$ are shown in Table (1) [6].

Table 1: the frequency coefficients of prototype

H_0	H_1	H_2	H_3
1	0.97196	$\frac{\sqrt{2}}{2}$	0.235147

The frequency response of the prototype filter can be obtained using equation (5).

$$H(f) = \sum_{k=-(\beta-1)}^{1} H_k \frac{sin(\pi(f - \frac{k}{M\beta})M\beta)}{M\beta sin(\pi(f - \frac{k}{M\beta}))} \quad (3)$$

2.2 PAPR in FBMC/OQAM system.

PAPR in FBMC/OQAM system can be defined by dividing $S(t)$ into $M+\beta$ intervals, each interval is equal to T (the last one is T/2). The PAPR of each interval can be written as in equation (7) [8, 9, 10]:

$$PAPR(dB) = log_{10} \frac{max(|s(t)|^2)}{E[|s(t)|^2]} \quad , iT \le t \le (i+1)T \quad (4)$$

where $i = 0, 1, \ldots, M + \beta - 1$, and $E[|s(t)|^2]$ denotes the $s(t)$ expectation. The PAPR is one of the quantities that describes the dynamic properties of the transmitted signal $s(n)$. The PAPR is defined as:

$$PAPR(dB) = 10log_{10}(\frac{max(|s(n)|^2)}{P_s}) \quad (5)$$

where $|s(n)|$ is the amplitude and P_s is the average power of the transmitted signal. The complementary cumulative distribution function (CCDF) has been used in our simulation to evaluate the PAPR of FBMC symbols. In general, a complementary formula of CCDF given by [7]:

$$PPAPR > z = 1 - P\{PAPR \le z\} = 1 - (1 - e^{-z})^N \quad (6)$$

where z represents a specific threshold power to evaluate the PAPR in FBMC.

3 Proposed Model

3.1 Clipping And Filtering Technique (CF)

In FBMC/OQAM, signal contains high peaks (exceeding a certain threshold) will be applied to clipping and filtering (CAF) processes as illustrated in Figure 3. In the clipping part, when amplitude exceeds a certain threshold, the amplitude is hard-clipped while the phase is saved [15, 11].

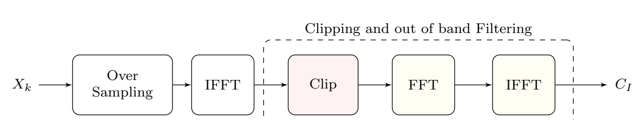

Figure 3: Repeating clipping and filtering technique.

In Figure 4, vector $A_l = [A_0, \ldots, A_{N-i}]$ obtained after over sampling stage is first transformed using an oversize IFFT. For an oversampling factor, denoted by IF, A_I is extended by adding $N(IF - I)$ zeros in the middle of the vector. This results in a trigonometric interpolation of the signal time domain signal $[I]$. The interpolated signal is then clipped and hard-limiting is applied to the amplitude of the complex values of the IFFT output. However, any other form of non-linearity could be used. The ratio of the clipping level value to the root mean square value of the unclipped signal is defined as the clipping ratio (CR). The filtering is used after the clipping to reduce out-of band power. The filter consists of two FFT operations. The forward FFT converts the clipped signal back into the discrete frequency domain resulting in a vector C_I. The in-band discrete frequency components of $[C_{0,i}, \ldots, C_{\frac{N}{2}-1,i}, C_{N_{I1}-\frac{N}{2}+1,i}, \ldots, C_{N_{I1}-1,i}]$, are passed unchanged to the inputs of the second IFFT while $[C_{\frac{N}{2}+1,i}, \ldots, C_{N_{I1}-\frac{N}{2},i}]$ the out-of-band components are nulled. In systems where some band-edge subcarriers are unused, the components corresponding to these are also nulled. The resulting filter is a time-dependent filter, which passes in-band and refuse out-of-band discrete-frequency components. This means that it causes no distortion to the in-band FBMC signal. Since the filter works on a symbol-by-symbol basis, it causes no inter-symbol interference. The main advantage to using filtering after clipping that the filtering causes some peak to re-growth. The clipping process sets a clipping threshold, when the amplitude of the signals exceeds the threshold, then cut the high peak power. According to the systematic acquisition, the following relation has been used to estimate the clipping ratio. $PAPR_0 = 10log(CR)$, where, $PAPR_0$ is concern the threshold value, and CR is the clipping ratio. $PAPR_0$ is selected to be inverse ratio to BER depend on or Due to the relation between $PAPR_0$ and the system BER. In this case, the proper threshold value should be selected carefully [15].

3.2 Conventional PTS reduction technique

The block diagram of conventional PTS is shown in Figure 5. The basic principles of practical partial transmit sequence (PTS) is as follows. First, we use vector data X to define the symbols. Second, divided this vector into M groups, denoted by $\{X_m, \ m = 1, 2 \ldots M\}$. Then the M group summed up as follows [15]:

$$X'(b) = \sum_{m=1}^{M} b_m X_m \tag{7}$$

where, $\{b_m, m = 1, 2 \ldots M\}$ is the weighted coefficient, so that $b_m = e^{j\Phi_m}, \Phi_m \in [0, 2\pi]$ which are considered auxiliary information. Then we adopt IDFT (inverse discrete Fourier transform) to $X'(b)$, so we obtain $x'(b) = IDFT(X'(b))$. Referred to the IDFT instruction, we use of M separate IDFT given as follows [15]:

$$x'(b) = \sum_{m=1}^{M} b_m.IDFT\{X_M\} = \sum_{m=1}^{M} b_m X_m \tag{8}$$

$x'(b)$ Choose appropriate weighted-coefficients $\{b_m, m = 1, 2 \ldots M\}$ corresponding to minimum PAPR of sequence described as follows [15]:

$$\{b_1, b_2, \ldots, b_m\} = \underset{\{b_1, b_2, \ldots, b_m\}}{argmin} (max|\sum_{m=1}^{M} b_m X_m|)^2 \tag{9}$$

where argument (.) represents the sentence condition which makes the function to achieve the minimum value. Thus, we use $(M - 1)$ IDFT to search the optimized weight coefficients $\{b_m\}$, and to achieve the purpose of reducing the PAPR value in FBMC/OQAM system.

3.3 Proposed PAPR reduction implementation method

In this section, we propose a new hybrid algorithm based on CF (clipping and filtering) and PTS schemes for PAPR reduction of FBMC/OQAM signal. The obtained QAM symbols are passed through a bank of transmission filters and FBMC modulated using modulators with N sub carrier and frequencies are $1/T$ spaced apart, forming the FBMC/OQAM. Then the FBMC/OQAM symbols are applied sequentially to RCF processing, after getting the optimal signals, then passed to the PTS processing to get transmitted signal with minimum PAPR. Figure 6 shows the implementation of hybrid scheme.

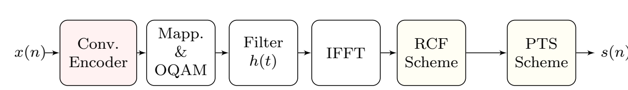

Figure 5: The implementation of hybrid scheme.

In the proposed FBMC/OQAM system, we have combined the use of convolutional code and RCF (repeating clipping and filtering) as shown in Figure 7. The main idea of the proposed PAPR method (RCF-PTS) is to use four main signal processing steps to reduce the PAPR value. First is to use the convolutional

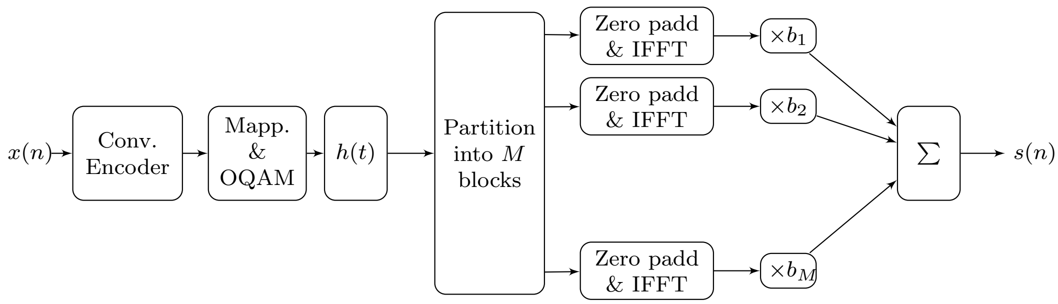

Figure 4: Block diagram of conventional PTS with convolutional code.

code and OQPSK with the FBMC/OQAM transmitter. Second, the feature of nonlinear clipping method is used to cut the high-power value of these minority symbols. Third, a filter module is added after clipping process to reject the out-of-band signals. Finally, a conventional PTS module is applied after the clipped and filtered symbols.

4 Performance Evaluation

The FBMC system is simulated with 64-subcarriers, 4QAM modulation, and oversampling factor of 2, at different clipping ratios (CR= 2, 3, 4) with number of iterations upto 5, with PTS (V = 4). The complementary cumulative distribution function (CCDF) of PAPR is used as a measure of PAPR reduction as shown in Figure 7.

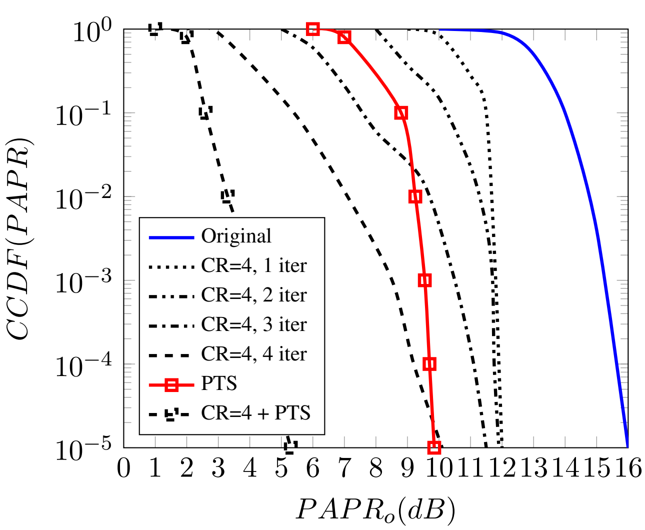

Figure 7: Effect of CF iterations at fixed CR on $CCDF(PAPR)$.

The effect of number of iterations on PAPR reduction in FBMC is depicted in Figure 7 for CF with CR= 4. It is clear that as the number of iteration increase, the PAPR reduction increases as shown by the shift of the corresponding curves to the left as the iteration number increase. The effect of PTS alone is also depicted in Figure 7, where PAPR after (PTS) is reduced by 6 dB when compared with original PAPR. It can be noted that despite of obtaining the same threshold PAPR at 10^{-5} in both cases of CF with 4 iterations and PTS, the curve corresponding to CR= 4 only is on the left of curve corresponding to the PTS only. When combining both CF with 4 iteration at CR= 4 and PTS (RCF-PTS), further PAPR reduction is obtained as shown by the left most curve in Figure 7. From this figure, it is obvious that the lowest PAPR is obtained by applying proposed PAPR reduction technique when compared with the other three cases, namely without reduction technique and using either of PTS or CF techniques.

The performance of proposed method (RCF-PTS) can reach up to 11 dB reduction value by the joint use of RCF and PTS after the Fourth iteration for CF scheme. It can be observed that the hybrid with clipping with additional filtering provides the best performance, at the cost of higher complexity implementation in addition to BER degradation.

The effect of iteration and clipping ratio on CCDF (PAPR) is depicted in Figure 8, by applying the proposed method (RCF-PTS) with (CR= 2, 3, 4) at different iterations.

Either increasing the values of CR or the number of iteration the PAPR reduction increases.Threshold PAPR at 10^{-5} shows negligible enhancement at third iteration at CR= 2, 3 , 4 with PAPR reduction around 9.5 dB . While using fourth iteration at different CR shows reduction of about 11 dB.

BER performance over additive white Gaussian channel with clipping ratios CR= 2, 3, 4 is illustrated in Figure 9.

It is clear as mentioned earlier that increasing CR value causes greater PAPR reduction, though this performance enhancement is obtained at the cost of BER degradation as show in Figure 9. Where a BER of

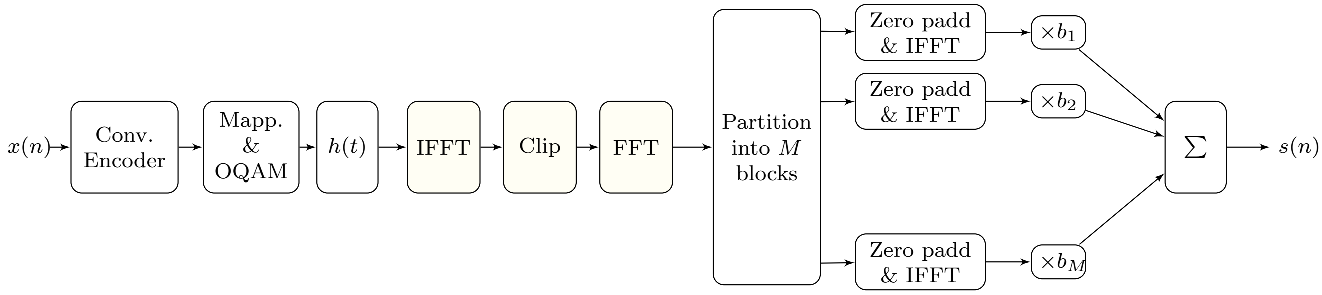

Figure 6: Proposed PAPR technique (RCF-PTS) block diagram for FBMC/OQAM system.

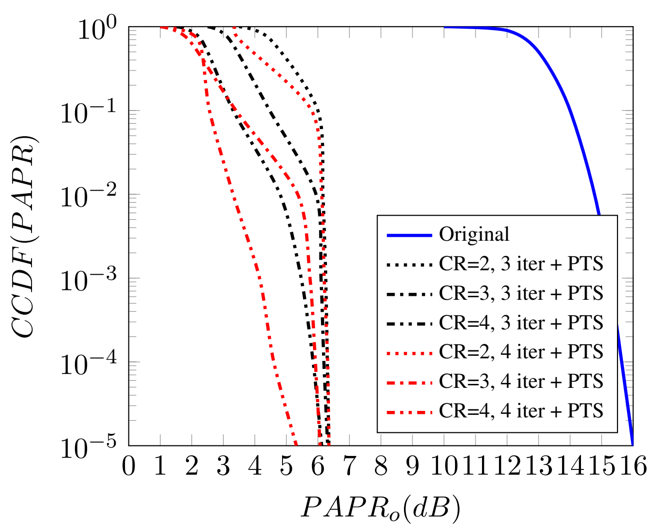

Figure 8: Effect of iteration and clipping ratio on $CCDF(PAPR)$.

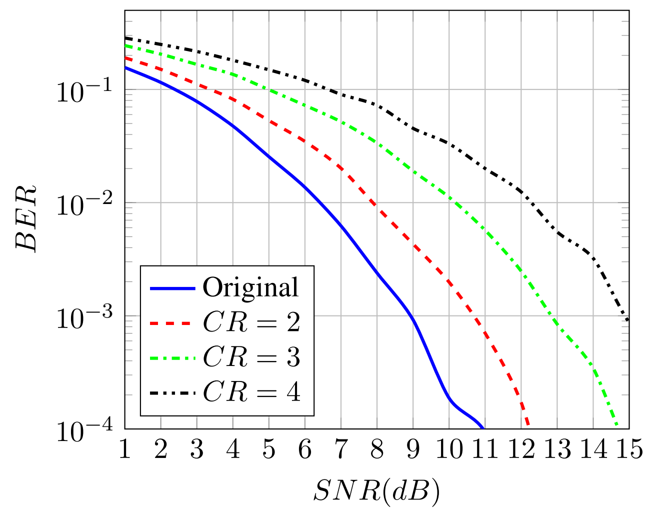

Figure 9: Effect of clipping ratio on BER performance.

10^{-3} is obtained at SNR = 9 dB in the original case, and 10.7 dB at CR = 2, while CR=3 requires 12.8 dB to obtain the same value of BER, and 15 dB is needed at CR = 4. This implies that increasing CR causes about 2 dB degradation per step.

The performance results of PAPR for conventional PTS scheme, different iteration of clipping filter scheme and our proposed technique are summarized in Table 2.

Summarization of simulation results of our proposed (RCF-PTS) technique for different clipping ratio and different number of stages for clipping and filter has been presented in Table 2. The symbols presented in this table are defined as follows. The mean peak average power of original of FBMC/OQAM system is denoted by $\mu_{PAPR_o} = 13dB$. The variance of peak average power of original of FBMC/OQAM system is denoted by $\sigma^2_{PAPR_o} = 0.5$. The difference in peak average power ratio between original FBMC/OQAM and proposed technique is denoted by D_{PAPR}. The reduction in peak average power ratio of absolute values of μ_{PAPR} of FBMC/OQPSK system after and before the reduction technique subtracted from one and multiplied by 100 is denoted by (power reduction factor) $PRF\%$.

A performance comparison shows that increasing CR causes larger PAPR reduction for the same number of iterations as in the cases of CR= 2, 3, 4 with 5 iterations that results in D_{PAPR} of 9.2 dB, 11 dB, and 11.6 dB respectively also $PRF\%$ records 70% , 83%, 89% respectively. Maintaining a constant CR value and increasing the number of iteration causes PAPR reduction enhancements as in the case of CR= 3, where increasing the number of iterations from 1 to 5 causes D_{PAPR} reduction from 7.58 dB to 10.99 dB and with $PRF\%$ ranging from 58% to 83%. However, setting CR= 3 with four iterations results in similar performance to that when setting CR= 4 with three iterations. This enables a compromisation between BER degradation caused by increasing CR, and complexity caused by increasing number of iterations.

Increasing the number of iterations more than four, results in negligible PAPR reduction enhance-

Table 2: Comparison between PAPR results with RFC-PTS using different CR values at different iterations.

CR	No. of Iterations	Proposed Method RCF + PTS			
		σ^2_{PAPR}	$\mu_{PAPR}(dB)$	$D_{PAPR}(dB)$	$PRF\%$
2	1	0.1112	5.8234	7.2681	55
	2	0.3148	5.4934	7.68	58
	3	0.6395	4.9968	8.09	62
	4	0.7837	4.4407	8.651	66
	5	0.7581	3.8886	9.202	70
3	1	0.1749	5.5040	7.58	58
	2	0.6416	4.4734	8.62	66
	3	0.5355	3.5874	9.50	73
	4	0.6562	2.4744	10.62	81
	5	0.2484	2.1921	10.99	83
4	1	0.2362	5.2530	7.84	60
	2	0.5035	3.8415	9.25	71
	3	0.3654	2.5689	10.52	80
	4	0.1404	2.2103	10.91	83
	5	0.5160	1.4820	11.61	89

ment as compared to the resulting complexity as depicted in Figure 10.

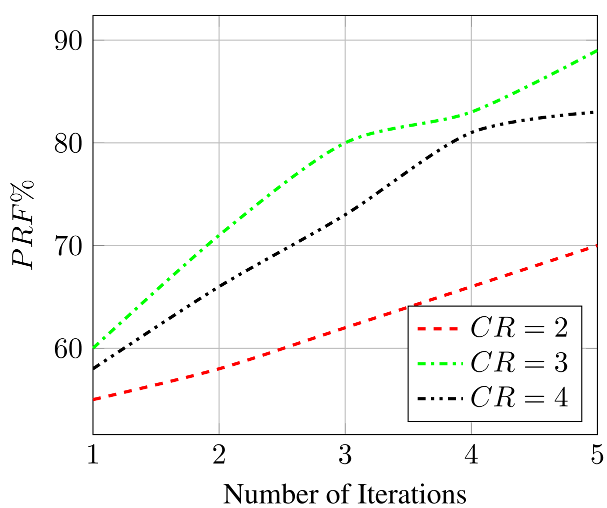

Figure 10: Effect of number of iterations on PRF performance.

Comparing the proposed technique with these presented in literature, requires the same performance measures for the later. Table 3 lists the two net performance measures of each techniques, namely, D_{PAPR} and PRF % in addition to the cost of PAPR reduction in each technique.

It can be noted that using the proposed RCF-PTS with CR greater than or equal to 3 with 3 or more iterations exceeds the performance of the presented techniques in the table in terms of $PRF\%$. The proposed technique only exceeded by [18] in terms of D_{PAPR} at the cost of 3 iterations in addition to 3 TI and companding.

Table 3: Comparing PAPR reduction techniques' performance.

Technique	Ref	D_{PAPR}	PRF %	Cost of Reduction
Signal Damping	[16]	8.7	49	Increase in BER + Companding + Pulse Shaping
Iterative	[17]	4.7	66.1	4 iterations + 8 TR out of 64 subcarriers
	[18]	12.7	77	3 iterations + 3 TI + Companding
	[19]	2	37	4 iterations SLM
	[20]	4.5	64.5	2 iterations + ACE that causes spectral regrowth
	[21]	6	74.88	8 iterations + increase in BER
	[22]	6.1	75.5	16 iterations + SLM + TR
	[23]	7	62.5	5 iterations + 5% of subcarriers for TR + ACE that causes spectral regrowth
PTS	[24]	4	60.2	4 overlapping symbols + 8 TR out of 64 subcarriers
SBO	[13]	4	36.3	4 overlapping symbols + PTS with 4 , 8 sub-blocks out of 64 subcarriers phase factor 1 , -1 that increase complexity + clipping with sparsity levels 15, 30, and 90 that increase BER

While using the proposed RCF-PTS with CR= 2 out performance the presented techniques in the tables by one of the two measures at least, except [18], [21], and [22] at the cost of larger number of iterations and computation complexities of these techniques.

5 Conclusion

A novel PAPR reduction technique of FBMC signal is proposed in this paper. It is denoted by (RCF-PTS) and it is based on combining repeated clipping & filtering, and PTS. By using different clipping iteration with suitable clipping ratio, and choosing a suitable number of phases in PTS.

Simulation results showed that the hybrid proposed scheme resulted in system performance enchantment in terms of power reduction factor. Increasing the number of iterations more than four, results in negligible PAPR reduction enhancement as compared to the resulting complexity. While increasing CR causes larger PAPR reduction for the same number of iterations, at the cost of BER degradation. The presented PAPR technique provided an excellent power reduction with an acceptable additional processing delay for clipping and filtering technique. The presented PAPR method in this paper is strongly enhanced the FBMC/OQAM system performance with acceptable complexity as well as processing time delay.

It is noted that using the proposed RCF-PTS with CR greater than or equal to 3 with 3 or more iterations exceeds the performance of the previously presented techniques in terms of $PRF\%$, with much reduced PAPR reduction costs.

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