Integrated PTS and OSLR (IPTS-OS-LR) Technique for Reducing PAPR in FBMC-based OQAM Systems of MIMO-OFDM

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Abstract

Peak-to-Average Power Ratio (PAPR) reduction is the most significant issue that needs to be addressed in MIMO-OFDM. The overlapping characteristics of neighborhood data blocks in Offset Quadrature Amplitude Modulation based Filter-based multi-carrier (FBMC-based OQAM) systems inspired digital communication in OFDM attracts the researchers towards this specific domain. The optimal data block in has to be selected for effective transmission and the neighborhood overlapping data blocks need to synchronized for ensuring minimum signal power as it is the unique option for facilitating air interface in the next-generation wireless networks. An Integrated PTS and OSLR (IPTS-OS-LR) scheme is propounded for FBMC-based OQAM Systems for maximal reduction of PAPR value and signal power by selecting the efficient data block and the tones for peak reduction is ensured through cancellation scheme triggered by OS-LR. Simulation results unveils the effectiveness of IPTS-OS-LR in reducing PAPR in comparison with the classical PTS and OS-TR techniques proposed for FBMC-based OQAM Systems. IPTS-OS-LR confirms an enhanced PAPR reduction rate of 3.1 dB which is nearly 34% and 23% greater to the reduction rate achieved by PTS and OS-TR techniques compared to the original FBMC-based OQAM signals. The BER of IPTS-OS-LR is also reduced to 22% better than the PTS and OS-TR techniques.

Keywords: Filter-based multi-carrier, Cyclic Prefix, Bit Error Rate, Time Frequency Localization, Sliding Window

1. Introduction

Generally, majority of the communication systems that enables transmission with high data rate applies multi-carrier approaches as the best candidates for next generation wireless networks. OFDM is the significant among the reliable multi-carrier schemes employed in digital data communications. The spectral efficiency is greatly impacted in OFDM due to the addition of Cyclic Prefix (CP) in the transmission of its symbol. In addition, out of band radiation is maximum as the sub-carrier in OFDM uses rectangular-shaped pulses. FBMC-based OQAM systems are found to be the better solutions for addressing the issue of CP and out of band radiation since they incorporate the process of pulse shaping using the concept of Time Frequency Localization (TFL) based on filter bank that uses Fast Fourier Transform/ Inverse Fast Fourier Transform. The staggered property of OQAM symbols and doubled rate of its transmission make it suitable for ensuring high rate of spectral efficiency. The non-utilization of CP in FBMC-based OQAM systems enables it to confirm better data rate compared to the CP-based OFDM systems. The common drawback between CP-based OFDM systems and FBMC-based OQAM systems is its high PAPR value. The reduction of PAPR value is achievable through the incorporation of maximum input back-off based amplifiers as they prevent the distortions of the signal to an appreciable degree. Thus, IPTS-OS-LR is contributed in this paper minimizing PAPR value and Bit Error Rate (BER) in FBMC-based OQAM Systems.

The significant contributions of IPTS-OS-LR are portrayed as follows:

- ✓ The advantages of PTS and OS-LR are integrated and re-generation of peak signals due to overlap effect in FBMC-based OQAM systems are prevented using segmentation.
- ✓ The neighborhood overlapping data blocks of FBMC-based OQAM systems are jointly considered for reducing the intensity of overlapping effect.
- ✓ The precision of the results of IPTS-OS-LR are verified through simulation under different levels of peak reduction tones, number of sub-blocks and different thresholds used for clipping and the results confirm significant PAPR and BER reduction over the traditional PTS and OS-TR techniques.

The roadmaps of the remaining sections of the paper are detailed as follows.

The significant contributions of the literature proposed for PAPR reduction in FBMC-based OQAM systems are highlighted with their pros and cons in Section 2. The importance of PAPR reduction, steps involved in the deployment of PTR, OS-TR and IPTR-OS-TR schemes with motivation for understanding their suitability is elaborated in Section 3. Section 4 highlights the accuracy of IPTS-OS-LR through simulation using different levels of peak reduction tones, number of sub-blocks and various thresholds used for clipping. Section 5 concludes with the potential contributions of IPTR-OS-TR approach with their significant improvement achieved.

2. Related Work

In the literature, considerable numbers of PAPR reduction techniques were propounded for OFDM and FBMC-based OQAM systems. The potential PAPR reduction schemes among them are enumerated as follows.

Numerous contributions have been propounded for addressing the issue of PAPR reduction in OFDM systems. Partial transmit Scheme (PTS), Selective Mapping (SLM) technique and Tone Reservations (TR) are competent among for reducing the rate of PAPR [10-12]. These potential schemes are found to be not highly suitable for FBMC-based OQAM systems as the structure of their signal is entirely different from the signal incorporated by OFDM. FBMC-based OQAM systems possess overlapping neighborhood data blocks and hence the data blocks are dependent on each other [13].

In the recent decade, potential number of PAPR minimization techniques has been contributed for addressing and handling dynamic data rate of FBMC-based OQAM systems [14-15]. Initially two SLM based PAPR minimization techniques called Trellis-based Selected Mapping (TSLM) [16] and are proposed for handling the overlapping characteristics of FBMC-based OQAM systems. In TSLM, the influence of time is investigated through upper and lower bounds and the benefits of trellis codes are utilized for reducing the value of PAPR. TSLM is also analyzed based on necessary memory, latency and computation overhead and it ensures reduced PAPR that incurs low memory requirements. Then SLM based on overlapping features (OSLM) [17] are proposed for reducing the intensity of PAPR signals of FBMC-based OQAM systems and they utilize optimal phase rotation sequence for synchronizing the present and past considered data blocks for reduction.

A significant Tone Reservation scheme [18] based on Sliding Window (TR-SW) is proposed for cancelling the sequential data blocks through the introduction of peak minimization tones. TR-SW is also contributed for understanding the impact of memory and computation overhead incurred during the peak cancellation technique. The performance is also found to outsmart OSLM and TSLM in terms of storage overhead and throughput as they facilitate the action of adjusting the factors that cancels peaks. Further, Tone Reservation-based on Multi-blocks (TRMB) are proposed for exploiting the overlapping structure of FBMC-based OQAM signals that uses neighboring data blocks for phenomenal reduction of noise that is introduced during clipping. Finally, an integrated PAPR scheme that combines SLM and TR (PAPR-SLM-TR) [19] is innovated for optimal combination of the techniques for reliable estimation.

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3. Description of Integrated PTS and OS-TR Scheme for PAPR Reduction in FBMC-based OQAM

3.1 PAPR of FBMC-based OQAM Signals

Generally, the structure of transmitter in FBMC-based OQAM Signals comprises of 'X' number of sub carriers as detailed in [20]. The QAM modulated data is further amplitude modulated and then the QAM symbols are transmitted from serial to parallel facilitating each of the sub carriers to transmit real and imaginary part of each of the symbols. The sub carrier signals are added during the transmission of FBMC-based OQAM data blocks after it is phase modulated and preprocessed in the prototype filter.

The structure of FBMC-based OQAM Signal is divided into two parts which are separated through the distance $\frac{T}{2}$ [21]. Thus the length of 'B' data block is $(\alpha + B - 1/2)T$ with individual data block length of $(B + 1/2)T$. It is clear that each segment gets overlapped with the adjacent $\alpha - 1$ data blocks. Considering the overlapping structure of FBMC-based OQAM Signal, PAPR for each interval 'T' is defined as;

$$FBMC-OQAM_{PAPR}(dB) = 10\log_{10} \frac{\max\limits_{iT \le t \le (i+1)T} [S_m(t)]^2}{E[S_m(t)^2]} \qquad (1)$$

$$S(t) = \sum_{m=1}^{N} S_m(t), 0 \le t \le (B + \alpha - 1/2)T \quad (2)$$

3.2 Traditional Partial Transmit Sequence Mechanism for FBMC-based OQAM

In general, the PAPR minimization schemes of the literature are categorized into coding, probability, and clipping and DFT-spreading mechanism. The probability-based PAPR reduction technique is the potential among the existing methodologies. This scheme performs the action of scrambling the input data block of symbols and enables the possibility of transmitting single data block at a time for phenomenal reduction of PAPR. The approaches namely PTS and OTR used in this proposed technique for integration are the significant among the probability-based PAPR minimization schemes.

$$C_{phf}^{n} = e^{j\phi n} \left(1 \le n \le M \right) \quad (3)$$

The time specific signal of frequency domain after integration is represented using PTS ' $S_{I_m}^{n}$ ' is

$$S_{I(m)}(t) = \sum_{n=1}^{M} C_{phf}^{n} S_{I_m}^{n}(t) \quad (4)$$

In PTS scheme, the phase vector of complexity is considered in such a way to reduce the degree of PAPR based on

$$[C_{phf}^{-1}, \ldots\ldots, C_{phf}^{M}] = \arg \min_{[C_{phf}^{-1}, \ldots C_{phf}^{M}]} \max_{0 \le t \le T} \left| \sum_{n=1}^{M} C_{phf}^{n} S_{I_m}^{n}(t) \right|^2 \quad (5)$$

The time specific signal of frequency domain with the least PAPR vector is

$$\tilde{S}_{I(m)}(t) = \sum_{n=1}^{M} \tilde{C}_{phf}^{n} S_{I_m}^{n}(t) \quad (6)$$

The complexity of searching is reduced significantly through the use of limited number of elements for selecting the phase vectors and using the binary kind of phase vectors is effective. As mentioned, the transmission of independent data signal necessitates the operation of phase rotation for reducing the PAPR value in FBMC-based OQAM. But the overlapping structure of FBMC-based OQAM reduces the optimal performance of PTS.

3.3. Traditional Overlapped Scaling-Tone Reservation (OS-TR) for FBMC-based OQAM

OS-TR is an enhanced tone reservation technique that facilitates the option of cancelling the peak of the input signal through the incorporation of approximation method of least squares with necessary overlap neighbourhood symbols. OS-TR is implemented in a level of multi-blocks for sustaining the dynamic nature of FBMC-based OQAM and for ensuring maximum cancellation of peak input signals. The function of OS-LR is analogous to the operation of TR [21] but the soft limiters used in [22] are used. The resultant clipped reserved tones of the output signal is represented through

$$\tilde{R}(n) = R(n), if \left| R(n) \right| \le F$$

(7) $$\tilde{R}(n) = F e^{j\theta_n}, if \left| R(n) \right| > F$$

(8)

Where $0 \le n \le (D + W - 1/2)T$ with 'F' and ' θ_n ' corresponds to the preset threshold and phase angle of the input signal under 'D' and 'W' as the lower and upper limits of time interval 'T'. Then clipping noise of the input signal is derived from

$$C_n = \tilde{R}(n) - R(n) \quad (9)$$

Further, the noise of clipping is demodulated for converting the signal to the frequency domain signal using

$$F_d^{v} = \Re\{ \sum_{n=0}^{(D+W-1/2)T} C_n h(n - fg) e^{j\frac{2\pi k_n}{T}} e^{-j\phi_m^{v}} \} \quad (10)$$

The peak cancelling reduction tones need to be real for satisfying the symbol structure of FBMC-based OQAM as the input symbols of the input frequency domain is already real valued. Thus the complementary parts of the reduction tones in the remaining sub-carriers are estimated as zero as portrayed in (9) and (10) respectively.

$$F_d^{v} = F_d^{v}, v \in \Re \quad (11)$$

$$F_d^{v} = 0, v \in \Re^{c} \quad (12)$$

Further the time dependent part of the clipped signal ' $f_d(n)$ ' is determined from ' F_d^{v} ' using the process of modulation. The approximation of peak cancelling signal ' $C_s(n)$ ' to be very closer to clipped signal ' $f_d(n)$ ', it is multiplied with the factor of scaling called ' S_{Const} '. Thus the peak cancelling signal ' $C_s(n)$ ' is determined in OS-TR using;

$$C_s(n) = \sum_{s=0}^{m-1} S_{Const(s)} * f_{d(s)}(n) \quad (13)$$

The OS-TR based PAPR reduction scheme formulates an objective function and reduces the Euclidean distance between the peak cancelling signal '$C_s(n)$' and clipped signal '$f_d(n)$' by considering the issue of symbol overlap. Furthermore, the method of least square approximation is used for computing the factor of scaling that needs to be dynamically computed depending on the degree of overlapping in adjacent symbols in FBMC-based OQAM.

3.4 Motivation behind the formulation of an Integrated PTS AND OS-TR Schemes

In addition, the potential of PTS and OS-TR depends on the application context and the degree of overlapping of adjacent symbols and hence the integration of PTS and OS-TR improves the reduction rate of PAPR in FBMC-based OQAM. Specifically, this integration of PTS and OS-TR aids to resolving issues when the time period used by FBMC-based OQAM symbols are greater than the prototype filter length. The better understanding of the characteristic nature of FBMC-based OQAM symbols [23] motivates the need of employing an integrated PTS and OS-TR for enabling efficient PAPR reduction. For effective PAPR reduction, defined number of iterations of clipping-based filtering algorithm has to be applied on 'B' data blocks which are divided into '$\frac{B}{\alpha}$' partitions in which the first block symbols overlap with the adjacent '$\alpha - 1$' data segments in of FBMC-based OQAM. In this context, OS-TR can provide better employability than the conventional TR scheme as it uses the least square approximation algorithm for preventing the cancellation of peak signal belonging to each individual data block.

Further the application of PTS approach is suitable in optimizing the possibility of every data block through the concept of optimal phase rotation. This optimal phase rotation depends on the influence of adjacent data blocks under which the power of the signal between the previous and current data block are minimized using data block optimization process. Hence the benefits of PTS and OS-TR are utilized for PAPR reduction..

3.5 Implementation of an Integrated PTS and OS-TR Scheme for PAPR Reduction

In this section, the steps of the proposed Integrated PTS and OS-TR Scheme for PAPR Reduction are elaborated below.

Step 1: Partition 'B 'number of data blocks into '$\frac{B}{\alpha}$ 'segments such that each of the segment is in turn divided into 'α 'data blocks.

Step 2: Perform the optimization functionality for each of the '$\frac{B}{\alpha}$ 'segments.

Step 3: The first data block signal '$S_{I(1)}(t)$' of the first signal is divided into 'U' mutually exclusive sub-blocks '$S^u{}_{I(1)}(t)$' for u=1,2,3,….,U.

Step 4: Binary phase rotation factor is multiplied with the first data block signal '$S_{I(1)}(t)$'.

Step 5: The optimal phase factor product of '$S_{I(1)}(t)$' and corresponding minimum PAPR is determined through

$$x_{i(1)}(t) = \arg\min_{b_1^v} \max_{0 \le t \le (\alpha+1/2)T} \left| \sum_{u=1}^{U} b^u{}_1 S_{I(1)}(t) \right|^2$$

Step 6: Similar to first data block signal, Compute the optimal phase rotation parameter in the second data block signal using

$$\arg\min_{b_2^v} \max_{0 \le t \le (\alpha+3/2)T} \left| x_{i(1)}(t) + \sum_{u=1}^{U} b^u{}_1 S_{I(1)}(t) \right|^2$$

This estimation is mainly for reducing the signal power between the first and second data block signal for effectively reducing PAPR.

Step 7: Iterate the calculation of optimal phase rotation parameter for the entire 'α' number of data block signal using

$$\arg\min_{b_{2\alpha}^v} \max_{(\alpha-1)T \le t \le (2\alpha-1)T} \left| x_{\alpha-1(1)}(t) + \sum_{u=1}^{U} b^u{}_\alpha S_{I(\alpha)}(t) \right|^2$$

Step 8: Thus the first data block signal is

$$x^1{}_{i(1)}(t) = \sum_{n=1}^{\alpha} x_m(t)$$

Step 9: A threshold value of 'F' is used for clipping the magnitude of amplitude of each corresponding signal form the first segment signal through $x_{i(1)}^{-1}(t) = x_{i(1)}$, if $|x_{i(1)}(t)| \le F$ and $x_{i(1)}^{-1}(t) = Fe^{i\theta_X}$, if $|x_{i(1)}(t)| > F$.

Step 10: The clipping signal related to the first data block signal is determined using $f_{i(1)}^{-1}(t) = 0$, if $|x_{i(1)}(t)| \le F$ and $f_{i(1)}^{-1}(t) = x_i^{-1}(t) - x_i^1 F e^{i\theta_x}$, if $|x_{i(1)}(t)| > F$.

In this scheme, least square approximation is used for minimizing the peak power for preventing the degree of interference and degradation of bit error rate in this Integrated PTS and OS-TR Scheme.

Step 11: Perform a number of iterations based on least square approximation to design an cancelling signal through $\bar{f}(t) = \sum_{m=1}^{\alpha} f_m^n(t)$

where $0 \le t \le (2\alpha - 1/2)T$ in which '$f_m^n(t)$' is time specific signal related to 'F_m^n'.

Step12: Similar to step 8, the second data block signal is $x^2{}_{i(1)}(t) = \sum_{m=\alpha+1}^{2\varepsilon} x_m(t)$

Step 13: Repeat the step (7) and (8) for estimating the remaining data block signals and finally the PAPR reduced signal facilitated through the integrated PTS and OS-TR Scheme is estimated using $x^1{}_{i(m)}(t) = \sum_{v=1}^{\frac{B}{\alpha}} x^v{}_m(t)$

4. Simulation result and discussion

The simulation results for verifying the investigation the suitability and applicability of IPTS-OS-TR scheme in FBMC-based OQAM is presented in this section. The potential of IPTS-OS-TR scheme in FBMC-based OQAM is comparatively investigated with PTS, OS-TR and the original signal under different number of data sub-blocks, Thresholds and peak reservation tones. In this PAPR scheme of FBMC-based OQAM, the implementation is facilitated using the square root cosine filter, roll-off parameter of 1, filter length set to 4T under maximum data block signal of 4 and random generation and selection as the tone set for peak reduction.

The significance of FBMC-based OQAM is evaluated using Complement Cumulative Distribution Function (CCDF). Table 1 highlights the detailed values of simulation parameters used for the implementation of IPTS-OS-TR scheme in FBMC-based OQAM.

Table 1-Simulation Parameter- IPTS-OS-TR scheme

Parameter used	Considered Values
Maximum number of sub-carriers	64
Number of data blocks(B)	16
Peak Reduction tones with zero sub-carriers	4,6,8
Modulation Technique	4OQAM
Clipping rounds	4
Sub-blocks count(P)	4,8
Threshold Factor(F)	2.4, 2.6, 2.8
Factor of overlap	4

Figures 1, 2 and 3 presents the plots of 'IPTS-OS-TR', 'PTS','OS-TR' and 'ORIGINAL' based on CCDF for different peak reduction rates of CF=4, 6 and 8 respectively. The curves 'IPTS-OS-TR', 'PTS','OS-TR' and 'ORIGINAL' presents the effectiveness of FBMC-based OQAM with integrated PTS and OS-TR scheme, performance of PTS alone for PAPR reduction, performance of OS-TR alone for PAPR reduction OS-TR and FBMC-based OQAM signal without the implementation of any incorporated PAPR reduction technique. At the CCDF point of 10^{-3}, IPTS-OS-TR facilitates a reduced PAPR gain of 3.4 dB, 3.7dB and 4.2 dB compared to the original signal at CF=4, 6 and 8 respectively. OS-TR reduces the PAPR to about 2.9 dB, 3.1 dB, and 3.4 dB than the original signal and PLS also reduces the PAPR gain by 2.5 dB, 2.8 dB and 3.0 dB higher than the original signal. The plots confirm that the rate of PAPR reduction gets improved depending on the increase of the peak reduction rates and thus IPTS-OS-TR, PLS, OS-TR facilitates minimized PAPR value at CF=8 compared to CF=4. Specifically, IPTS-OS-TR ensures better mean PAPR reduction rate of nearly 2.5 dB compared to the original signal of FBMC-based OQAM.

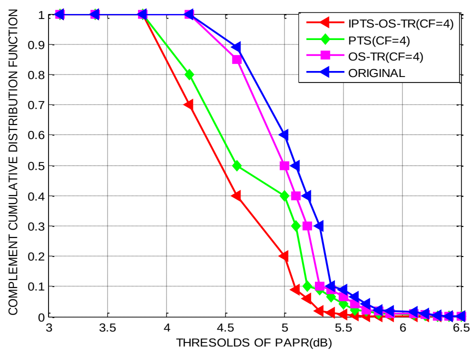

Fig. 1. CCDF of IPTS-OS-TR scheme under CF=4

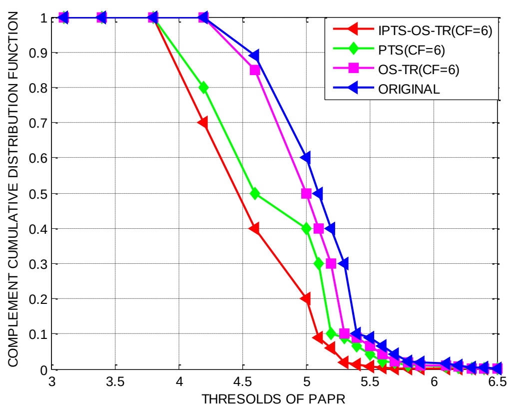

Fig. 2. CCDF of IPTS-OS-TR scheme under CF=6

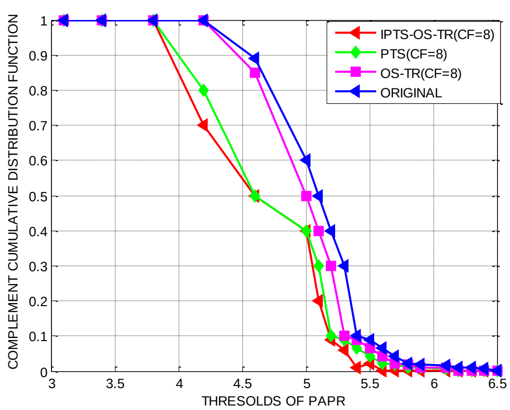

Fig. 3. CCDF of IPTS-OS-TR scheme under CF=8

From figures 4, 5 and 6 presents the plots of 'IPTS-OS-TR', 'PTS','OS-TR' and 'ORIGINAL' based on CCDF for different clipping thresholds of F=2.4, 2.6 and 2.8 respectively. These plots confirm that the minimization of PAPR value is phenomenal with increase in clipping thresholds from F=2.4 to 2.8 in increments of 0.2. At the CCDF point of , IPTS-OS-TR confirms the minimized PAPR of about 2.9 dB, 2.5 dB and 2.2 dB compared to the original signal at F=2.4, 2.6 and 2.8 respectively. OS-TR reduces the PAPR to about 2.1 dB, 2.4 dB, and 2.6 dB than the original signal and PTS also reduces the PAPR gain by 1.9 dB, 2.1 dB and 2.3 dB higher than the original signal at F=2.4, 2.6 and 2.8 respectively.

The plots also proves that PAPR is reduced with increasing clipping thresholds and hence IPTS-OS-TR, PTS, OS-TR enables minimized PAPR value at F=8 compared to the value of F=6 and F=8. In particular, IPTS-OS-TR provides enhanced average PAPR reduction of about 1.6 dB compared to the original signal of FBMC-based OQAM.

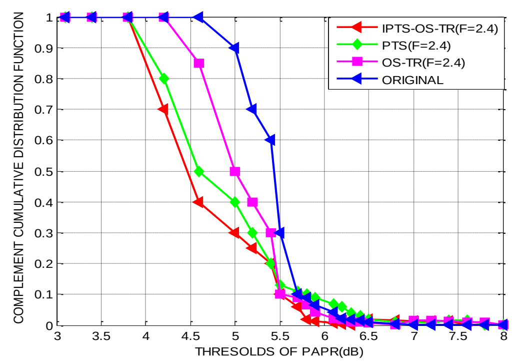

Fig. 4. CCDF of IPTS-OS-TR scheme under clipping factor threshold (F=2.4)

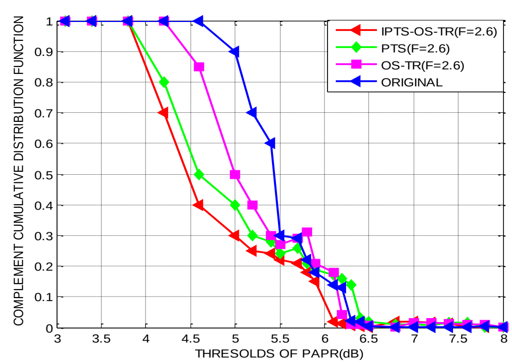

Fig. 5. CCDF of IPTS-OS-TR scheme under clipping factor threshold (F=2.6)

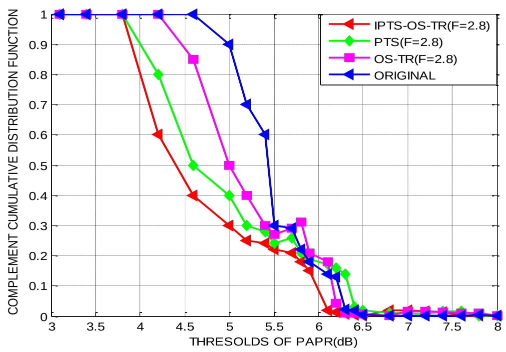

Fig. 6. CCDF of IPTS-OS-TR scheme under clipping factor threshold (F=2.8)

Figures 7 and 8 presents the plots of 'IPTS-OS-TR', 'PTS','OS-TR' and 'ORIGINAL' based on CCDF for increasing Sub-Block Count(SBC=4 and SBC=8). IPTS-OS-TR confirms a minimized PAPR of about 2.4 dB and 2.1 dB compared to the original signal at SBC=4 and SBC=8 respectively. OS-TR reduces the PAPR value to about 1.9 dB and 1.6 dB superior than the original signal and PTS also reduces the PAPR gain by 1.7 dB and 1.4 dB higher than the original signal at SBC=4 and SBC=8. In particular, IPTS-OS-TR provides a difference in average PAPR reduction rate of 1.4 dB compared to the original signal of FBMC-based OQAM as the PAPR value decreases with increase in Sub-Block Count from SBC=4 to SBC=8.

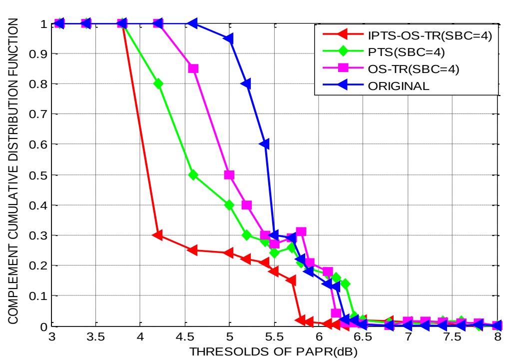

Fig. 7. CCDF of IPTS-OS-TR scheme under Sub-Block Count (SBC=4)

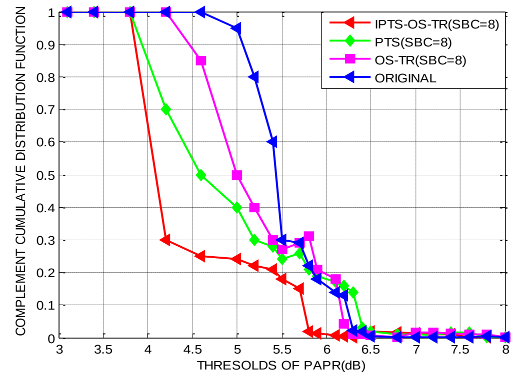

Fig. 8. CCDF of IPTS-OS-TR scheme under Sub-Block Count (SBC=8)

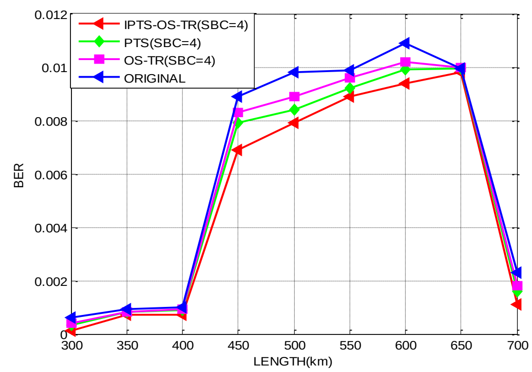

Fig.9. BER of IPTS-OS-TR scheme under Sub-Block Count (SBC=4)

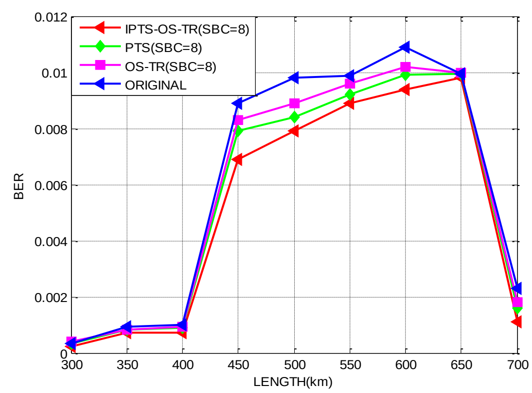

Fig. 10. BER of IPTS-OS-TR scheme under Sub-Block Count (SBC=8)

Figures 9 and 10 presents the plots of 'IPTS-OS-TR', 'PTS','OS-TR' and 'ORIGINAL' based on BER for increasing Sub-Block Count(SBC=4 and SBC=8) for understanding the influence of increasing distance(Meters). IPTS-OS-TR enables the reduced

BER rate of nearly 24% and 29% greater than the BER rate facilitated by PTS and OS-TR techniques at SBC=4 and SBC=8 respectively. OS-TR achieves a mean reduction in BER value of about 22% and 24% compared to the original signal and PTS also reduces the BER by 17% and 19% higher than the original signal when the distance is increased from 300m to 700m investigated under different value of SBC=4 and SBC=8.

5. Conclusion

IPTS-OS-LR presented in this paper is an attempt to integrate the merits of PTS and OS-TR for effective reduction of PAPR in FBMC-based OQAM signal. The re-generation of peak is prevented in the overlapped FBMC-based OQAM signal through the processing of segmenting the data blocks using PTS and the reduction tones of OS-TR estimated based on neighborhood data blocks are used for minimizing signal power of data blocks.

The simulation results of IPTS-OS-TR unveil a difference in reduced mean PAPR reduction value of 1.4 dB in comparison to the original FBMC-based OQAM signal under the impact of Sub-Block Count and it is realized to improve the PAPR reduction rate by 1.6 dB. The results ensures the better mean PAPR reduction rate of nearly 2.5 dB compared to the original signal and also facilitates reduced BER rate of 24% and 29% greater than the BER rate ensured by PTS and OS-TR techniques.

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