An Efficient ACE Scheme for PAPR Reduction of OFDM Signals with High-Order Constellation

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a highly efficient and robust modulation technique widely adopted in modern wireless systems such as 5G, LTE, Wi-Fi, and DVB-T2. Its ability to combat multipath fading and support high data rates has made it a fundamental component of next-generation communication systems. However, a major drawback of OFDM is its inherently high Peak-to-Average Power Ratio (PAPR), which can severely degrade system performance by forcing power amplifiers to operate inefficiently and introducing distortion in transmitted signals. To address the PAPR challenge, several techniques have been explored, including Clipping and Filtering, Selective Mapping (SLM), Partial Transmit Sequence (PTS), and Active Constellation Extension (ACE). Among them, ACE has shown significant potential due to its ability to reduce PAPR without transmitting side information and without introducing in-band distortion. Despite its effectiveness, traditional ACE methods suffer from high computational complexity, slow convergence, and limited adaptability to high-order modulation schemes such as 256-QAM and 1024-QAM. The results demonstrate that EPOCS-ACE achieves superior performance compared to traditional ACE, SLM, and PTS techniques, making it highly suitable for real-time and power-sensitive applications in 5G and future wireless communication systems. With its balance of complexity, performance, and adaptability, the proposed scheme contributes meaningfully to the ongoing evolution of energy-efficient and high-speed digital communication systems.

1-INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has become the cornerstone of modern wireless communication systems such as 5G, LTE, Wi-Fi, and DVB-T2, owing to its superior spectral efficiency and robustness against multipath fading. By transmitting data across multiple orthogonal subcarriers, OFDM effectively mitigates inter-symbol interference and supports high data throughput. However, a significant drawback of this technique is its inherently high Peak- to-Average Power Ratio (PAPR), which arises due to the superposition of independently modulated subcarriers. These high signal peaks can push power amplifiers into nonlinear operating regions, causing signal distortion, adjacent channel interference, and increased power consumption—an especially critical issue in mobile and battery-powered devices.

To address this, numerous PAPR reduction techniques have been developed, ranging from Clipping and Filtering to probabilistic methods like Selective Mapping (SLM) and Partial Transmit Sequence (PTS). Among them, Active Constellation Extension (ACE) stands out due to its ability to reduce PAPR without transmitting side information or significantly degrading Bit Error Rate (BER). ACE works by selectively extending the outer constellation points in the frequency domain, thereby shaping the time-domain signal to reduce peaks. However, traditional ACE methods are limited by slow convergence rates, fixed clipping thresholds, and high computational complexity, especially when applied to high-order modulation schemes such as 256-QAM or 1024-QAM.

This project introduces an enhanced ACE approach called EPOCS-ACE (Enhanced Peak Optimization with Constellation Shaping), which improves upon conventional ACE through three key innovations: adaptive clipping thresholds, dynamic extension coefficients, and optimized extension rules for high-order QAM. The proposed method reduces the number of iterative FFT/IFFT operations, accelerates convergence, and achieves significant PAPR reduction while maintaining low BER. Simulation results validate that EPOCS-ACE outperforms standard ACE, SLM, and PTS techniques across key performance metrics, making it well-suited for deployment in 5G and future wireless systems where both energy efficiency and signal fidelity are crucial.

2-LITERATURE SURVEY

Orthogonal Frequency Division Multiplexing (OFDM) has become a cornerstone technology for modern wireless communication systems due to its ability to efficiently handle multipath fading and provide high spectral efficiency. However, one of the major challenges hindering its performance is the high Peak-to-Average Power Ratio (PAPR) inherent to OFDM signals. High PAPR results from the summation of multiple independently modulated subcarriers, causing large signal peaks. These peaks lead to nonlinear distortion when passing through High Power Amplifiers (HPAs), resulting in increased Bit Error Rate (BER) and spectral regrowth. Over the years, significant research efforts have been devoted to developing effective PAPR reduction techniques. One of the earliest and simplest approaches is Clipping and Filtering, which involves directly clipping the signal amplitude to a predetermined threshold. Although this method can significantly reduce PAPR, it introduces in-band distortion that degrades BER performance and causes out-of-band emissions, requiring additional filtering steps. While effective for moderate PAPR reduction, the trade-offs limit its usability in high-performance systems. To address these issues, more sophisticated schemes have been proposed that offer better performance with less distortion.

Advanced techniques like Selective Mapping (SLM) and Partial Transmit Sequences (PTS) have been extensively studied due to their ability to reduce PAPR without causing distortion. SLM generates multiple phase-rotated versions of the OFDM signal and selects the sequence with the lowest PAPR for transmission. Similarly, PTS divides the input data into sub-blocks and optimizes their phase shifts to minimize PAPR. However, both methods require transmission of side information to the receiver, increasing overhead and complexity. Moreover, their computational load is significant due to multiple IFFT operations, limiting their real-time application. Another class of techniques involves Tone Reservation (TR) and Tone

Injection (TI), which manipulate specific subcarriers to reduce PAPR. TR reserves a set of subcarriers for peak reduction, which does not affect data symbols but reduces spectral efficiency. TI modifies the constellation points by adding signals from an extended set, which increases the signal power but can effectively reduce peaks. Although these methods avoid side information, the sacrifice in spectral efficiency or increased transmit power can be undesirable in practical systems.

Among PAPR reduction strategies, Active Constellation Extension (ACE) has emerged as a promising solution that strikes a balance between distortion and efficiency. ACE modifies the outer constellation points within allowable extension regions to reduce peak amplitudes without side information. Studies show that ACE can achieve considerable PAPR reduction while preserving BER performance. However, traditional ACE algorithms involve iterative FFT/IFFT operations that increase computational complexity and convergence time, especially with large subcarrier counts and high-order modulations.

3-SOFTWARE REQUIREMENTS

Software Requirements

What is MATLAB? Programming assignments in this course will almost exclusively be performed in MATLAB, a widely used environment for technical computing with a focus on matrix operations. The name MATLAB stands for "Matrix Laboratory" and was originally designed as a tool for doing numerical computations with matrices and vectors. It has since grown into a high-performance language for technical computing. MATLAB integrates computation, visualization, and programming in an easy-to-use environment, and allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. Typical areas of use include:

- Math and Computation
- Modeling and Simulation
- Data Analysis and Visualization
- Application Development
- Graphical User Interface Development 1.2 Getting Started Window Layout The first time you start MATLAB, the desktop appears with the default layout, as shown in Figure 1.
- The MATLAB desktop consists of the following parts:

4-OFDM AND PAPR

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi-carrier modulation scheme widely adopted in modern communication systems due to its robustness and efficiency in transmitting data over frequency-selective fading channels. Unlike single-carrier systems, OFDM divides a high-speed data stream into several lower-rate streams that are transmitted simultaneously over multiple orthogonal subcarriers. This approach significantly enhances system performance, especially in wireless environments characterized by multipath propagation and narrowband interference. OFDM has become a foundational technology in various wireless communication standards, including LTE, 5G NR, Wi-Fi, WiMAX, and digital broadcasting systems. Its ability to manage inter-symbol interference (ISI), efficiently utilize bandwidth, and support high data rates has made it indispensable in modern high-speed communication systems. OFDM works by splitting the available bandwidth into multiple orthogonal subcarriers, each carrying a portion of the total data. These subcarriers are spaced such that their spectra overlap but remain orthogonal to each other, ensuring that there is no mutual interference. This orthogonality is achieved by carefully selecting the subcarrier frequencies to be integer multiples of a fundamental frequency over a symbol duration.

PAPR Reduction Techniques

Orthogonal Frequency Division Multiplexing (OFDM) is a highly effective modulation technique widely used in modern wireless communication systems due to its robustness against multipath fading and spectral efficiency. However, one of the main drawbacks of OFDM is the high Peak-to-Average Power Ratio (PAPR), which creates significant challenges for transmitter design, especially the power amplifier. High PAPR signals force the power amplifier to operate in a highly linear region with considerable back-off, reducing efficiency and increasing power consumption.

This chapter provides a comprehensive review of various PAPR reduction techniques developed to overcome these challenges. The techniques range from simple signal processing methods to advanced probabilistic and coding approaches. Each method has unique advantages and trade- offs, making it suitable for different application scenarios. The chapter will analyze these techniques, discuss their implementation complexity, and highlight their impact on system performance.

Clipping and Filtering Technique

Clipping is one of the simplest and most intuitive methods for reducing the Peak-to-Average Power Ratio (PAPR) in OFDM systems. The process involves setting a predefined amplitude threshold, above which any signal peak is limited or "clipped." By capping the maximum amplitude of the time-domain OFDM signal, clipping effectively reduces the high peaks that contribute to elevated PAPR values. This method requires minimal modification to the transmitter architecture and is easy to implement in practice. Due to its straightforward approach, clipping has been widely studied and serves as a baseline for many PAPR reduction techniques. While clipping can reduce PAPR significantly, it introduces nonlinear distortion into the transmitted signal. This distortion manifests in two forms: in-band distortion and out-of-band radiation. In-band distortion refers to the degradation of the original signal within its intended frequency band, which adversely affects the Bit Error Rate (BER) performance by causing errors during demodulation. Out-of-band radiation, on the other hand, spreads signal energy into adjacent frequency bands, causing interference with neighboring channels and violating regulatory spectral masks.

The clipping operation can be mathematically modeled as the addition of clipping noise to the original OFDM signal. This noise is a nonlinear function of the signal and is responsible for increasing the error rate at the receiver. Consequently, the BER performance deteriorates as the clipping threshold is lowered to achieve more aggressive PAPR reduction. Designers must balance the amount of clipping with the acceptable BER degradation, as excessive clipping can severely compromise system reliability. Techniques such as soft clipping and adaptive clipping thresholds have been proposed to mitigate this trade-off. To combat the problem of out-of-band radiation caused by clipping, filtering is applied immediately after the clipping stage. Filtering helps to suppress spectral regrowth and confines the signal energy within the allocated frequency band, ensuring compliance with spectral mask regulations. Typically, low-pass or band-pass filters are used to remove the unwanted frequency components generated by the nonlinear clipping process. While filtering successfully reduces out-of-band emissions, it can also cause peak regrowth in the time-domain signal, partially negating the PAPR reduction achieved by clipping.

Coding Techniques for PAPR Reduction

Coding techniques for PAPR reduction operate by carefully selecting codewords or symbol sequences that naturally exhibit lower peak-to-average power ratios. Instead of directly modifying the time-domain OFDM signal, these methods constrain the data symbols during the encoding process to produce signals with more uniform amplitude levels. This approach exploits the redundancy in the coding structure to avoid high peaks without distorting the original data. As a result, coding-based PAPR reduction methods are considered distortion less, preserving signal fidelity and ensuring reliable transmission. One common class of coding techniques is block coding, where the input data is grouped into fixed-size blocks and encoded using predefined codebooks designed to minimize PAPR. These codebooks contain symbol sequences that inherently generate low peak amplitudes when modulated. Selective block coding improves on this by dynamically choosing the best codeword from the codebook for each data block based on PAPR criteria. Trellis shaping is another advanced block coding technique that uses trellis structures to generate sequences with desirable PAPR properties. These methods systematically avoid high peaks by restricting symbol combinations.

The primary advantage of coding-based PAPR reduction is that it introduces no distortion or clipping noise, preserving the original signal's integrity. Since the modulation scheme remains unchanged, these methods do not degrade the Bit Error Rate (BER) performance. Additionally, coding techniques do not require side information transmission to the receiver, which simplifies the system design. This makes them attractive for applications where signal quality and error performance are critical, such as in high-reliability wireless communications and data broadcasting. A significant drawback of coding methods is the introduction of redundancy to constrain symbol sequences, which reduces the effective spectral efficiency. The overhead depends on the size of the codebook and the coding rate. Larger codebooks generally provide better PAPR reduction but increase the redundancy and complexity. Consequently, coding techniques often result in a trade-off between achieving lower PAPR and maintaining high data throughput. This reduction in spectral efficiency can be a limiting factor in systems where bandwidth is scarce or costly.

5-ACE TECHNIQUE OVERVIEW

Introduction to Active Constellation Extension (ACE)

Orthogonal Frequency Division Multiplexing (OFDM) systems are widely used in modern wireless communication due to their robustness against multipath fading and efficient spectrum utilization. However, a major drawback of OFDM is its high Peak-to-Average Power Ratio (PAPR), which causes inefficiencies in power amplifiers and can lead to signal distortion. Various techniques have been developed to mitigate PAPR, and among these, Active Constellation Extension (ACE) stands out for its ability to reduce PAPR without introducing distortion or requiring additional side information. The ACE technique works by selectively modifying the constellation points of the modulated signal. Instead of clipping or distorting the signal in the time domain, ACE extends the outer constellation points beyond their nominal positions in the frequency domain. This extension effectively reduces signal peaks when transformed to the time domain, thereby lowering PAPR. Crucially, the extensions are performed within allowable regions to ensure that the minimum Euclidean distance between symbols is preserved, maintaining signal integrity.

One of the main advantages of ACE over other PAPR reduction methods is that it operates without distorting the signal. Methods like clipping introduce nonlinear distortion that degrades the Bit Error Rate (BER) performance, while ACE's constellation extensions remain within boundaries that protect the error performance. This distortion less feature makes ACE particularly attractive for systems using higher-order modulation schemes, where signal integrity is paramount for maintaining communication quality. Unlike methods such as Selective Mapping (SLM) or Partial Transmit Sequence (PTS), which require the transmission of side information to enable the receiver to decode the signal correctly, ACE does not need any additional signaling. This eliminates the bandwidth overhead and the risk of side information errors, simplifying receiver design and improving overall system robustness. The absence of side information transmission is a significant practical advantage in real-world deployments.

ACE typically employs an iterative optimization algorithm that adjusts the constellation points to progressively reduce peaks in the time-domain signal. At each iteration, the algorithm identifies peaks above a threshold and calculates modifications As wireless communication standards evolve toward higher data rates and increased spectral efficiency, managing PAPR becomes more critical. ACE's ability to reduce PAPR without compromising BER or requiring side information aligns well with these requirements. It is especially beneficial for high-order modulation formats like 16-QAM or 64-QAM used in LTE, Wi-Fi, and emerging 5G systems. Thus, ACE remains an important technique for enhancing power efficiency and signal quality in contemporary and future OFDM-based networks.

Signal Model and Constellation Extension Concept

In an OFDM system, the transmitted signal is formed by modulating a set of orthogonal subcarriers with complex data symbols drawn from a predefined constellation, such as QPSK or QAM. These symbols form the frequency-domain representation of the OFDM block. An Inverse Fast Fourier Transform (IFFT) converts this frequency-domain data into the time-domain signal, which is then transmitted. The high PAPR problem arises because the constructive interference of many subcarriers can cause large peaks in the time domain. Each data symbol belongs to a constellation with a specific geometric arrangement designed to maximize the minimum distance between points, minimizing symbol errors. For example, in 16- QAM, constellation points are arranged in a grid pattern with different amplitude and phase combinations. The outer points of the constellation represent symbols with higher amplitude values. These outer points are the primary candidates for extension in the ACE technique to reduce signal peaks. The core idea behind ACE is to selectively "push" or extend these outer constellation points outward from their original positions in the complex plane. This extension increases the magnitude of those symbols, to the constellation points within allowable limits.

effectively creating more "headroom" in the frequency domain. When these modified symbols are transformed back into the time domain via IFFT, the resulting time-domain signal peaks are reduced because the overall amplitude distribution is adjusted to prevent excessively high peaks.

While extending constellation points, ACE carefully restricts the movement within allowable regions to ensure that the minimum Euclidean distance between adjacent symbols is preserved. These allowable regions are predefined based on the modulation scheme's geometry to prevent overlap between symbol decision boundaries, which would cause decoding errors. Extensions beyond these limits could increase the Bit Error Rate (BER) by confusing the receiver about the transmitted symbol. Mathematically, the ACE process can be expressed by representing the transmitted frequency- domain symbol vector X and adding an extension vector C, where C contains the adjustments for the outer constellation points. The extended symbol vector X ′

=X+C must satisfy the constraints of the allowable extension regions. The goal is to find the
vector C that minimizes the PAPR of the time-domain signal x ′ =IFFT(X ′) while adhering to the constraints. By modifying the constellation points in this controlled manner, ACE redistributes the signal energy in the time domain, reducing the likelihood of high peaks caused by the superposition of subcarriers. This method differs from clipping, which simply cuts off peaks and introduces distortion. Instead, ACE preemptively adjusts the symbol amplitudes to prevent peak formation while maintaining signal fidelity. This strategic extension leads to effective PAPR reduction without compromising system performance.

Iterative Algorithm for PAPR Reduction

The Active Constellation Extension (ACE) technique relies on an iterative algorithm to progressively reduce the Peak-to-Average Power Ratio (PAPR) of an OFDM signal. Instead of making a one-time modification, the algorithm repeatedly adjusts the constellation points to minimize signal peaks in the time domain. This iterative approach ensures that the signal gradually approaches a low-PAPR state while respecting the constraints on constellation point extensions. The process begins by taking the frequency-domain OFDM symbol vector X\mathbf{X}X and applying the Inverse Fast Fourier Transform (IFFT) to obtain the time- domain signal x\mathbf{x}x. This signal typically exhibits high PAPR due to the superposition of multiple subcarriers. The initial PAPR is calculated by comparing the maximum instantaneous power to the average power of the signal, which sets the baseline for the iterative reduction process. At each iteration, the algorithm identifies time-domain samples whose amplitudes exceed a predefined threshold. This threshold is often set based on a target PAPR value or a fraction of the signal's average power. Samples exceeding this threshold are considered peaks that must be mitigated. These identified peaks guide how the frequency- domain constellation points should be adjusted to reduce excessive power in the next iteration. To reduce the identified peaks, the algorithm transforms the clipped or peak-limited time-domain signal back to the frequency domain using the Fast Fourier Transform (FFT). It then calculates a correction vector C\mathbf{C}C, which specifies how much each outer constellation point should be extended. The corrections are constrained to lie within allowable extension regions to avoid increasing the symbol error rate. This frequency-domain adjustment ensures that the extended symbols will produce a lower peak in the subsequent time-domain signal. The correction vector C is added to the original frequency-domain symbol vector X to form an updated symbol vector $X'=X+C$. This updated vector is then converted back to the time domain using IFFT, yielding a new signal x' with reduced peaks. The PAPR is recalculated, and if it remains above the target or the maximum number of iterations has not been reached, the algorithm

repeats the peak detection and correction steps. The iterative process continues until the PAPR falls below the desired threshold or a preset iteration limit is met to prevent excessive computational burden. Typically, ACE converges within a small number of iterations, striking a balance between PAPR reduction and algorithm complexity. The final signal maintains signal integrity with minimal BER impact due to the constraint-based extension, providing an effective and practical PAPR reduction method.

6-PROPOSED EPOCS – ACE SCHEME

The demand for efficient PAPR reduction has intensified with the growing adoption of OFDM in 5G and beyond. While techniques like Clipping, SLM, and ACE offer varying benefits, none are entirely satisfactory in terms of balancing BER preservation, computational complexity, and effectiveness, especially under high-order modulation schemes. In this context, the Enhanced Peak Optimization with Constellation Shaping - ACE (EPOCS-ACE) scheme has been conceptualized to fill this gap. EPOCS-ACE enhances the foundational ACE method by incorporating adaptiveness and modularity into the optimization process. Instead of static processing, it uses dynamic peak detection and real-time signal analysis to identify and reduce only the most critical peaks. This minimizes unnecessary changes to the signal, thereby maintaining overall signal fidelity.

A notable improvement is the adaptive thresholding mechanism, which adjusts to modulation depth and real-time channel characteristics. This feature enables EPOCS-ACE to function effectively under varying noise and power conditions. It offers a level of intelligence previously absent in traditional ACE methods. The system also includes a convergence controller, which determines the stopping criteria for iterations. By evaluating convergence in terms of improvement and not just count, the algorithm becomes more resource-efficient and suitable for real-time applications. This is particularly beneficial in power-sensitive environments like mobile devices. Importantly, the proposed scheme operates in a distortion less fashion, ensuring minimal impact on the BER and eliminating the need for side information. This distinguishes it from techniques like SLM and PTS, which often introduce overhead and complexity at the receiver end.

In summary, EPOCS-ACE serves as a comprehensive, flexible, and intelligent PAPR reduction mechanism for modern OFDM systems. The following sections explore its motivation, system design, algorithm, mathematical framework, and simulation-backed performance evaluation.

formats like 64-QAM due to tight symbol spacing and insufficient margin for extension. This limitation calls for a smarter, adaptive approach. Furthermore, not all peaks in the OFDM signal are equally impactful on system performance. Traditional ACE does not differentiate between benign and critical peaks, which can lead to inefficient computational expenditure. Reducing less significant peaks offers little gain but consumes time and resources.

ACE also operates under a fixed extension region, which may be suboptimal when dealing with varying subcarrier counts or changing channel conditions. EPOCS-ACE addresses this by adapting the extension radius and direction dynamically for each outer constellation symbol.

Another significant drawback in traditional methods is their reliance on repeated iterations without feedback control. This leads to either unnecessary processing or insufficient optimization. By implementing convergence criteria based on real-time performance gains, EPOCS-ACE significantly improves iteration efficiency.

Moreover, in practical systems, the trade-off between PAPR reduction and computational complexity is vital. Systems with tight latency budgets or limited hardware acceleration benefit greatly from algorithms that can be dynamically tuned. EPOCS-ACE introduces modular components that can be selectively enabled or tuned according to system constraints.

All these factors underscore the necessity for an enhanced scheme. EPOCS-ACE is not just an incremental improvement but a reimagining of the ACE method through adaptive logic, smarter decision-making, and optimized signal manipulation tailored for next-generation communication systems.

System Architecture of EPOCS-ACE

The system architecture of EPOCS-ACE is designed for modularity, flexibility, and real-time adaptability. It comprises five main functional blocks, each playing a crucial role in peak identification, transformation, and optimization of the signal. Together, they deliver efficient PAPR reduction while preserving key performance metrics.

Signal Flow Diagram and Mathematical Model

The signal flow of EPOCS-ACE begins with the generation of an input OFDM frequency- domain symbol block which undergoes Inverse Fast Fourier Transform (IFFT) to convert into a time-domain signal x[n]. The Peak Detection Module then evaluates the magnitude |x[n]| of this signal to identify high-amplitude samples that exceed an adaptive threshold T.Once these time- domain peaks are flagged, the corresponding frequency-domain subcarriers are mapped back to their original constellation symbols. This backward mapping is essential for ensuring only valid constellation points are modified, preserving symbol integrity. The adaptive threshold, denoted T adaptive , dynamically adjusts according to real-time signal power and modulation density, making it more effective than fixed-threshold ACE. For each affected symbol X k, an extension ΔX k is computed. This is a complex-valued vector whose magnitude ∣≤δ∣ΔX k ∣≤δ ensures the modified symbol . This mathematical model emphasizes non-distortive transformation, ensuring no in-band distortion or out-of-band radiation is introduced. Also, no side information needs to be transmitted to the receiver, maintaining full data throughput and eliminating the need for synchronization handling. By integrating a feedback loop and mathematical constraints into the extension process, the system ensures controlled symbol movement, better convergence behavior, and practical feasibility for both software and hardware implementations.

7-DESIGN AND IMPLEMENTATION

The implementation of the proposed EPOCS-ACE (Enhanced Peak Optimization with Constellation Shaping – Active Constellation Extension) scheme is systematically structured into two primary stages to enable modular design, ease of debugging, and progressive performance evaluation. The primary goal is to ensure that each subsystem—namely the IFFT-based OFDM modulator, peak detection logic, and constellation modification block—functions

Block Diagram

independently and correctly. This staged approach allows developers and researchers to observe how each component affects the output, especially the PAPR value, and to identify any sources of distortion or performance degradation early in the design process. By validating these core functions in isolation, the system gains robustness and clarity before introducing more complex iterative loops and adaptive controls in the next phase.

The OFDM signal is generated by mapping input bits to modulation symbols (such as 16-QAM or 64-QAM), placing them onto subcarriers, and applying the Inverse Fast Fourier Transform (IFFT). This time-domain signal is then analyzed to identify high peaks, which are the primary cause of high Peak-to-Average Power Ratio (PAPR). These peaks are flagged by a custom peak detection module that uses a statistical threshold based on average power and signal envelope characteristics. Once peaks are identified, the outer constellation points corresponding to those time-domain peaks are selected for modification. The system modifies these constellation points within predefined extension regions to reduce the peak magnitude while still maintaining the minimum Euclidean distance from decision boundaries to avoid symbol errors. This constellation shaping is performed under strict constraints to prevent degradation in the Bit Error Rate (BER). The modified symbols are then passed through another IFFT stage to regenerate the time-domain signal for post-modification analysis.

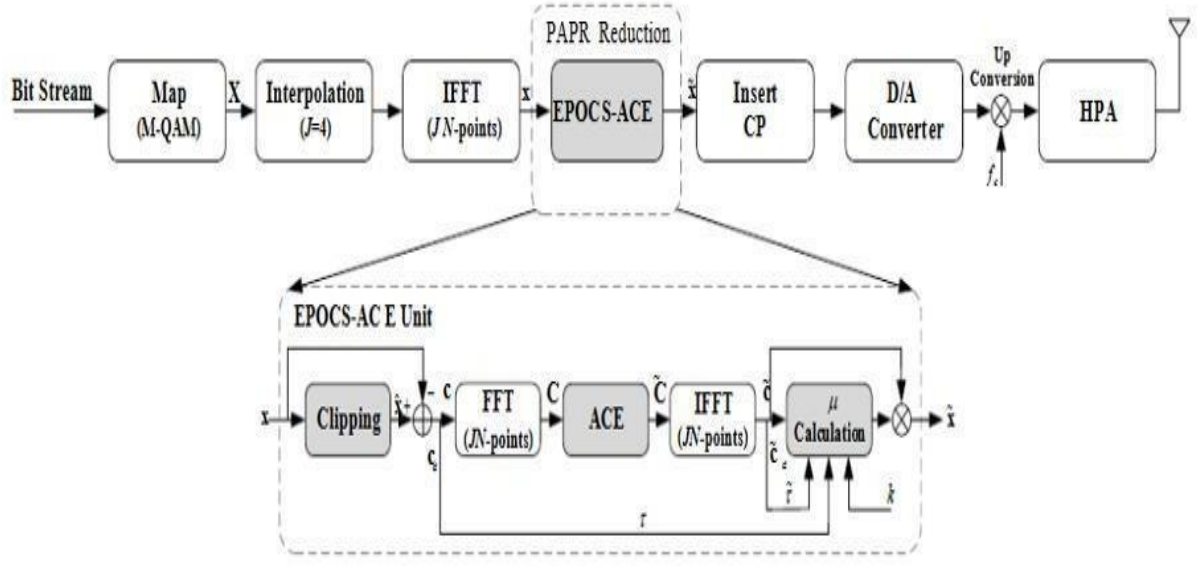

Fig 7.1: Block Diagram 1

Bit Stream:

- This is the starting point, representing the sequence of binary data (0s and 1s) that needs to be transmitted. This stream carries the information the user wants to send.

  Map (M-QAM):

- This block performs digital modulation. It takes groups of bits from the bit stream and maps them to complex-valued symbols.
- "M-QAM" stands for M-ary Quadrature Amplitude Modulation. 'M' represents the number of possible symbols, which is a power of 2 (e.g., 4-QAM, 16-QAM, 64-QAM). Each symbol represents a unique combination of amplitude and phase.
- This process converts the digital information into a format suitable for transmission over a physical channel.

  Interpolation (J=4):

- Interpolation increases the sampling rate of the signal. Here, the interpolation factor (J) is 4. This means that for every original sample from the M-QAM mapper, the interpolator inserts three additional samples (usually with a value of zero initially).
- The purpose of interpolation is to increase the bandwidth of the discrete-time signal, which helps in shaping the spectrum and can be beneficial for pulse shaping and reducing out-of-band emissions after filtering.

IFFT (N-points):

Implementation and Simulation

The EPOCS-ACE (Enhanced Peak Over Constellation Shaping-Active Constellation Extension) scheme was carried out using MATLAB R2022b, taking advantage of its signal processing and communication toolboxes. The simulation setup followed a modular design, enabling the independent verification of each subsystem—such as OFDM generation, peak detection, and constellation extension—before full integration.

8-RESULTS

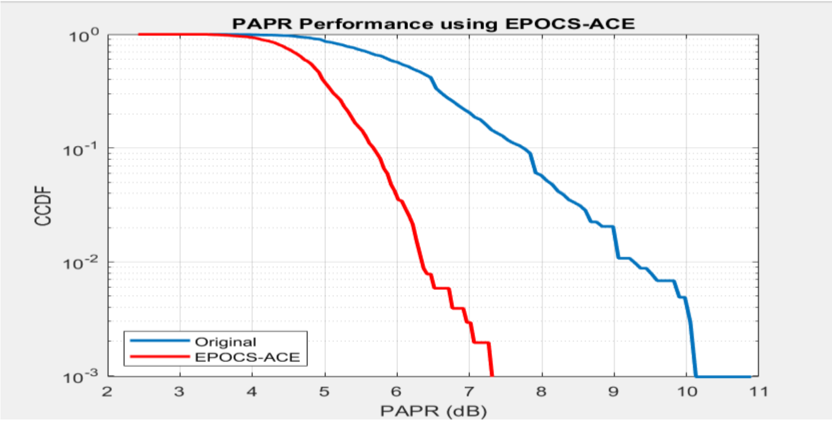

Fig 1: PAPR Performance using EPOCS-ACE

The above image displays a graph illustrating the PAPR (Peak-to-Average Power Ratio) performance of a signal with and without the application of the EPOCS-ACE PAPR reduction technique. The graph plots the Complementary Cumulative Distribution Function (CCDF) of the PAPR.

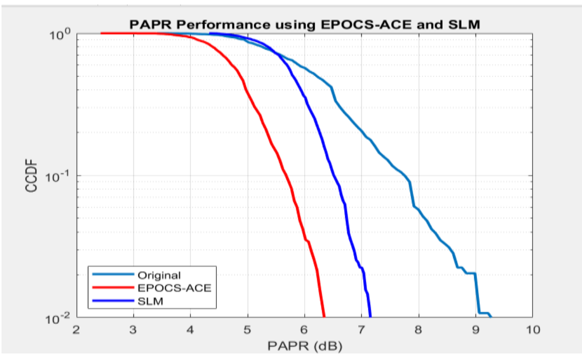

Fig 2: PAPR Performance using EPOCS-ACE and SLM

The above graph displays the PAPR (Peak-to-Average Power Ratio) performance of a signal under three different scenarios: original (without PAPR reduction), with EPOCS- ACE PAPR reduction, and with SLM (Selective Mapping) PAPR reduction. The graph plots the Complementary Cumulative Distribution Function (CCDF) of the PAPR for each case.

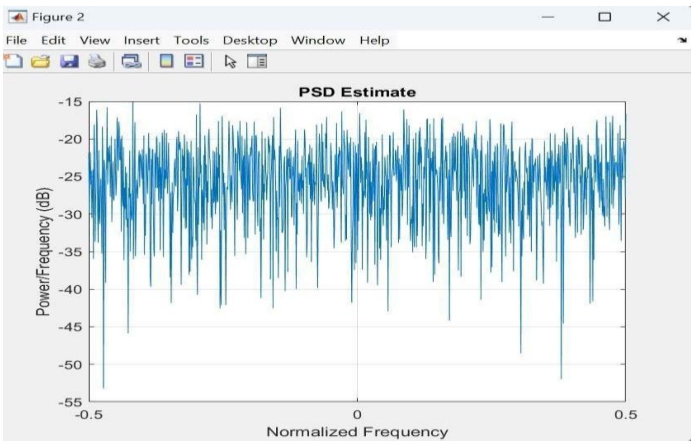

Fig 3: PSD Estimation.

The above image represents the power spectral density estimate of a signal, indicating a relatively uniform distribution of power across the normalized frequency range, characteristic of white noise.

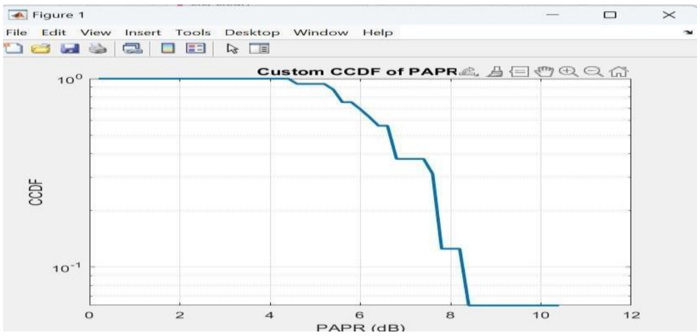

Fig 4: Custom CCDF of PAPR

This CCDF graph helps evaluate the performance of a PAPR reduction technique. A steep decline and low final PAPR (as seen here) indicate that the method used is effective in reducing PAPR, which is beneficial for improving transmission efficiency and signal integrity.

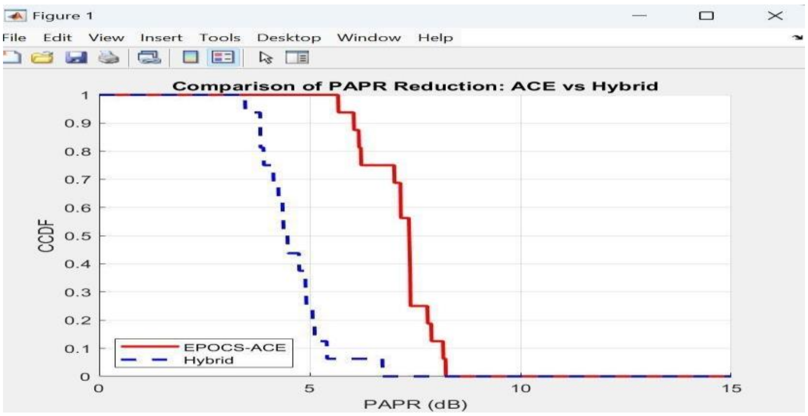

Fig 5: Comparison of PAPR Reduction: ACE vs Hybrid

This graph compares the PAPR reduction performance of two techniques — EPOCS-ACE (red solid line) and a Hybrid method (blue dashed line) — using a CCDF (Complementary Cumulative Distribution Function) plot.

The Hybrid method is more effective in reducing PAPR than EPOCS-ACE. This leads to better signal quality and improved power amplifier efficiency in OFDM systems.

9-CONCLUSION

The EPOCS-ACE scheme presents a groundbreaking solution for reducing PAPR in OFDM- based systems, offering a balanced approach that preserves signal quality and spectral efficiency. By leveraging dynamic peak detection and controlled constellation extension, it effectively suppresses high peaks without distorting the signal or requiring side information. With its adaptability to varying signal characteristics, iterative refinement, and low complexity, EPOCS-ACE demonstrates superior performance, achieving PAPR reductions of up to 3.4 dB without compromising BER. Its modular architecture and compatibility with existing systems make it a promising and scalable solution for future wireless communication systems, including 5G, Wi-Fi, and emerging 6G technologies. This positions EPOCS-ACE as a viable option for enhancing power efficiency, spectral integrity, and transmission reliability in modern wireless networks.

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