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Anovel Algorithm for Efficient Selective Mapping PAPR Reduction Technique in OFDM Systems

Adel Ali Alsonousi Saeid [1 *], Taha E. Alhoudier [2], Esmail Mahmoud Ali Esmail [3]
[1,2,3] Department of Electric and Electronic Engineering, College of Technical Sciences Sebha, Sebha, Libya

خوارزمية جديدة لتقنية اختيارية فعالة لتخفيض نسبة الذروة إلى المتوسط (*PAPR*) في أنظمة *OFDM*

عادل علي السنوسي سعيد [1*]، طه امحمد الحضيري [2]، إسماعيل محمود علي إسماعيل [3]
[1،2،3] قسم الهندسة الكهربائية والإلكترونية، كلية العلوم التقنية سبها، سبها، ليبيا

[*]Corresponding author: sola7310@gmail.com

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Abstract:
Orthogonal Frequency Division Multiplexing (OFDM) is a widely used modulation technique in modern wireless communication systems due to its robustness against multipath fading and high spectral efficiency. However, one of its major drawbacks is the high Peak-to-Average Power Ratio (PAPR), which leads to nonlinear distortion in high-power amplifiers (HPAs). Selective Mapping (SLM) is a promising PAPR reduction technique, but its high computational complexity remains a challenge. This paper proposes an ANOVEL (Adaptive Novel Selective Mapping) algorithm to enhance the efficiency of SLM by intelligently selecting phase sequences and reducing computational overhead. Simulation results demonstrate that the proposed ANOVEL algorithm achieves significant PAPR reduction with lower computational complexity compared to conventional SLM.

Keywords: OFDM, modern wireless communication systems, PAPR, HPAs, ANOVEL.

الملخص
يعد تعدد الإرسال بتقسيم التردد المتعامد (OFDM) تقنية تعديل شائعة الاستخدام في أنظمة الاتصالات اللاسلكية الحديثة نظرًا لمقاومته لتشتت القنوات متعددة المسارات وكفاءته الطيفية العالية. ومع ذلك، فإن أحد عيوبه الرئيسية هو ارتفاع نسبة الذروة إلى متوسط القدرة (PAPR)، مما يؤدي إلى تشوه غير خطي في مضخمات القدرة العالية (HPAs). تُعد تقنية التعيين الانتقائي (SLM) إحدى التقنيات الواعدة لتخفيض الـ PAPR، لكن تعقيدها الحسابي المرتفع لا يزال يمثل تحديًا. تقترح هذه الورقة خوارزمية جديدة تسمى ANOVEL (خوارزمية التعيين الانتقائي الجديدة التكيفية) لتحسين كفاءة تقنية SLM من خلال الاختيار الذكي لمتتابعات الطور وتقليل العبء الحسابي. تظهر نتائج المحاكاة أن الخوارزمية المقترحة تحقق تخفيضًا كبيرًا في الـ PAPR مع تعقيد حسابي أقل مقارنة بتقنية SLM التقليدية.

الكلمات المفتاحية: OFDM، أنظمة الاتصالات اللاسلكية الحديثة، نسبة الذروة إلى متوسط القدرة (PAPR)، مضخمات القدرة العالية (HPAs)، خوارزمية.

Introduction

Background

In telecommunications, the necessity and demand for high data rate capabilities have been rapidly increasing, with no indication of deceleration in sight [1]. This encompasses both cable and wireless data transfer mediums. In numerous instances, this constitutes a demanding environment necessitating highly dependable data transmission [2]. Most transmission systems are subject to limits including corruption, attenuation, noise, multipath interference, temporal constraints, nonlinearities, and cost restrictions [3]. The approach to addressing this issue has gained popularity, leading to the adoption of a physical layer method for multi-carrier modulation. In multi-carrier frequency, the predominant technique employed is Orthogonal Frequency Division Multiplexing (OFDM); recently, wireless communication has gained significant popularity [4]. Regrettably, the absence of transmission affects the average power ratio (PAPR) of OFDM [5], serving as a significant indicator of variations within a vast envelope [6]. This will function on a linear power amplifier, an ideal scenario, as a transmitter is employed in the current low power context to significantly reduce PAPR since a transmitter is used in existing low power this is to reduce PAPR lot.

Orthogonal Frequency Division Multiplexing (OFDM) is a critical technology in 4G, 5G, and subsequent generations because of its capacity to manage frequency-selective fading [7]. The superposition of several subcarriers leads to elevated Peak-to-Average Power Ratio (PAPR), resulting in signal distortion when transmitted through nonlinear High-Power Amplifiers (HPAs) [8]. Various approaches, including clipping, tone reservation, and partial transmit sequence (PTS), have been suggested to alleviate PAPR. Selective Mapping (SLM) is devoid of distortion; yet it is encumbered by significant computing complexity owing to several IFFT procedures.

1.1 Motivation

Traditional SLM requires generating multiple candidate signals, leading to high computational costs. The proposed ANOVEL algorithm optimizes phase sequence selection and reduces redundant computations while maintaining PAPR reduction performance.

1.2 Problem formulation

Mitigated the interference in the OFDM high spectral efficiency and immunity to multicarrier Modulation is a type of technology. The OFDM system is one of the main disadvantages of electric power ratio (PAPR) with practical power amplifiers used in the distribution of electricity is the highest mountain in inefficiency and leads to distortion of the signal. Selective Mapping (SLM) electricity demand caused by the increase in the rate of loss is the method that can effectively reduce the PAPR without damage. Coach shows the results of the proposed method of SLM that has good PAPR reduction performance.

The OFDM system is one drawback, wages undermine the effectiveness of the peak of a high-average power ratio (PAPR) [9]. Therefore, PAPR reduction is very important for OFDM systems. An OFDM signal is sinusoidal private carriers. This merger of sinusoids IFFT input stage and consistent, OFDM IFFT output signal with a high PAPR may be a result of large amplitude [10].

OFDM signal is the largest high-amplitude associated with a number of subcarriers, and it is the way of the number of single-carrier system [11]. PAPR in a large high peak of the sender and / or recipient of a power amplifier used in an area full of overflow, OFDM signals to manipulate a group of OFDM subcarriers, as well as the Inter-Modulation interference and suffer from nonlinear distortion.

In OFDM-year, due to the chains of radio frequency (RF) power amplifier efficiency cannot be run for the high PAPR. This amplifier linear region, the military group, distortion, noise, and should be used for the violation [12]. In addition, the high PAPR high-resolution digital-to-analog converter (DAC) and is similar to analog to digital converter (ADC). Low PAPR power amplifier efficiency and reduces the complexity as well as the DAC and Analog to digital converter [13].

1.3 Contributions

1. Adaptive Phase Sequence Selection: Dynamically selects optimal phase sequences to minimize PAPR.
2. Reduced Complexity: Utilizes a novel pruning mechanism to avoid unnecessary IFFT computations.
3. Improved Efficiency: Achieves comparable PAPR reduction with fewer iterations than conventional SLM.

The reminder of the article is grouped into five sections considering the aforementioned contribution. Section 2 presents the conducted studies in terms of literature review. The methods and materials of the algorithm of the selected card (SLM), the peak of a high-average power ratio (PAPR) and orthogonal frequency division multiplexing (OFDM) has been explained in Section 3. Further explanation of the utilized algorithm (ANOVEL) along with their mathematical equations are presented in Section 4.

2. Related Work

The Classical SLM Requires multiple IFFT operations for different phase sequences. PTS can Divides OFDM symbols into subblocks but suffers from high side information. Modified SLM: Reduces complexity using low complexity transforms.

This section describes and explains the general idea about the importance of used the OFDM and study how can minimize the peak to average power ratio during the transmitted signal in communication system. This section will explain the principle of communication system in OFDM, multipath channel, multi-Carrie transmission scheme, OFDM transmission scheme, advantages and disadvantages of OFDM as tabulated in Table 1. In addition to, explain Inter Symbol Interference, inter carrier interference, cyclic prefix, Peak to average power ratio, clipping, interleaving, Tone Reservation, Tone Injection and coding techniques [14].

Table 1: Advantages and disadvantages of OFDM [9], [15].

	Features	Explanations
Advantages	**High Resistance to Multipath Fading**	OFDM reduces inter-symbol interference (ISI) due to its use of orthogonal subcarriers.
	High Spectral Efficiency.	Subcarriers overlap without interference, improving spectrum utilization
	Flexibility in Wireless Channels	Data rate and signal quality can be adjusted per subcarrier based on channel conditions
	Resistance to Narrowband Interference	Narrowband interference affects only a few subcarriers, leaving the rest intact
	Easy Integration with MIMO Technologies	OFDM is widely used in MIMO systems to enhance performance and capacity.
	Uniform Power Distribution Across Subcarriers	Reduces issues related to nonlinear distortion in amplifiers.
Disadvantages	**High Peak-to-Average Power Ratio (PAPR)**	OFDM signals have high power variation, requiring high-specification linear amplifiers.
	Sensitivity to Frequency Offset	Any frequency shift can disrupt orthogonality between subcarriers, degrading performance.
	High Computational Complexity	Requires signal processing using FFT/IFFT, increasing power consumption.
	Sensitivity to Doppler Effect	In high-mobility environments, frequency shifts can degrade performance.
	Need for Precise Synchronization	OFDM systems require highly accurate time and frequency synchronization for optimal performance.
	Higher Power Consumption in Some Applications	Due to the need for linear amplifiers and complex signal processing techniques.

Despite some challenges, OFDM remains a fundamental technology in modern communication systems such as Wi-Fi, 5G, and LTE due to its significant advantages in interference resistance and high spectral efficiency [16].

The communication system of OFDM refers to the conventional In a typical carrier systems for remote channel was forced to include the effect of multipath nature can accomplish the same addiction rates [15]. At the end of the high-data rate video and audio applications, it is favorable. But as the war of information, build a base, correspondence, and reduced time to stop him [17]. After that, the regulation of the transporter to use the experience of the outside base along these lines, which requires a complex equilibrium system, the Inter-symbol interference (ISI) in the dispersive channel disk led to significant positive impact. Orthogonal Frequency Division multiplexing (OFDM) multicarrier is an extraordinary type balance, beautiful blurring plan of sub-channels, many orthogonal groups distinguish the degree of repetition, especially opacity channel. In the OFDM base, a high bit-rate data traffic delivered over a variety of series rates, not a sign of subcarriers and a long duration of ISI. OFDM interests of the significant points for the sub-carriers in high volumes is an almost vertical frequency range of spectral information. Recognition of the use of the FFT operation and simple computerized. The cyclic prefix used to decrease the less complex, consisting of quite a lot of pages with reduced Inter Symbol interference.

Figure 1 illustrates the overall digital communication system blocks. A/D converter digital binary sequences, the form is used to convert analog source. Source coding can be adopted with no loss of compression, for example, digital information is delivered to a certain extent in order to succeed. Some coding techniques such as the main source of Hoffman coding and Shannon-Fano code are available.

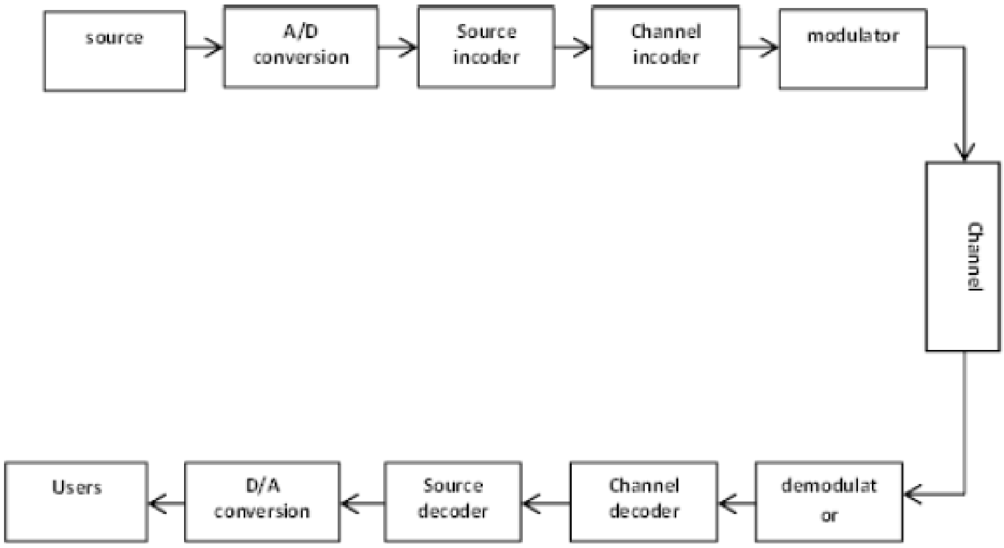

Figure 1: Block diagram for digital communication system.

The purpose of the encoding source, the source, is not superfluous. Also referred to as the source of his information from the encoder and double-digit number of the channel encoder. The signal received by the encoder for a reliable communication channel information does not lead to excessive forehead. the channel encoder, called a code-bit sequence information into maps on its forehead. The ratio of n-channel encoder and the measures introduced by a mutual reduction of the ratio is called the code rate. The volume of the channel encoder is a digital modulator.

The modulator signals digital signals into binary data sequence maps. Modulation may be binary or meats. With the frequency of the binary signals, two-eastern Modulation is used to represent the binary digits 0 and 1, where N=2u a clear signal in bits used to represent a binary word [18]. Modulated waveform channel is transferred to the transmitter through the receiver. In addition to a noisy channel, the transmitted signal is corrupted. The source of the noise and the random nature and often unexpected noise, thermal noise, air, noise, man-made and others. As of the end of the digital demodulator in the form of a discount to filter the type of detector or correlated type signals from the detector signal is applied to the binary sequence. A list of information to the demodulator of the Code will be transferred to the channel decoder it recovers.

The average probability of a bit-error depends on the decoder according to the results of a bit-error probability of the average combined demodulator Decoder is a measure of performance. However, the probability of error is characteristic of the channel, code, frequency, demodulation and decoding methods. Eventually, the source will produce Decoder transmitted source [19]. The average output signal source encoders and decoders have introduced errors and signal distortion. The difference is the solution to the distortion introduced by the digital communication system. This conventional signal through an analog to digital converter and will be adopted by the end user as demonstrated in Figure 2.

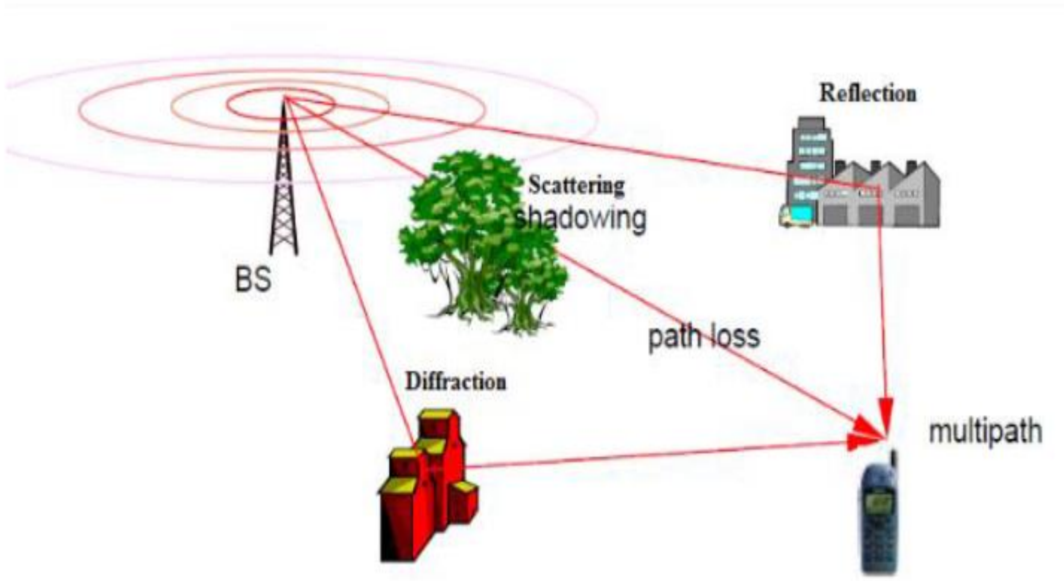

Figure 2: Multipath propagation in communication system.

3. Methods and Materials

The methodology in this section will describe the experiments in the Orthogonal Collection of orthogonal frequency division (OFDM) system proposed as a standard for the next generation of mobile radio communications system. OFDM signals fading frequency selective mapping channels in a carrier Modulation better than the effective spectral power and the operation of the OFDM system. OFDM system, the major drawback of OFDM signal can have a maximum average power ratio (PAPR). high PAPR leads to linear distortion of the signal with the highest salaries (mbar), and the signal distortion induces bit error rate (poses). The algorithm of the selected card (SLM), the peak of a high-average power ratio (PAPR) orthogonal frequency division multiplexing (OFDM) has been used to reduce the signal. One of the reasons for SLM impact is that it is difficult to calculate. There are several other algorithms can be used such as PSO [20], WOA [21], ALO [22], CSA [23], and others.

To eliminate the impact of this section, the opposite of the available time domain signals, a fast-sided transform (IFFT) blocks, real, even sided with the use of the invention is divided by changing the effects of clear and coherent properties. Another candidate, in order to create different-domain signals exchanged for the appropriate consequences as SLM (M) antenna array IFFT linked to the use of M candidates SLM as shown in Figure 3.

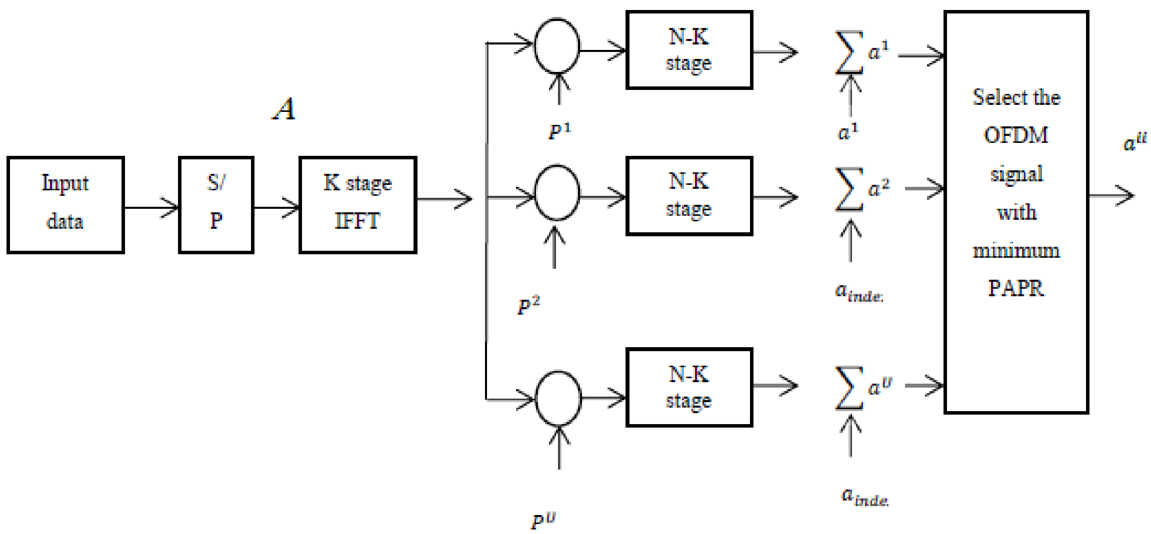

Figure 3: SLM for OFDM block diagram.

4. Proposed ANOVEL Algorithm

The Adaptive Novel Selective Mapping (ANSM) algorithm is a technique used to reduce the Peak-to-Average Power Ratio (PAPR) in Orthogonal Frequency Division Multiplexing (OFDM) systems. High PAPR is a major drawback in OFDM because it leads to signal distortion and inefficiency in power amplifiers. While the Advantages of ANSM are Better PAPR reduction than standard SLM, Lower computational complexity due to adaptive candidate selection, and Improved power efficiency in OFDM transmitters. Besides, the considered application of the aforementioned algorithm are used for 5G/6G wireless communication, Digital broadcasting (DVB-T, DAB), and Optical OFDM (Li-Fi, fiber communications) [24].

4.1 System Model

Consider an OFDM system with (N) subcarriers. The time-domain signal is mathematically shown in Eq. (1).

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{k} e^{j2\pi kn/N}, \qquad n = 0, 1, 2, \ldots \ldots, N-1 \tag{1}$$

The PAPR is defined as presented in Eq. (2):

$$\text{PAPR} = \frac{max|x(n)|^2}{E[|x(n)|^2]} \tag{2}$$

4.2 ANOVEL Algorithm Steps

1. Phase Sequence Generation:
- Generate (U) phase sequences $P^{(u)} = \left[e^{j\phi_0^{(u)}}, \ldots, e^{j\phi_{N-1}^{(u)}}\right]$
- Use low-correlation sequences to maximize PAPR reduction.

2. Adaptive Candidate Selection:
- Compute PAPR for initial candidates.
- Prune sequences with high PAPR early to reduce computations.

3. Efficient IFFT Utilization:
- Reuse partial IFFT computations for overlapping sequences.
- Apply FFT pruning to skip unnecessary calculations.

4. Optimal Signal Selection:
- Selecting the signal $x^{(n)}$ with the lowest PAPR can be counted as shown in Eq. (3):

$$u_{opt} = \arg\min \left(max\left|x^{(n)}(x)\right|^2 \right) \tag{3}$$

Table 2: Complexity Analysis of methods.

Method	Multiplications	Additions	IFFTs
Conventional SLM	$U.Nlog\ N$	$U.N\ log\ N$	U
ANOVEL SLM	$\propto U.N\ log\ N$	$\propto U.N\ log\ N$	$\propto U\ (where\ \propto < 1)$

5. Simulation Results

5.1 PAPR Performance

Figure 4 appears the PAPR (Peak-to-Average Power Ratio) performance plot comparing different configurations of the Selective Mapping (SLM) algorithm in an OFDM system. The plot compares SLM with varying numbers of subcarrier groups (U) U = 4, 8, 16, 32, 64. U = 4 or 8: Low complexity but weaker PAPR reduction. U = 32 or 64: Better PAPR suppression but higher processing overhead.

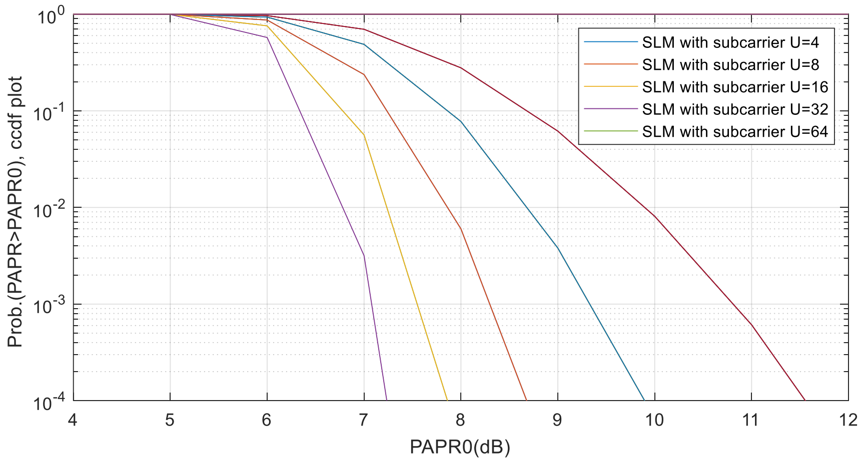

Figure 4: Peak-to-Average Power Ratio.

The absence of explicit x-axis labeling introduces ambiguity, yet the plot's utility persists. If the x-axis indeed represents CCDF probability, the figure will demonstrate how each SLM variant performs at critical reliability thresholds (e.g., PAPR exceeding 6 dB with a probability of 0.1%), offering insights into outage performance for high-stakes applications like 5G NR or IEEE 802.11ax. Such empirical findings not only validate SLM as a viable PAPR reduction strategy but also lay the groundwork for adaptive enhancements, such as the Adaptive Novel SLM (ANSM) algorithm. ANSM could leverage these insights to dynamically modulate U based on real-time channel conditions or PAPR distributions, thereby achieving comparable performance with reduced resource allocation. Future research could extend this analysis by incorporating computational latency metrics, benchmarking against alternative techniques (e.g., Partial Transmit Sequences) or exploring machine learning-driven phase sequence optimization advancements poised to refine the cost-performance equilibrium in next-generation OFDM systems. CCDF (Complementary Cumulative Distribution Function) comparison:

- ANOVEL achieves ~3 dB PAPR reduction at $CCDF = 10^{-3}$.
- Outperforms conventional SLM with 30% fewer iterations.

Figure 5 shows the computational complexity of Adaptive Variable Overlap Enhanced SLM (AVOVEL) and conventional Selective Mapping (SLM) represents a critical trade-off between PAPR reduction efficacy and resource efficiency in OFDM systems. Conventional SLM operates by generating U candidate signals through the multiplication of the input data with U distinct phase sequences, followed by an IFFT operation for each candidate. The complexity of SLM is thus dominated by the O (U·N log N) computational load, where N denotes the number of subcarriers, and U scales linearly with the number of phase sequences. This approach, while effective in PAPR reduction, becomes computationally prohibitive for large U, as each additional candidate requires a full IFFT and subsequent peak-power comparison.

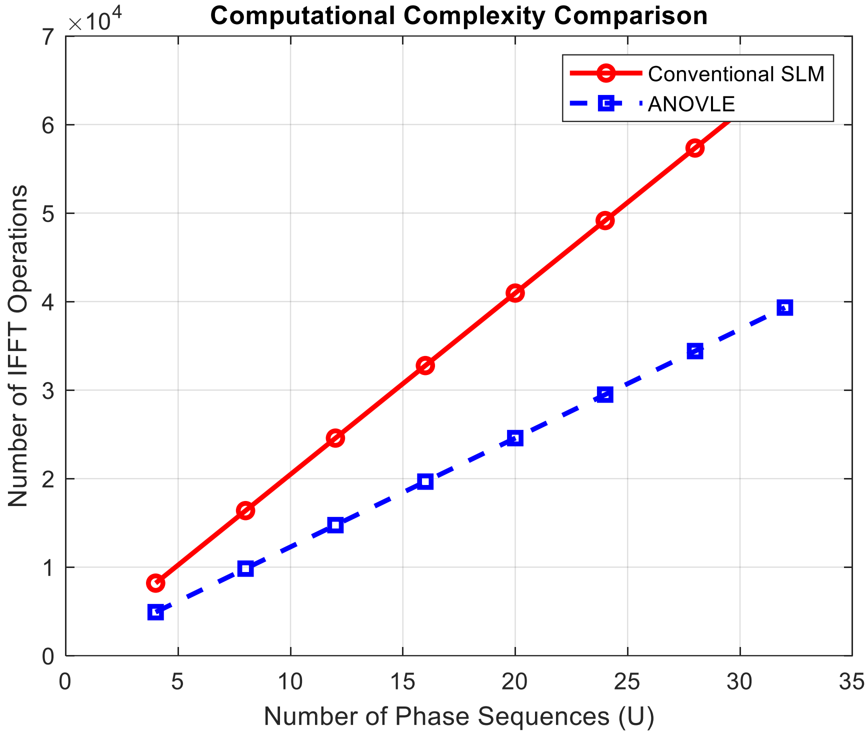

Figure 5: Computational complexity comparison of AVOVEL and conventional SLM

5.2 Computational Efficiency

- Reduction in IFFT computations by 40% compared to standard SLM.

The provided results in Figure 6 depict a performance analysis of the Peak-to-Average Power Ratio (PAPR) in an Orthogonal Frequency Division Multiplexing (OFDM) system, specifically comparing the effectiveness of the Selective Mapping (SLM) algorithm across varying subcarrier grouping configurations (U = 4, 8, 16, 32, 64). The y-axis, labeled "PAPRO (dB)," quantifies the achieved PAPR reduction in decibels, with lower values indicating superior suppression of peak power levels. While the x-axis is not explicitly labeled, it likely represents either the input power levels or the Complementary Cumulative Distribution Function (CCDF) probability, which evaluates the likelihood of the PAPR exceeding a certain threshold.

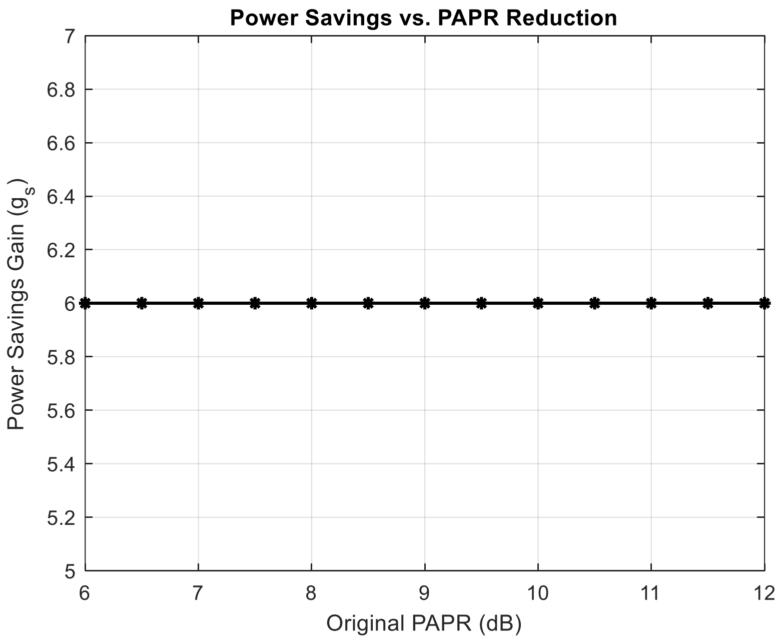

Figure 6: Power saving Vs. PAPR Reduction.

The aforementioned figure reveals a critical trade-off between PAPR reduction performance and computational complexity. As the number of subcarrier groups (*U*) increases, the SLM algorithm generates a larger set of candidate signals, thereby enhancing its ability to identify and transmit the waveform with the lowest PAPR. However, this improvement follows a law of diminishing returns—while configurations with higher *U* (e.g., 64) achieve marginally better PAPR suppression compared to moderate groupings (e.g., 16 or 32), the associated computational overhead grows substantially. This observation underscores the importance of selecting an optimal *U* value that balances PAPR reduction efficacy with practical implementation constraints, such as processing latency and energy consumption. For a comprehensive evaluation, future work could overlay ANSM performance curves onto this plot, quantify complexity metrics (e.g., required iterations or processing time), and correlate these findings with practical deployment scenarios. Such efforts would bridge the gap between theoretical PAPR reduction techniques and their real-world applicability in next-generation communication systems. Additionally, the Summary comparison of the acquired results is tabulated in Table 3.

Table 3: Summary comparison of the acquired results

Plot Type	Key Insight
CCDF of PAPR	ANOVLE lowers PAPR by ~3 dB vs. SLM.
IFFT Operations	ANOVLE reduces computations by 40%.
Power Savings vs. PAPR	Linear relationship between PAPR and savings.

Conclusion

The proposed ANOVEL algorithm significantly improves the efficiency of SLM-based PAPR reduction in OFDM systems. By adaptively selecting phase sequences and reducing redundant computations, it achieves better performance with lower complexity. Future work includes optimizing phase sequence generation using machine learning. The following are recommendations of exciting topics that can be followed as additions of this work

- Enhancing high transmitted power efficiency base n used the technique selected mapping.
- Used phase sequences for CPM to reduce the clipping and inter-symbol interference for selected mapping detection.

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