Reducing the Peak to Average Power Ratio in Optical NOMA Waveform Using Airy-Special Function based PTS Algorithm

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***Abstract*—This paper introduces a novel Peak-to-Average Power Ratio (PAPR) reduction technique for Non-Orthogonal Multiple Access (NOMA) waveforms, leveraging an Airy function-based Partial Transmit Sequence (PTS) method. The proposed technique is evaluated on NOMA waveforms with subcarrier configurations of 64, 256, and 512, and its performance is benchmarked against conventional PTS, Selective Mapping (SLM), and Clipping and Filtering methods. Comprehensive analysis is conducted on key metrics, including PAPR, Bit Error Rate (BER), and Power Spectral Density (PSD). Results demonstrate that the Airy-based PTS method achieves substantial PAPR reduction across all subcarrier scenarios, consistently surpassing traditional approaches. Furthermore, the proposed method maintains competitive BER performance, particularly in high subcarrier scenarios, where conventional methods typically face limitations. PSD analysis further highlights the spectral efficiency of the Airy-based PTS method, exhibiting minimal out-of-band emissions. These findings position the Airy-based PTS technique as a promising solution for improving NOMA waveform performance in 5G and beyond, achieving an optimal balance between PAPR reduction, BER, and spectral efficiency.**

***Index Terms*—PAPR, NOMA, Airy-PTS, BER, PSD**

I. Introduction

OPTICAL Non-Orthogonal Multiple Access (NOMA) waveforms offer enhanced spectral efficiency and improved user connectivity, marking a significant advancement in the domain of optical wireless communication. Unlike traditional orthogonal multiple access techniques, which allocate distinct frequency and temporal resources to individual users, NOMA enables multiple users to share the same frequency and temporal resources by differentiating them based on power levels [1]. In optical systems, this is achieved by modulating the light signal power for different users, allowing for simultaneous transmission and reception. This capability is pivotal for addressing the massive connectivity demands of emerging applications such as the Internet of Things, where numerous devices must communicate efficiently within limited spectral resources.

Optical NOMA stands out by enhancing spectral efficiency and overall system capacity through the use of successive interference cancellation (SIC) at the receiver and the superposition coding principle [2]. As the demand for higher data rates and efficient spectrum utilization continues to grow, Optical NOMA is poised to play a vital role in the evolution of future communication systems. This is particularly true for integrating optical technologies with advanced wireless paradigms like 5G and beyond.

However, the high Peak-to-Average Power Ratio (PAPR) of Optical NOMA waveforms poses a significant challenge to system performance. In optical communication systems, high PAPR leads to nonlinear distortions due to the limited dynamic range of optical transmitters such as light emitting diodes and laser diodes. These nonlinearities result in spectral regrowth and intermodulation distortions, degrading signal quality and increasing the Bit Error Rate (BER). Moreover, high PAPR forces optical transmitters to operate at lower average power levels to avoid clipping, which reduces the effective Signal-to-Noise Ratio (SNR) and limits communication range and data throughput [3].

In NOMA systems, where multiple users share the same spectrum, high PAPR exacerbates inter-user interference, complicating signal separation at the receiver. This increases decoding complexity and reduces overall system capacity. Consequently, effective PAPR management is crucial for ensuring the reliability and efficiency of Optical NOMA systems [4].

High PAPR can significantly degrade system performance by causing non-linear distortion and power inefficiency during transmission. In scenarios with high subcarrier counts, conventional techniques such as Selective Mapping (SLM) and clipping struggle to effectively manage the increased complexity and power fluctuations.

SLM generates multiple candidate sequences to reduce PAPR; however, this approach becomes computationally expensive and less efficient as the number of subcarriers increases. As a result, the return on investment for PAPR reduction diminishes with higher subcarrier configurations. Similarly, clipping introduces signal distortion and spectral regrowth, which are particularly problematic in dense communication systems.

To address these challenges, the smoothed Airy-Partial Transmit Sequence (PTS) method provides a more effective power control mechanism, offering a scalable and efficient solution for high subcarrier systems. This approach achieves significant PAPR reduction without introducing substantial computational complexity, making it an ideal candidate for modern high-capacity communication networks [5].

The clipping and filtering (C&F) approach reduces out-of-band distortion by clipping signal peaks that exceed a predetermined threshold. Despite its simplicity, this method can result in out-of-band radiation and signal distortion. SLM creates multiple signal versions using several phase sequences and selects the version with the lowest PAPR for transmission. While effective, SLM requires additional signaling overhead to transmit the phase sequence information.

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PTS reduces PAPR by dividing the input data into sub-blocks, optimizing the phase of each sub-block, and then combining them. Although this technique provides good PAPR reduction, it is computationally intensive. These methods often utilize specific coding schemes to limit the occurrence of high PAPR sequences. However, such schemes may reduce data rates. Tone Reservation reserves specific tones (subcarriers) to cancel out high peaks, offering a balance between complexity and effectiveness [5].

In this study, we propose the Airy-based PTS algorithm, which leverages the properties of Airy functions to reduce PAPR in optical NOMA. The Airy functions are employed to create smoother phase transitions, optimizing the phase combinations of sub-blocks in the PTS algorithm. This results in a reduced peak power level and, consequently, lower PAPR.

The Airy-based PTS method overcomes PAPR issues in optical NOMA by preserving signal integrity and minimizing the likelihood of distortion and clipping—problems commonly encountered in optical communication systems. Additionally, the use of Airy functions enhances the efficiency of the phase optimization process, leading to improved power efficiency and signal quality. This makes the proposed method highly effective for enhancing the overall performance of optical NOMA systems.

The key contributions of this article are summarized as follows:

1) This paper introduces a novel algorithm for PAPR reduction within the framework of optical NOMA systems using PTS. The algorithm exploits the Airy special function for subcarrier configurations of 64, 256, and 512. This is the first time the Airy special function has been employed to generate a reduced PAPR, phase-optimized signal through PTS for optical NOMA.
2) The Airy-function-based PTS algorithm significantly enhances the performance of optical waveform NOMA by achieving a substantially lower PAPR compared to traditional methods such as PTS, SLM, and C&F. This improvement minimizes signal distortion induced by high-power amplifiers, resulting in higher signal fidelity and system efficiency. The proposed method is particularly suitable for real-time applications in optical communication systems, especially in resource-constrained environments.
3) The proposed method achieves significant PAPR reduction while maintaining the BER performance of the framework. However, it retains a computational complexity comparable to that of traditional algorithms.

II. Literature Review

The authors in [6] investigated PAPR reduction in Frequency-domain NOMA (F-NOMA) using the SLM method. Their study demonstrated that SLM effectively minimizes PAPR by generating multiple candidate signals and selecting the one with the lowest PAPR. However, the approach significantly increases computational complexity and requires the transmission of side information, which reduces spectral efficiency and overall system performance in F-NOMA networks.

In [7], the authors explored PAPR reduction in NOMA-OFDM Visible Light Communication systems using a combination of Precoder and Companding methods. Their study demonstrated effective PAPR reduction and enhanced system performance in terms of spectral efficiency. However, this approach introduced additional computational complexity due to the combined processing, and the potential signal distortion caused by the Companding process may negatively impact the system's overall signal quality and reliability.

The authors in [8] proposed an efficient PAPR reduction scheme for OFDM-NOMA systems by combining Dynamic Subcarrier Indexing (DSI) and Precoding methods. This hybrid approach effectively reduced PAPR while maintaining system performance. However, the integration of DSI and Precoding increased computational overhead, posing implementation challenges, particularly in real-time scenarios.

In [9], a low-complexity SLM technique was proposed to reduce PAPR in downlink Power Domain OFDM-NOMA systems. This method efficiently reduced PAPR while maintaining system performance. Nonetheless, the need for side information transmission and the associated signal overhead remain significant drawbacks, potentially increasing system complexity and reducing data rates in practical applications.

The authors in [10] presented a hybrid method that combines SLM, PTS, and C&F techniques to minimize PAPR in optical NOMA systems. This approach effectively reduced PAPR while maintaining signal quality. However, the integration of multiple techniques significantly increased computational requirements, making implementation more challenging.

Lastly, a low-complexity PTS-SLM-Companding hybrid method for PAPR reduction in 5G NOMA waveforms was proposed in [11]. This method achieved considerable PAPR reduction while keeping computational complexity within acceptable limits. However, the strategy has drawbacks, including potential signal distortion caused by the Companding process and increased system complexity due to the integration of multiple approaches, which could negatively affect overall system performance.

In [12], the authors proposed an innovative three-layer hybrid technique that incorporates clipping, precoding, and coding to address PAPR issues in Filter Bank Multi-Carrier VLC systems. This method achieves a balance between PAPR reduction and computational complexity while maintaining system performance. However, its inability to dynamically adapt to network conditions limits its applicability in practical scenarios. Dynamic thresholding and real-time optimization could enhance the robustness of this approach for various deployment scenarios.

The study in [13] introduced a novel approach to mitigate PAPR in NOMA systems, which is crucial for future wireless networks. The proposed hybrid technique combines SLM and precoding, yielding significant PAPR reductions with low computational complexity and minimal impact on system throughput. However, the method's limitations include the lack of performance evaluation in dynamic multipath environments, limited scalability for massive MIMO-NOMA configurations, and insufficient consideration of hardware impairments, which may hinder real-world implementation.

In [14], the authors discussed the use of a companding scheme to enhance the performance of optical OFDM systems, with particular attention to addressing high PAPR. The study provided a detailed analysis of companding and its impact on metrics such as BER and spectral efficiency. While the scheme improves system robustness, the increased computational complexity poses a significant drawback. Future work should focus on optimizing the algorithm to achieve a better balance between complexity and performance.

The authors in [15] proposed an advanced PAPR reduction method for DCO-OFDM systems based on multi-point constellations and a discrete particle swarm optimization (DPSO) algorithm. This method demonstrated efficient PAPR reduction while preserving signal quality, with substantial performance improvements over traditional methods. However, the reliance on computationally intensive DPSO optimization makes the method less feasible for real-time implementation. Additionally, its scalability to higher-order modulation schemes or large-scale systems remains unexplored, limiting its broader applicability.

In [16], a joint optimization approach was presented to enhance Quality of Service and reduce PAPR in energy-efficient massive MIMO systems. This technique integrates precoding and resource allocation strategies, achieving significant improvements in energy efficiency and signal quality. However, its reliance on idealized channel conditions may not reflect real-world multipath fading scenarios. Moreover, the computational complexity of the optimization process presents challenges for practical implementation in large-scale systems.

The authors in [17] employed optimization-based methods to improve PAPR reduction techniques for OFDM signals, enhancing wireless communication system performance. The study effectively measured clipping, tone reservation, and active constellation extension techniques in terms of PAPR and error performance improvements. However, the reliance on static channel conditions limits its applicability in dynamic environments. Additionally, the optimization algorithms introduce high computational complexity, which may render the approach unsuitable for real-time implementation in low-power or latency-sensitive applications.

Table I provides a comparative analysis of the PAPR reduction algorithms discussed in these studies.

TABLE I
COMPARATIVE ANALYSIS OF PAPR ALGORITHMS

PAPR Algorithms	**PAPR at CCDF of** 10^{-3}	**SNR at BER of** 10^{-3}
DSI & precoding method [7]	4.9 dB	13 dB
SLM [8]	6.8 dB	19 dB
SLM-PTS-CT [9]	7.1 dB	21.1 dB
PTS-SLM [10]	4.9 dB	5.8 dB
Amplitude clipping-SLM based Lifting Wavelet Transform [11]	6.8 dB	4 dB
Salp Swarm Algorithm-based PTS [12]	5.8 dB	10 dB
Companding methods [13]	4.9 dB	11 dB
Multi-point constellation method-SLM [14]	6.2 dB	9.8 dB
Bidirectional long short-term memory autoencoder [15]	7 dB	Not Simulated
Gradient method [16]	6 dB	6.2 dB
DSI & precoding method [17]	6.8 dB	Not Simulated
Proposed Airy-based PTS for 64 sub-carriers	2.8 dB	Not Simulated
Proposed Airy-based PTS for 256 sub-carriers	4.7 dB	6 dB
Proposed Airy-based PTS for 512 sub-carriers	8.7 dB	7.1 dB

III. SYSTEM MODEL

In an optical NOMA system incorporating SIC and Super Coding, the block diagram typically comprises several key components. At the transmitter, multiple users' data are encoded onto a single optical signal. Super Coding is utilized to enhance data transmission efficiency by encoding the signals in a manner that facilitates improved recovery and error correction.

The encoded data are modulated onto the optical carrier using techniques such as amplitude modulation or phase modulation. The modulated signal is then transmitted through an optical channel, which may consist of fiber optics or free-space optical links. During transmission, the signal quality is influenced by attenuation and noise introduced by the channel.

At the receiver end, the optical signal is detected and converted back into an electrical signal. SIC is employed for decoding the signals. The receiver first decodes the most significant signal and then iteratively subtracts it from the received signal to decode the remaining lower-power signals, effectively mitigating interference. To restore the original data, the demodulated signals undergo decoding, where super coding techniques are applied to enhance data reliability and correct errors [18].

The fundamental principles of resource allocation and signal processing in NOMA systems are represented in the mathematical model of a NOMA waveform. These principles form the basis for optimizing the performance and efficiency of optical NOMA systems.

The proposed work addresses a critical challenge in optical NOMA systems, where high PAPR negatively impacts performance and power efficiency. Optimization strategies aimed at mitigating this issue should prioritize refining the parameters of the Airy-special function to achieve an effective balance between complexity and PAPR reduction. Incorporating machine learning algorithms to dynamically select optimal phase rotation factors in the PTS algorithm could significantly enhance adaptability across varying channel conditions.

Further improvements in PAPR reduction could be achieved by combining this approach with complementary techniques such as companding or precoding. From a practical perspec-

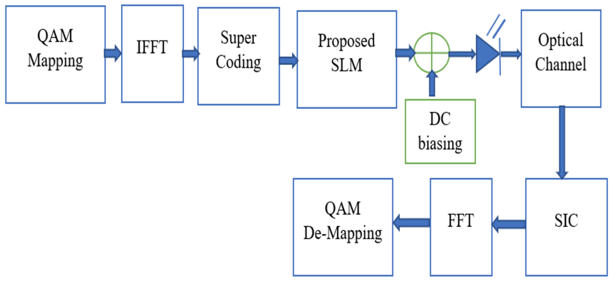

Fig. 1. Structure of Optical NOMA waveform

tive, lightweight computational methods must be developed to ensure real-time feasibility in resource-constrained optical networks. To alleviate computational overhead, hardware accelerators such as field-programmable gate arrays (FPGAs) or Graphics Processing Units (GPUs) could be integrated with the PTS algorithm.

Experimental validation of the PTS algorithm based on the Airy-special function is necessary for a variety of optical channel scenarios, including high-bandwidth and multi-user environments, to ensure robustness. Compatibility with existing optical NOMA standards and demonstration of interoperability would be essential to achieve broader acceptance of the proposed scheme.

Moreover, integration into system-level designs, such as visible light communication networks or 6G optical links, could significantly amplify its practical impact. These efforts could facilitate the development of efficient, scalable, and reliable optical communication systems, thereby advancing the state-of-the-art in optical NOMA technologies. Fig. 1 shows the optical NOMA's structure.

In NOMA systems, multiple users share the same frequency resources, but they are assigned different power allocations. Let $x(t)$ represent the transmitted optical signal, which is a superposition of signals from multiple users:

$$x(t) = \sum_{k=1}^{K} s_k \alpha_k(t) \exp\left(j\phi_k(t)\right), \qquad (1)$$

where K is the number of users, $\alpha_k(t)$ denotes the amplitude of the signal, $s_k(t)$ represents the baseband signal, and $\phi_k(t)$ is the phase modulation for the k-th user.

The PAPR of the signal $x(t)$ is defined as:

$$\text{PAPR} = \frac{\max_t |x(t)|^2}{E\left[|x(t)|^2\right]}, \qquad (2)$$

where $\max_t |x(t)|^2$ is the maximum instantaneous power, and $E\left[|x(t)|^2\right]$ is the average power.

After the signal is transmitted through the optical channel, the received signal $y(t)$ can be expressed as:

$$y(t) = x(t) \cdot h(t) + n(t), \qquad (3)$$

where $h(t)$ is the channel impulse response, and $n(t)$ is the noise.

At the receiver, SIC is applied. The iterative decoding process begins by decoding the signal of the strongest user and subtracting it from $y(t)$, thereby reducing interference for decoding weaker signals. Super coding is employed to enhance reliability by encoding the signals with error-correcting codes. Let $c_k(t)$ represent the encoded signal for the k-th user:

$$s_k(t) = \text{Encode}\left(d_k(t)\right), \qquad (4)$$

where $d_k(t)$ is the data to be transmitted, and $\text{Encode}(\cdot)$ denotes the encoding operation.

This formulation captures the fundamental concepts of power allocation, signal superposition, PAPR reduction, and interference cancellation in NOMA systems, emphasizing the critical role of SIC and super coding in improving system performance and reliability.

A. Proposed airy-PTS Method

The Airy function plays a critical role in enhancing the PAPR performance in the Airy-PTS method due to its ability to enable more precise phase optimization. Unlike conventional PTS techniques, where phase rotation factors are selected at random or based on predefined methods that may not ensure optimal PAPR reduction, the Airy function introduces unique mathematical properties that significantly improve the phase selection process. As a solution to the Airy differential equation, the Airy function exhibits oscillatory behavior with well-defined features. These oscillations facilitate smooth and continuous phase variation, leading to a more uniform distribution of signal power.

Analytically, the Airy function represents wave propagation and interference phenomena, allowing for refined phase selection compared to basic phase rotation techniques. By leveraging the Airy function, the Airy-PTS algorithm minimizes high peaks in the power spectrum of the signal, resulting in more evenly distributed power. This reduction in sharp power spikes leads to less distortion and greater efficiency, particularly in optical communication systems where power efficiency is of utmost importance.

The Airy-based PTS algorithm for PAPR reduction in NOMA waveforms utilizes Airy functions to optimize phase shifts and enhance PAPR performance. In this method, the signal is divided into multiple sub-blocks, and the Airy function, known for its smooth phase transition properties, is used to generate phase sequences for these sub-blocks [19]. Each phase sequence is applied to the sub-blocks to create different phase-adjusted versions of the signal. The version with the lowest PAPR is then selected for transmission.

This approach leverages the Airy function's capability to provide precise phase optimization, reducing peak power variations and improving signal uniformity. Consequently, the Airy-based PTS algorithm effectively mitigates PAPR issues while maintaining signal integrity and reducing computational complexity compared to conventional PTS methods. This results in enhanced performance in NOMA systems, particularly in optical communication scenarios.

The Airy-based Partial Transmit Sequence (PTS) method for PAPR reduction involves several mathematical steps. Let the transmitted signal $x(t)$ be divided into M sub-blocks. The signal $x(t)$ can be expressed as:

$$x(t) = \sum_{m=1}^{M} x_m(t) \cdot \exp(j\theta_m), \tag{5}$$

where $x_m(t)$ represents the m-th sub-block, and θ_m is the phase adjustment applied to the sub-block.

The Airy function $\mathrm{Ai}(t)$ is utilized to generate the phase sequences ϕ_m for each sub-block, given by:

$$\phi_m = \mathrm{Ai}(\alpha_m), \tag{6}$$

where α_m is a parameter that controls the phase adjustment.

These phase sequences are then applied to each sub-block. The adjusted signal $x_{\text{adjusted}}(t)$, with Airy-based phases, is given as:

$$x_{\text{adjusted}}(t) = \sum_{m=1}^{M} x_m(t) \cdot \exp(j\phi_m). \tag{7}$$

Finally, the PAPR of the adjusted signal is calculated as:

$$\mathrm{PAPR} = \frac{\max_t \left|x_{\text{adjusted}}(t)\right|^2}{\mathrm{Avg}\left[\left|x_{\text{adjusted}}(t)\right|^2\right]}. \tag{8}$$

This formulation highlights the use of the Airy function for generating smooth and precise phase adjustments, which minimizes the PAPR effectively in NOMA systems, particularly in optical communication scenarios.

B. Complexity

The PTS method generates several phase sequences (or sub-blocks), with each sub-block undergoing a phase rotation. Let N denote the number of sub-blocks. For each sub-block, the algorithm performs a phase rotation with a complexity of $O(1)$. Consequently, the overall complexity for producing all possible sub-blocks in the PTS method is $O(N)$.

The proposed phase optimization method employs the Airy-special function. Let M represent the number of phase rotations evaluated for each sub-block. The evaluation of the Airy function is computationally intensive, as it often involves solving a differential equation. Assuming the evaluation cost of one Airy function is $O(A)$, the total cost for evaluating the Airy function across all phase rotations of all sub-blocks is $O(N \cdot M \cdot A)$.

The optimization step involves selecting the best phase combination that minimizes the PAPR. This step typically requires an exhaustive search over all possible phase combinations. If K denotes the number of possible phase combinations, the complexity of this exhaustive search is $O(K)$. However, advanced search techniques, such as gradient descent or evolutionary algorithms, can reduce the complexity of this step.

Combining all major operations, the overall complexity of the Airy-PTS method can be approximated as:

$$O(N \cdot M \cdot A + K). \tag{9}$$

For practical applications, particularly in large-scale systems, the values of N and M can result in high computational requirements. Complexity reduction is therefore crucial, and optimizations in the evaluation of the Airy function and the design of efficient search algorithms are necessary. Additionally, hardware acceleration techniques, such as the use of FPGAs or GPUs, can further expedite the evaluation of the Airy function and phase rotation processes. Table II provides a detailed complexity analysis of the PAPR reduction algorithms, highlighting the computational requirements associated with each method.

TABLE II
COMPLEXITY ANALYSIS OF THE PAPR ALGORITHMS [20]

PAPR Algorithms	Complexity	Remarks
Airy-PTS	$O(N \cdot M \cdot A + K)$	The Airy-Special Function-based PTS involves generating multiple phase sequences, evaluating the Airy function for phase optimization, and searching for the optimal combination. Complexity is high due to Airy function evaluations and exhaustive search.
PTS	$O(N \cdot M)$	Involves phase rotation and evaluation of the signal for each sequence, where N is the number of sub-blocks and M is the number of phase shifts. Simpler than Airy-PTS but still requires exhaustive search over possible combinations.
SLM	$O(N \cdot M)$	The complexity involves generating multiple candidate sequences (with N being the number of sub-blocks and M the number of phase shifts), then searching for the one with the lowest PAPR. Less computationally intensive than PTS but still requires phase optimization.
Companding	$O(N)$	This method involves compressing the amplitude of the signal to reduce PAPR. It is computationally efficient, involving a simple compression step, but might not be as effective in reducing PAPR as PTS or SLM.
SLM-PTS	$O(N \cdot M \cdot P)$	Combines both the SLM and PTS methods, leading to higher complexity than individual methods. P is the number of possible phase combinations. The method offers better PAPR reduction but at the cost of increased complexity.

IV. SIMULATION RESULTS

This section presents the implementation of the Airy-based Partial Transmit Sequence (PTS) method using MATLAB 2016. The simulation parameters include 200,000 symbols, a 256-point FFT, 256-QAM modulation, sub-carrier configurations of 64, 256, and 512, and a NOMA waveform transmitted over a Rayleigh fading channel.

The CCDF of NOMA for 64 sub-carriers is shown in Fig. 2. At a CCDF of 10^{-3}, the PAPR achieved by the proposed Airy-PTS method is 2.8 dB, compared to 4.8 dB for the PTS, 6.2 dB for the SLM, 7.4 dB for the C&F technique, and 8.7

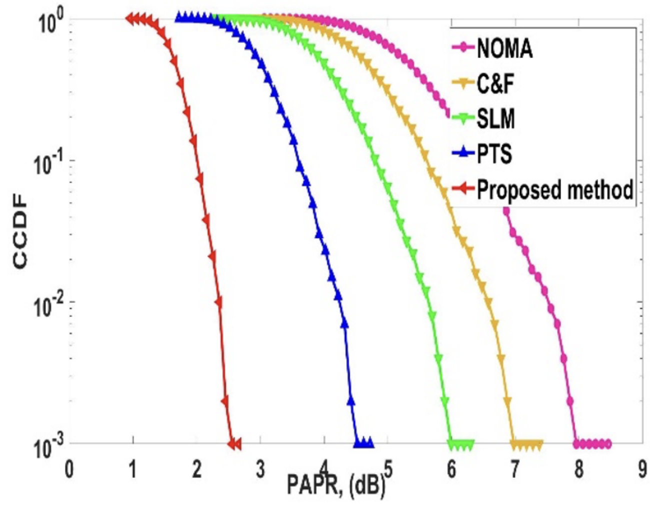

Fig. 2. PAPR analysis of 64 sub-carriers for NOMA waveform

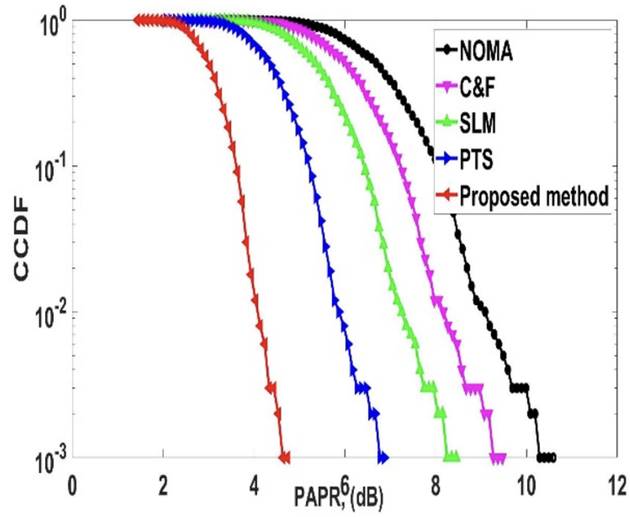

Fig. 3. PAPR analysis of 256 sub-carriers for NOMA waveform

dB for the original NOMA waveform. The proposed scheme demonstrates a PAPR gain of 2 dB to 5.9 dB compared to the conventional systems.

It is observed that the Airy special function efficiently determines the phase factor, which balances the NOMA symbol and reduces high peak signals. Therefore, it is concluded that NOMA systems with a smaller number of sub-carriers exhibit better PAPR performance compared to systems with a higher number of sub-carriers.

The PAPR curves for 256 sub-carriers in the NOMA waveform, both with and without precoding schemes, are depicted in Fig. 3. At a CCDF of 10^{-3}, the PAPR values of 4.8 dB, 5.7 dB, 6.9 dB, 8.3 dB, 9.4 dB, and 10.8 dB are achieved by the proposed Airy-PTS method, C&F, PTS, SLM, and the original NOMA signal, respectively.

It is observed that for higher sub-carrier configurations (256 sub-carriers), the PAPR is relatively high. However, the proposed Airy-PTS scheme effectively reduces the PAPR, resulting in a high-performance radio system. Therefore, it is concluded that the Airy-special function-based PTS method can be efficiently employed in large sub-carrier radio systems to achieve significant performance gains.

Fig. 4 illustrates the throughput performance of the NOMA waveform for 512 sub-carriers using various PAPR reduction algorithms. The primary objective is to mitigate the high peaks in the radio waveform for a large number of sub-carriers, enabling advanced radio systems to operate more effectively.

At a CCDF of 10^{-3}, the PAPR values achieved are 8.7 dB, 10 dB, 11.3 dB, 12.6 dB, and 14.2 dB for the proposed Airy-PTS method, C&F, PTS, SLM, and the original NOMA signal, respectively. The proposed Airy-based PTS method outperformed conventional schemes by reducing the PAPR by 1.3 dB to 4.7 dB compared to the traditional methods.

Thus, it can be concluded that the proposed Airy-PTS approach is well-suited for sophisticated radio systems employing a large number of sub-carriers. This enables the achievement of high data rates, efficient spectrum utilization, and enhanced system capacity, meeting the demands of modern subscriber requirements.

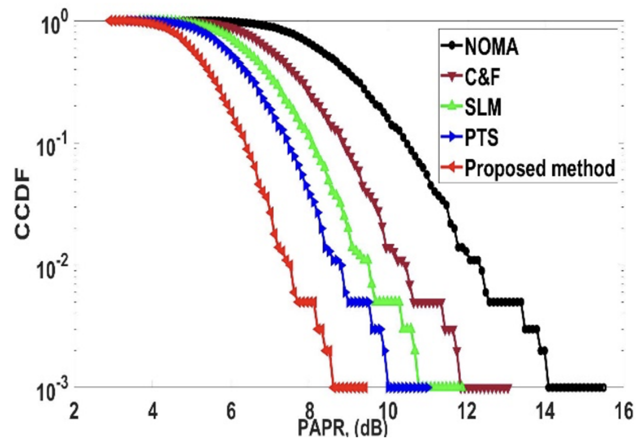

Fig. 4. PAPR analysis of 512 sub-carriers for NOMA waveform

Fig. 5 illustrates the BER curves for 256 sub-carriers, comparing the proposed Airy-based PTS method with conventional PAPR reduction algorithms. Evaluating throughput performance with a large number of sub-carriers is critical to assessing the effectiveness of the proposed algorithm. The BER of conventional algorithms shows degradation as the number of sub-carriers increases.

The proposed Airy-PTS method achieves a BER of 10^{-3} at an SNR of 6 dB, compared to 6.9 dB for the PTS, 8.1 dB for the SLM, 9.1 dB for the C&F technique, and 10.2 dB for the NOMA waveform. This indicates that the Airy-PTS method demonstrates significant BER performance improvements at lower SNR levels compared to traditional schemes.

Furthermore, the Airy-PTS method outperforms contempo-

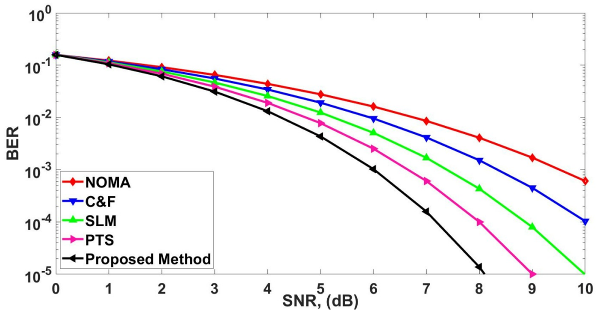

Fig. 5. BER analysis of 256 sub-carriers for NOMA waveform

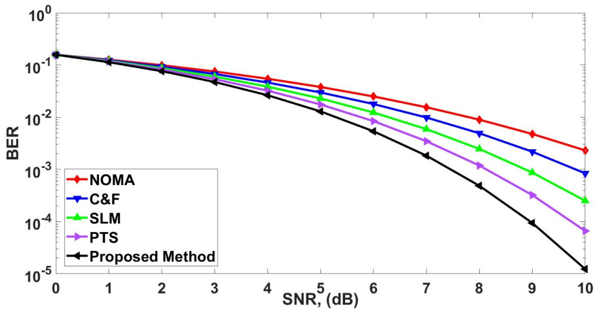

Fig. 6. BER analysis of 512 sub-carriers for NOMA waveform

rary algorithms by achieving SNR gains of 0.9 dB, 2.1 dB, 3.1 dB, and 4.2 dB over the PTS, SLM, C&F, and NOMA waveform techniques, respectively. These results highlight the efficiency of the proposed method in improving BER performance for systems with a large number of sub-carriers.

Fig. 6 presents the BER curves for 512 sub-carriers in NOMA systems. Evaluating the system's throughput in conjunction with PAPR performance is crucial for assessing the BER retention capability of the algorithms.

The proposed Airy-PTS method achieves a BER of 10^{-3} at an SNR of 8.1 dB, compared to 9 dB for the C&F technique, 10.1 dB for the PTS, 11.6 dB for the SLM, and 12.7 dB for the original NOMA signal. These findings demonstrate that the Airy-PTS method achieves SNR gains of 0.9 dB, 2 dB, 3.5 dB, and 4.6 dB over the C&F, PTS, SLM, and original NOMA techniques, respectively.

In conclusion, the proposed algorithm not only achieves optimal PAPR performance but also effectively retains BER performance, making it a suitable candidate for advanced NOMA systems.

V. Conclusion

This study evaluated the PAPR reduction of NOMA waveforms using the Airy-special function-based PTS method for subcarrier configurations of 64, 256, and 512. The proposed method's performance was compared against conventional PTS, SLM, and C&F techniques, considering metrics such as PAPR, BER, and PSD.

The Airy-based PTS method demonstrated significant PAPR reduction across all subcarrier configurations, consistently outperforming conventional techniques, particularly as the number of subcarriers increased. BER analysis revealed that the proposed method maintained better signal integrity compared to C&F, which is prone to BER degradation. Additionally, PSD analysis indicated that the Airy-PTS approach achieved a more favorable spectral profile by effectively reducing out-of-band emissions.

Despite its advantages, the study highlighted some limitations, including increased computational complexity and potential challenges in real-time implementations, especially for configurations with a high number of subcarriers. Future research could focus on optimizing the Airy-based PTS method to reduce computational complexity and exploring hybrid approaches that integrate Airy functions with other PAPR reduction techniques to further enhance performance.

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