INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

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OPEN ACCESS

Received: 22-07-2022

Accepted: 15-09-2022

Published: 08-11-2022

Citation: Sharma MK, Kumar A (2022) Analysis of Peak to Average Power in the 5G NOMA-FBMC Waveform. Indian Journal of Science and Technology 15(41): 2182-2187. https://doi.org/10.17485/IJST/v15i41.1528

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Analysis of Peak to Average Power in the 5G NOMA-FBMC Waveform

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Abstract

Objectives: In this work, we investigate suitable techniques to reduce the Peak to Average Power Ratio (PAPR) for advanced modulation schemes in order to obtain better performance than current or commonly used modulation schemes for Fourth Generation (4G) and Fifth Generation (5G). **Methods**: The proposed scheme incorporates a combination of Selective Mapping (SLM) and Partial Transmission Scheme (PTS) and thereby efficiently minimizes the PAPR and the complexity of the framework. Further, it is seen that the proposed algorithm is crucial to achieving better spectral and power characteristics compared with the existing waveforms. **Findings**: The comparative results of the bit error rate (BER) and PAPR of the advanced SLM-PTS when applied to the OFDM, FBMC, NOMA, and NOMA-FBMC structures are shown, and it is found that the power and complexity are significantly decreased in the advanced waveforms, which makes the proposed algorithm efficient for the advanced waveforms. **Novelty**: A natural motivation for future modulation schemes is to harmoniously merge the newer modulation technique, Filter Bank Multi Carrier (FBMC), with the Non-Orthogonal Multiple Access (NOMA) framework. This has led to a recent modulation paradigm called FBMC-NOMA, wherein the NOMA power domain principle is applied to a group of FMBC modulated signals. The proposed SLM-PTS-based NOMA-FBMC structure efficiently enhances the throughput and PAPR performance for 5G and beyond 5G systems.

Keywords: PAPR; FBMC; SLM; PTS; NOMA

1 Introduction

The next generation of wireless communications is expected to roll out across the entire globe with new infrastructure and technologies. As compared to previous generations, the new generation is expected to have a high data rate, better spectral access, low latency, and the ability to connect multiple devices with low energy utilization. There are enormous expectations for 5G networks, which can be compiled under three pillars. The first pillar is enhanced mobile broadband (e-MBB) to support multimedia and gaming applications. The second pillar deals with the advent of the Internet of Things (IoT), for which it is anticipated that 5G networks will need to support massive machine-type communications (MMTC). The last pillar deals with the preference for real-time requirements of modern communication systems, whereby the 5G networks should support ultra-reliable and low-latency communications (URLLC). The necessity of improving advanced waveforms has become a key research zone in this field[(1)]. In the present scenario, OFDM is the commercially available waveform scheme. However, the researchers are not considering OFDM as a primary contender for 5G and beyond. OFDM suffers from spectrum leakage, high PAPR, is incapable of handling multiple device connections and so on. Hence, in the past few years, an investigation suitable for 5G has been going on for the successful deployment of advanced waveforms in radio networks. FBMC with offset quadrature amplitude modulation (O-QAM) is a lucrative option for the advanced radio framework due to its characteristics such as limited out-of-band spillage of spectrum as well as low bandwidth requirements and simple operation[(2)]. However, FBMC has some compatibility issues with Massive Multiple Inputs and Multiple Outputs (M-MIMO), which makes it unsuitable for 5G waveforms. Power Domain-Non-Orthogonal Multiple Access (PD-NOMA) is an inherent multiple access technology that offers a significant contraction of spectrum needs as it can accommodate multiple users in the same spectrum band via the use of Superposition coding (SC)[(3)]. High intricacy in the receiver is one of the crucial concerns in its deployment. Hence, the combination of NOMA-FBMC is considered an alternate waveform which can overcome the drawbacks of existing waveform techniques. The utilization of multiple sub-carriers in advanced waveforms introduces a high PAPR issue due to which the performance of amplifiers significantly degrades. In the past years, several PAPR schemes have been suggested for 4G, but these PAPR algorithms cannot be utilized in advanced waveforms due to compatibility issues. So, a key research investigation is to design a suitable PAPR scheme for 5G waveforms. SLM and PTS are considered two simple methods to overcome the PAPR. However, both suffer from issues such as complexity and high BER. In order to obtain a satisfying BER and PAPR performance with trivial complexity, we propose the SLM-PTS for 5G waveforms. The optimal performance is obtained in two stages for the proposed SLM-PTS. In the first stage, SLM is applied to the NOMA-FBMC structure to lower the high amplitude symbols. In the next stage, PTS is applied to reduce the intricacy of the framework. In[(4)], an overlapped PTS-based Artificial Bee Colony (ABC) is introduced to reduce the PAPR and improve the computational intricacy. The simulation results confirmed that the PAPR of the proposed method is 0.6 dB, less than the conventional PTS method. In[(5)], A combination of TSLM and A-Law companding function is applied. Firstly, TSLM is used to find the optimal phase rotation factor. Further, the compression of high amplitudes and expansion of low amplitudes are performed through the A-Law function to reduce the level of PAPR. Simulation results observed a sharp decline in PAPR compared to the FBMC A-Law Companding technique. Further, the proposed scheme has a 5dB lesser PAPR than the T-SLM technique. In[(6)], Authors compared the coded NOMA with Low Density Parity Check (LDPC) to un-coded NOMA with OFDM and Filtered OFDM (F-OFDM) in terms of Bit error rate and PAPR. Simulation results suggest that F-OFDM outperforms the OFDM with a significant gap of 0.5 dB in PAPR. The remainder of the proposed work is as follows: Section II defines the PAPR and further discusses the system model of FBMC-NOMA technique. Section III summarizes the simulation and various results of applied schemes. Finally, in Section IV conclusion of the proposed work is presented with quantitative data.

2 System Model

In modern wideband modulation schemes, PAPR is the ratio of peak power to the average power, as presented in the following equation:

$$PAPR = \left(\frac{\max\left\{|T[n]|^2\right\}}{E\left\{|T[n]|^2\right\}} \right) \tag{1}$$

Where T [n] is the amplitude of the transmitted signal and E denotes the expectation of the signal. The Complementary Cumulative Density Function (CCDF) measure the performance of PAPR reduction schemes, as shown:

$$CCDF = \text{ Probability } (\text{ PAPR } > \text{ Threshold }_1) \tag{2}$$

FBMC is the multicarrier technique used in the 5G communication system. Unlike OFDM, which is the modulation technique for 4G communications, significantly better spectrum conservation is achieved in FBMC, which makes it a great potential candidate 5G standard. FBMC, however, has the drawback of significant PAPR, which needs to be resolved using additional techniques. The FBMC modulation has recently be augmented via the addition of the NOMA scheme, which greatly improves its capacity. It, too, suffers from significant PAPR. Hence, we need to apply suitable PAPR reduction techniques to benefit from these modulation schemes in next-generation communications. The FBMC symbols are expressed as:

$$X_L = \sum_{m=-\infty}^{\infty} \sum_{n=0}^{2N-1} x_{n,\,m}\, F\,(L-nN)\, exp\frac{(i3.28m(L-\frac{d}{2})}{2N} exp(j\;\theta_{n,\,m}) \tag{3}$$

The FBMC symbols are represented by X_L, while L is the overlap of symbols, F(n) is the cluster of filters, and the phase elements $exp(j\ \theta_{n,m})$ is given by:

$$\theta_{n,m} = \frac{\pi}{2}(n+m) \tag{4}$$

Where n and m represent the time shift and the frequency shift, respectively. The PAPR of the FBMC transmitter signals can also be written as:

$$PAPR = \frac{Maximum\ t \in T\ (x_L(n)|^2}{\frac{1}{T}\int_0^T (x_L(n)|^2} \tag{5}$$

The result is typically expressed in dB and is given as:

$$PAPR_{dB} = 10\ log_{10}\frac{Maximum\ t \in T\ (x_L(n)|^2}{\frac{1}{T}\int_0^T (x_L(n)|^2} \tag{6}$$

The CCDF of the FBMC signal is estimated as:

$$CCDF = (1 - exp(-X_L(n)) \tag{7}$$

For the NOMA-FBMC scheme, the superposition coding is applied at the transmitter to coherently combine signals meant for different receivers in the NOMA group. The receivers extract their relevant symbols via either the Successive Interference Cancellation (SIC) procedure or via considering the non-relevant superposed components as noise[(7)].

The NOMA symbols are packed via the following equation:

$$X_m(t) = \frac{1}{\sqrt{2}}\sum_{l=0}^{N-1} X(L)\, exp(\frac{i6.28Ln}{N}) \tag{8}$$

A filter is applied to the $X_m(t)$ to limit the out of band signal and is given as:

$$X_m(t) = exp(i6.28F_c t)\ \sum_{m=0}^{N-1} X_n \delta_{filter}(t - nT) \tag{9}$$

The schematic of NOMA-FBMC is given in Figure 1.

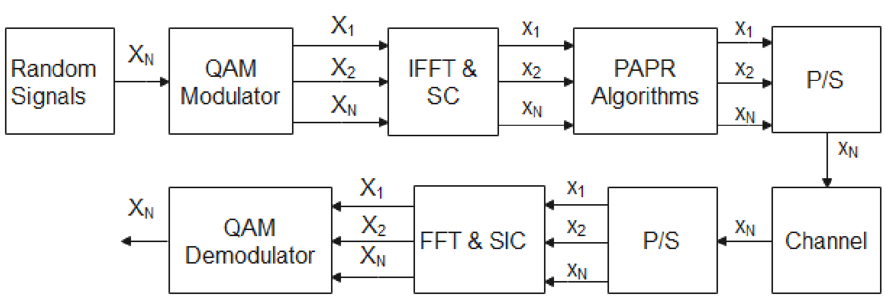

Fig 1. NOMA- FBMC system with PAPR components

3 Result and Discussion

In this section, we have compared the proposed work with already published articles. For comparison purpose, we have considered a PAPR performance at 10^{-3} CCDF, and we have also analyzed the articles with thorough investigation captivated in remarks, given in Table 1.

Table 1. Result discussion of published and proposed work

	Proposed Method	PAPR (dB)	Remarks
(8)	DSI & Precoding Method	8.2 dB	The authors have introduced a novel combination of DSI and pre-coding algorithms to lower the high PAPR of the framework. It is seen that the proposed algorithm obtained a significant PAPR reduction of 8.2 dB.
(9)	SLM	6.5 dB	In this work, SLM is applied to the OFDM waveform to enhance the PAPR performance. The simulation outcome reveals that the projected SLM obtained a 3–5.5 dB peak reduction as compared with existing SLM approaches.
(10)	Hybrid		A hybrid algorithm is implemented to reduce the high amplitude of the NOMA waveform. The simulation outcome demonstrates that the proposed procedure obtains a significant gain and power performance. However, the intricacy of the algorithm is high.
(11)	D-SLM	8.3 dB	In this work, D-SLM is implemented to minimize the PAPR of UFMC. An optimal phase factor is obtained, and each sub-block is multiplied by the phase factor to achieve a low PAPR value. The projected method obtained a gain of 1 dB as compared with conventional SLM.
(12)	LS-TR	9.8 dB	The proposed article integrates LS and TR algorithms to overcome the PAPR issue in the FBMC framework. The simulation curves reveal that the proposed LS-TR obtained a gain of 1 dB as compared with the Extended-TR.
(13)	Precoding and Companding	15.4 dB	The authors have introduced a novel hybrid algorithm based on a combination of pre-coding and companding approaches. The outcome of the work shows a significant enhancement of the BER performance. However, the PAPR curves show a trivial increase in performance.
(14)	DFT+PTS	11.8 dB	The authors integrated the DFT and PTS algorithms to lower the high peak value of the 5G waveform. It is observed that the throughput of the framework is reduced due to the overlapping of FBMC symbols. However, the PAPR curves show good performance as compared with the existing PTS.
(15)	Clipping and Filtering	6.2 dB	It is observed that the conventional clipping method reduces the PAPR of the system but also increases the noise. In the proposed approach, the authors combine the clipping and filtering methods to enhance the PAPR and noise performance of the waveform. The PAPR curves reveal that the projected method reduces the PAPR to 6.2 dB as compared with the reference (9.5 dB).
(16)	TSLM + Companding	8.1 dB	The authors proposed a hybrid algorithm for 5G waveforms. In the first step, the TSLM method is applied to reduce the PAPR. However, the performance was not satisfactory. Hence, in the second step, a companding method is performed to obtain an optimal PAPR reduction of 8.1 dB.
Proposed work	SLM-PTS	5.6 dB	In this work, we combined SLM and PTS to improve the BER and PAPR performance of the 5G waveform. Further, the intricacy of the structure is analyzed. It is observed that the SLM-PTS obtained a significant gain with less computational complexity.

4 Simulation Results

In this article, we investigated the PAPR for various advanced waveforms such as OFDM, FBMC, NOMA, and NOMA-FBMC with SLM-PTS reduction schemes. The PAPR performance of the systems under these schemes is evaluated using the CCDF curve. The vertical axis represents the CCDF and the horizontal axis represents the signal-to-noise ratio (SNR). Using MATLAB simulations, comparisons of various schemes are done as per the parameters explained in Section II. According to Figure 2, the PAPR performance of the FBMC-NOMA with SLM-PTS reduction schemes is inferior to that of existing schemes. It maintains a gap of approximately 4 dB, 6 dB, and 8 dB from FBMC, NOMA, and OFDM waveforms using SLM-PTS reduction schemes at 10^{-3} CCDF. Figure 3 shows the comparison of the proposed scheme with all existing techniques for BER v/s SNR (dB). NOMA-FBMC shows significant improvement as it maintains 5 dB SNR at 10^{-3} BER while other existing techniques requires approximately 6.5 dB, 7 dB, and 9dB respectively. Figure 4 shows the power saving in percentage form for various schemes. NOMA-FBMC, a hybrid and complex technique, shows considerable power saving compared to exiting advanced waveforms. Additionally, the computation complexity of the proposed PAPR algorithm is compared to conventional ones showing the efficacy of this approach is given in Table 2.

Table 2. Complexity

Technique	Addition	Multiplication
PTS	$N(2*log_2(N))$	$N*(\frac{S}{2}l0g_2(S))$ [8]
SLM	$S*(l0g_2(\frac{N}{2}))$	$s*(\frac{S}{2*N}l0g_2(S+N))$ [8]
Proposed SLM-PTS	$P^{N-1}S(N-1)$	$P^{S-1}N(S+1)$

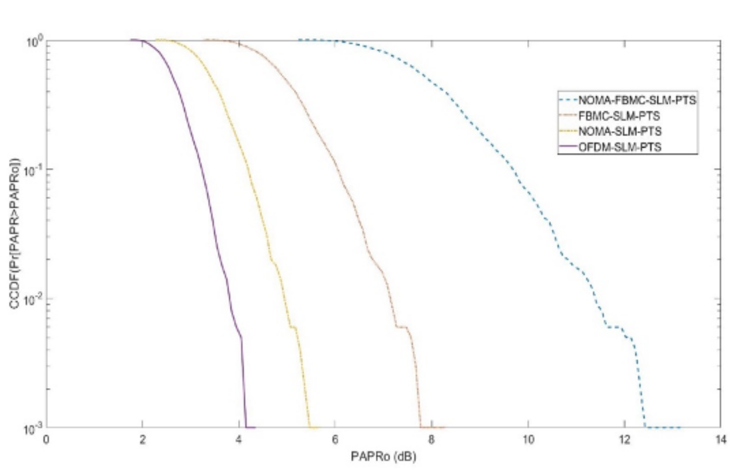

Fig 2. PAPR performance comparison for the fourmodulation schemes

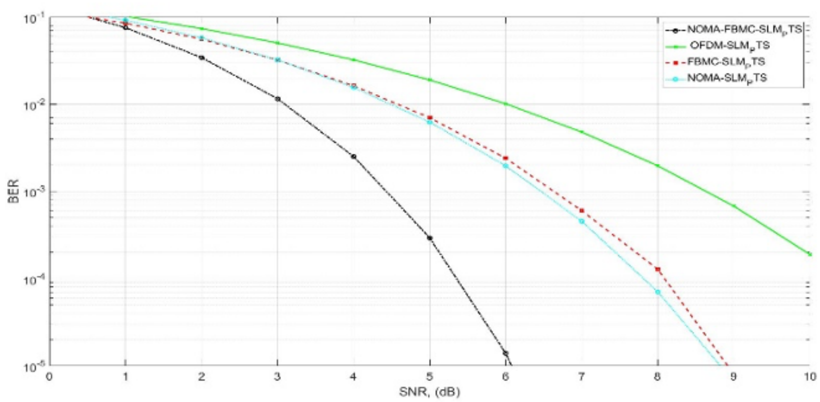

Fig 3. PAPR performance comparison for the four modulation schemes

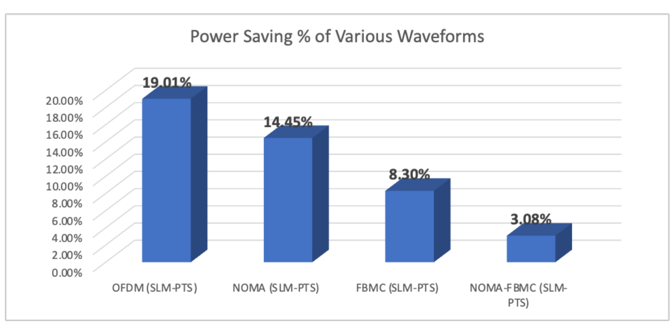

Fig 4. Power saving comparison of various techniques

5 Conclusion

In this work, the PAPR and BER performance of OFDM, FBMC, NOMA, and NOMA-FBMC was analyzed after applying the proposed SLM-PTS reduction scheme. NOMA and FBMC, because of the overlapping structure, have different requirements to reduce the PAPR. SLM-PTS reduction scheme was proposed, and PAPR and BER performance of all the waveforms was demonstrated with computational complexity. The simulation results show significant improvement in BER and moderate improvement in PAPR compared to conventional schemes. The proposed method with the NOMA-FBMC waveform maintains the gap of 1.5 dB, 2 dB, and 4 dB from the existing techniques, respectively. Additionally, the computational complexity was discussed, and in the future, we will focus on reducing it further.

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