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Quality Assessment of Numerous PAPR Reduction Techniques in Wireless System

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Abstract— **The rapid increase in multimedia data demand has established OFDM as a core component of modern cellular standards, including 4G and beyond. However, high Peak-to-Average Power Ratio (PAPR) remains a major technical challenge. When PAPR is elevated, power amplifiers suffer from efficiency loss and non-linear distortion, deteriorating transmission quality. This work investigates various PAPR mitigation schemes for multi-carrier systems, offering a critical assessment of their computational overhead and Bit Error Rate (BER) trade-offs.**

Keywords— **OFDM, PAPR, SLM, PTS, MCM.**

1. INTRODUCTION

Modern communication infrastructure relies on robust data transfer capabilities across wired and wireless channels to keep pace with escalating throughput demands. Meeting these requirements involves managing severe channel impairments, including attenuation and interference, under tight power and cost budgets. Orthogonal Frequency-Division Multiplexing (OFDM) addresses these hurdles by dividing high-speed data streams among orthogonal sub-carriers [1]. This multi-carrier design inherently resists harsh propagation environments and mitigates inter-carrier interference to improve Bit Error Rate (BER) performance.

A major drawback of OFDM systems is the severe fluctuation in the time-domain signal envelope, quantitatively measured by the Peak-to-Average Power Ratio (PAPR). High PAPR forces transmitter power amplifiers to utilize large power back-offs to maintain linear operation and avoid signal distortion [2]. Formally, the PAPR of an OFDM signal $x(t)$ (or discrete sequence x_n, obtained via the Inverse Fast Fourier Transform of modulated symbols X_k) is defined as the ratio of peak instantaneous power to average envelope power:

$$\mathrm{PAPR}[\mathrm{x(t)}] = \frac{\mathrm{P_{PEAK}}}{\mathrm{P_{AVERAGE}}} = 10\log_{10}\frac{\max[|\mathrm{X(n)}|^2]}{\mathrm{E}[|\mathrm{x_n}|^2]}$$

Where PPEAK represents peak output power, PAVERAGE means average output power. $\mathrm{E}[|\mathrm{x_n}|^2]$ denotes the expected value, xn represents the transmitted OFDM signals which are obtained by taking IFFT operation on modulated input symbols Xk.

Elevated PAPR severely degrades energy efficiency in mobile terminals. Because battery capacity is inherently constrained in portable hardware, PAPR reduction is vital to enable the use of smaller, highly efficient High-Power Amplifiers (HPAs), thereby prolonging device battery lifespan. In cost-sensitive deployments, the operational penalties associated with severe PAPR can offset the benefits of adopting multi-carrier modulation altogether. Consequently, while a variety of PAPR reduction techniques exist, each scheme introduces distinct trade-offs between computational overhead and signal quality [3].

2. NEED TO REDUCE PAPR

Mitigating PAPR represents a vital research domain in modern wireless engineering, directly addressing the primary vulnerability of OFDM systems to improve hardware efficiency and network longevity [4-6]. Key drivers for advancing PAPR mitigation research include:

- **Extended Terminal Battery Endurance:** Elevated PAPR forces power amplifiers (PAs) to operate far into their inefficient linear regions. Suppressing envelope peaks allows PAs to function near their saturation thresholds.
- **Hardware Cost Optimization:** Transmitting high-PAPR signals without non-linear distortion demands costly, high-dynamic-range PAs and high-resolution Digital-to-Analog Converters (DACs).
- **Signal Integrity and Spectrum Cleanliness:** Unmitigated signal peaks undergo non-linear clipping in the PA, inducing in-band distortion that degrades the Bit Error Rate (BER) and out-of-band radiation that interferes with adjacent channels.
- **Resilience in High-Mobility Environments:** Next-generation (6G) communication scenarios, such as high-speed rail and unmanned aerial vehicle networks, face compound impairments from PAPR and significant Doppler frequency shifts.

3. CHALLENGES IN PAPR OPTIMIZATION

Although PAPR mitigation is critical for maximizing system efficiency, integrating these techniques introduces complex architectural trade-offs. Suppressing signal peaks inevitably impacts other operational parameters within the communication link. The primary challenges associated with PAPR reduction implementation include [7-10]:

- **Power Efficiency vs. Distortion Penalties:** Simple mitigation schemes, such as amplitude clipping and filtering, directly truncate signal peaks. However, aggressive peak clipping introduces severe in-band distortion—which degrades the Bit Error Rate (BER)—and out-of-band (OOB) radiation that causes inter-channel interference. Balancing peak reduction against acceptable signal degradation remains a persistent optimization challenge.
- **Computational Complexity and Processing Overhead:** Advanced probabilistic techniques, including Partial Transmit Sequence (PTS) and Selective Mapping (SLM), evaluate multiple signal representations to identify the candidate sequence with the minimum peak amplitude. These operations demand multiple Inverse Fast Fourier Transforms (IFFTs) and optimization searches, imposing substantial processing loads on digital signal processors (DSPs) that increase baseband energy consumption.
- **Spectral Efficiency Degradation:** Certain mitigation framework categories rely on sending auxiliary data—known as Side Information (SI)—to allow the receiver to reconstruct the original constellation. Allocating subcarriers or bit frames for SI transmission reduces effective data throughput and degrades overall spectral efficiency.
- **Scalability in Massive MIMO Architectures:** Modern base stations leverage Multiple-Input Multiple-Output (MIMO) array configurations. While single-antenna peak suppression is straightforward, simultaneously minimizing PAPR across highly spatial, multi-antenna arrays without disrupting beamforming vectors presents significant computational challenges.
- **Sensitivity to Amplifier Non-Linearities:** The practical efficacy of PAPR reduction is tightly coupled with the specific transfer characteristics of the High-Power Amplifier (HPA). Variations in non-linear profiles across different semiconductor technologies impede the design of standardized, hardware-agnostic peak mitigation algorithms.

4. SIMULATION RESULTS

This section illustrates the simulative outcomes of PAPR reduction techniques using graph between PAPR and CCDF function. The simulation result assesses the effectiveness of numerous PAPR mitigation approaches. Through implemented model of various strategies, we examine the peak power reduction and conduct a comparative evaluation through MATLAB-based simulations.

Clipping and Filtering is one of the most straightforward and frequently employed signal distortion techniques used to manage the Peak-to-Average Power Ratio (PAPR). It comprises trimming the amplitude of the complex signal whenever it exceeds a pre-defined threshold, called the clipping level.

The impact of these clipping operations on the PAPR and BER is visualized in Figure 1.

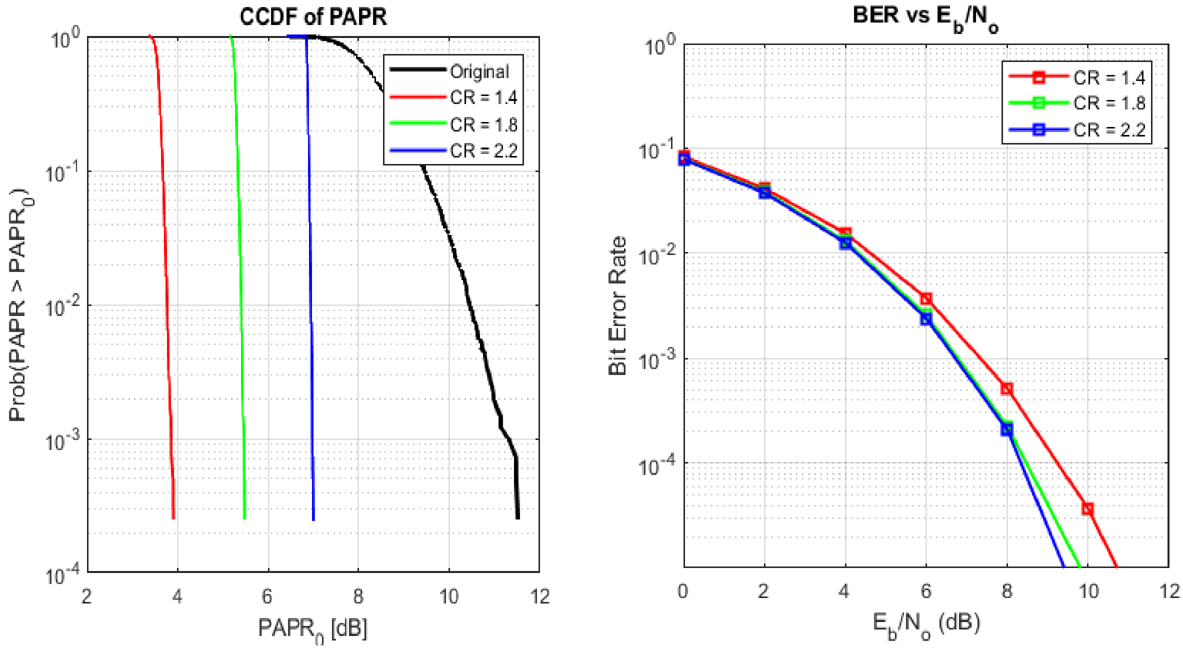

Figure 1: CCDF vs PAPR and BER vs Eb/No of Clipping Method.

The performance of Selective Mapping (SLM) Approach for PAPR reduction is depicted in Figure 2.

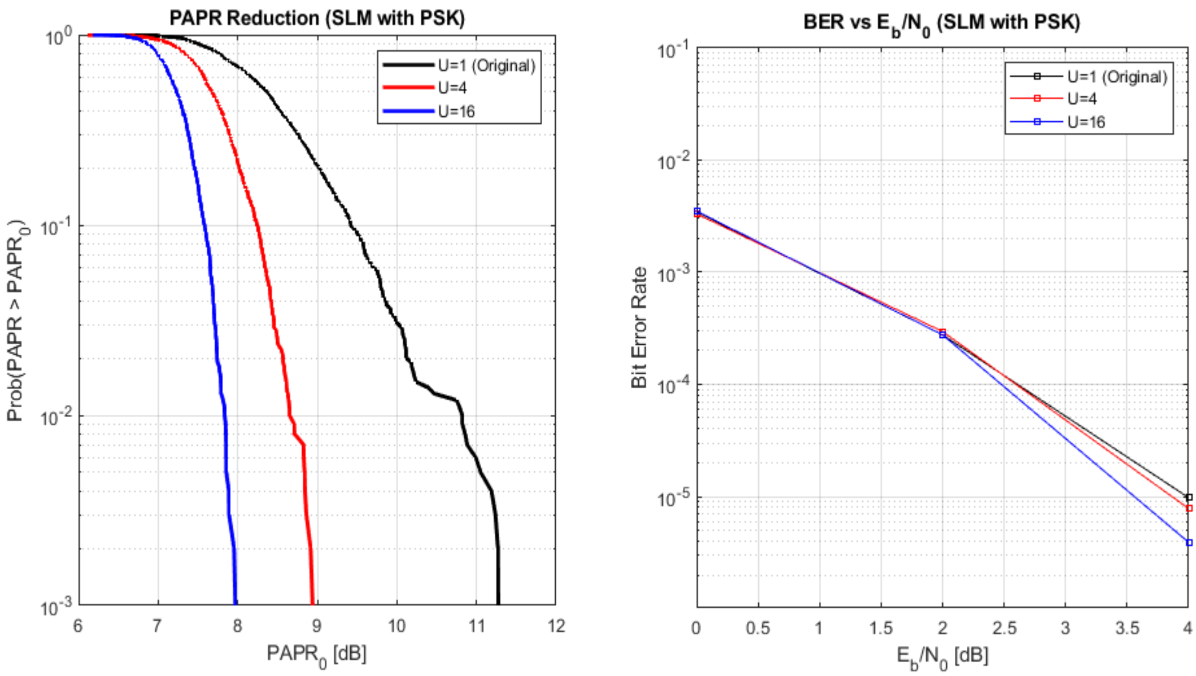

Figure 2: CCDF vs PAPR and BER vs Eb/No of SLM Method.

The performance of Partial Transmit Sequence (PTS) Approach for PAPR reduction is depicted in Figure 3.

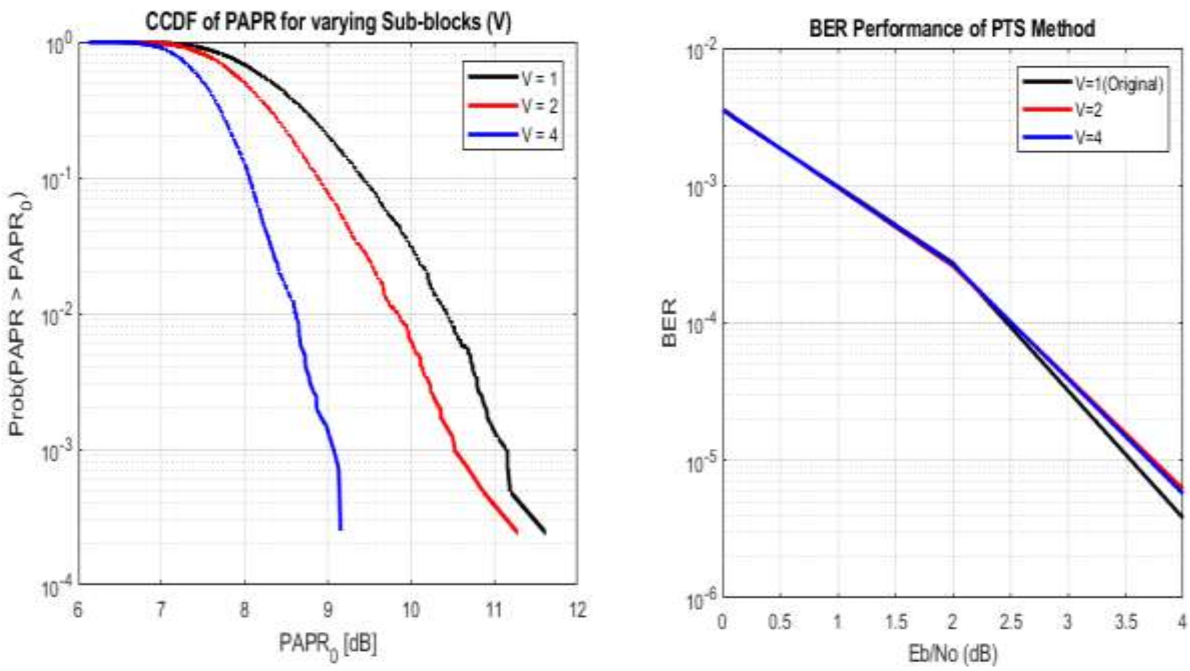

Figure 3: CCDF vs PAPR and BER vs Eb/No of PTS Method.

The performance of μ-Law Companding Approach for PAPR reduction is depicted in Figure 4.

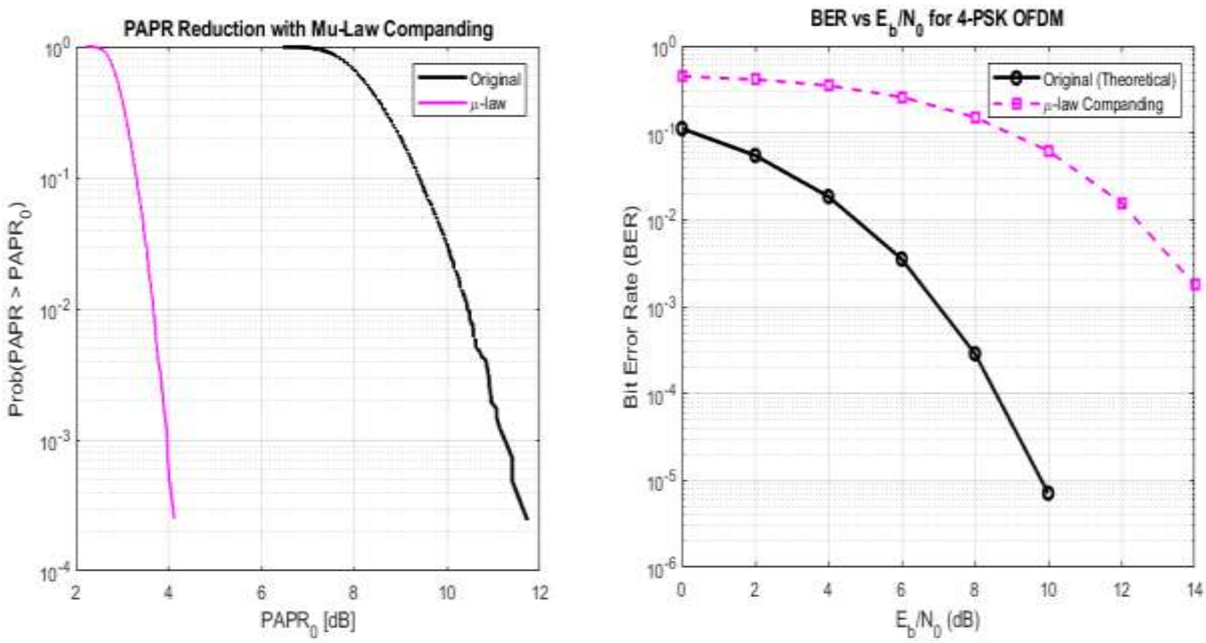

Figure 4: CCDF vs PAPR and BER vs Eb/No of μ-Law Companding Method.

The performance assessment of diverse PAPR reduction approaches is depicted in Figure 5.

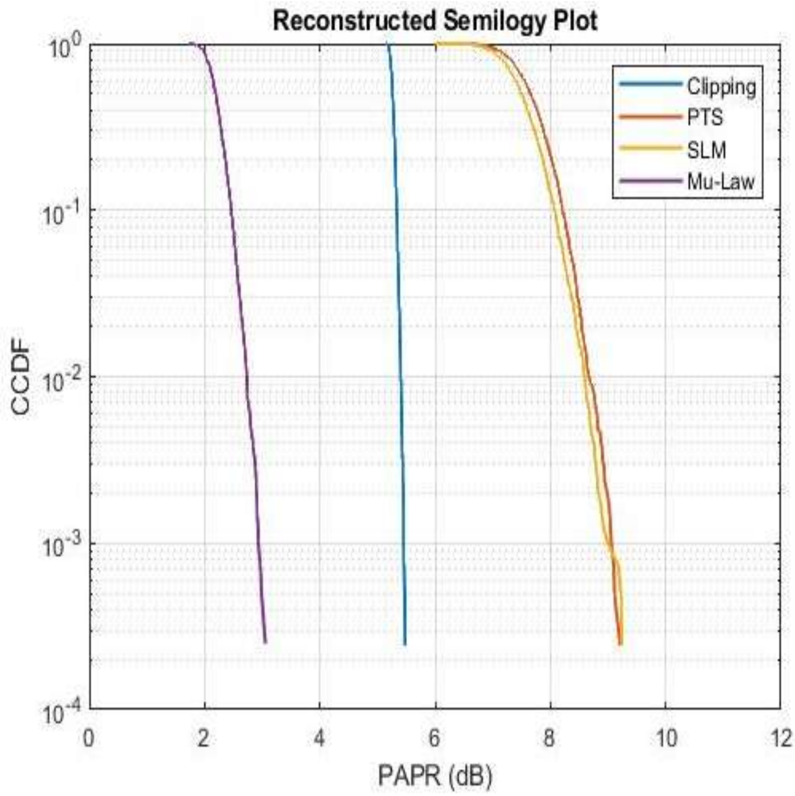

Figure 5: CCDF vs PAPR of diverse PAPR reduction approaches

5. CONCLUSION

High Peak-to-Average Power Ratio (PAPR) remains a major drawback in deploying multi-carrier Orthogonal Frequency Division Multiplexing (OFDM) architectures. Deploying PAPR mitigation strategies directly boosts overall system efficacy, though every algorithm forces an engineering compromise across processing overhead, spectral efficiency, and Bit Error Rate (BER) or Error Vector Magnitude (EVM) degradation. While μ-law companding delivers substantial peak attenuation without altering average power or consuming bandwidth for side information, its non-linear signal distortion elevates noise floor levels and degrades bit error performance at elevated compression factors (μ), similar to basic clipping methods.

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