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PAPR REDUCTION IN OFDM-WLAN COMMUNICATION USING HYBRID CLIPPING, TONE RESERVATION, AND PARTICLE SWARM OPTIMIZATION

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***Abstract*:** Orthogonal Frequency Division Multiplexing is widely used in Wireless Local Area Network systems because it supports high-speed data transmission, makes efficient use of the available bandwidth, and performs reliably in multipath fading environments. Large peak power variations are a significant limitation of OFDM transmission. When the signal exhibits excessive peak levels, the High-Power Amplifier (HPA) must operate over a wider linear range, reducing its efficiency and potentially causing signal distortion, higher Bit Error Rate (BER), and degradation of overall communication quality.

To solve this problem, this work proposes a hybrid PAPR reduction technique by combining three methods: Clipping, Tone Reservation (TR), Particle Swarm Optimization (PSO). First, Clipping reduces the highest peaks of the OFDM signal. Next, Tone Reservation removes the remaining peaks using reserved subcarriers. Finally, PSO optimizes the reserved tones to obtain the best PAPR reduction while maintaining good BER performance. The proposed technique was simulated in MATLAB over an AWGN channel to evaluate its performance.

The results show that the Clipping-TR-PSO method reduces PAPR more efficiently than the existing clipping and clipping with tone reservation techniques. Improved Signal-to-Noise Ratio (SNR) contributes to a reduction in the Bit Error Rate (BER), thereby enhancing transmission accuracy and minimizing communication errors. Overall, the proposed hybrid method reduces signal distortion efficient power amplifier operation, providing more reliable performance for OFDM- based WLAN communication systems.

Keywords: **OFDM, WLAN, PAPR, Clipping, Tone Reservation, Particle Swarm Optimization, BER, SNR.**

I. INTRODUCTION

Modern wireless communication systems, including Wi-Fi and 5G, widely employ Orthogonal Frequency Division Multiplexing (OFDM) because of its high data transmission capability and efficient use of available bandwidth. Instead of transmitting information over a single carrier, OFDM divides the data into several parallel streams and sends them simultaneously through orthogonal subcarriers. Thia approach improves spectral efficiency, supports high data rates, and enhances communication reliability by reducing the effects of multipath fading and interference.

High Peak-to-Average Power Ratio (PAPR) remains a significant limitation that affects the performance of OFDM transmission. A high PAPR means that the OFDM signal has some very high peak values compared to its average power. Because of these peaks, the power amplifier must work in its linear region to prevent distortion. This reduces the amplifiers efficiency and increases power consumption. If it cannot handle the peaks, the signal becomes distorted, resulting in poor transmission quality, higher Bit Error Rate, and increased power consumption.

Many techniques have been developed to reduce PAPR. One common method is Clipping, where the signal peaks above a threshold are cut off. It is simple and effective, but it introduces signal distortion. Another technique used approach is Tone Reservation, where selected unused subcarriers are assigned to create a compensation signal that suppresses excessive peaks without affecting the transmitted information.

An integrated hybrid strategy is developed to reduce PAPR through the combined use of Clipping, Tone Reservation, and Particle Swarm Optimization. First, clipping reduces the highest peaks in the OFDM signal. Next, Tone Reservation further decreases the remaining peaks by using reserved subcarriers. Finally, PSO optimizes the reserved tone values to achieve better PAPR reduction with minimum signal distortion. This hybrid approach improves power amplifier efficiency maintaining good BER performance and overall communication reliability.

The main contributions of this work are:

- Improve BER performance while minimizing signal distortion.
- Implement and evaluate the proposed method using MATLAB simulations.
- Compare the proposed approach with conventional PAPR reduction techniques.

II. LITERATURE SURVEY

Orthogonal Frequency Division Multiplexing is commonly used in wireless communication systems because it supports efficient and reliable high-speed data transmission. The presence of large signal peaks in OFDM can reduce power amplifier efficiency and may cause nonlinear distortion in the transmitted waveform. Researchers have investigated multiple approaches for reducing PAPR in OFDM systems, with clipping, Tone Reservation, and Particle Swarm Optimization being among the commonly used techniques.

Li and Cimini studied the clipping and filtering technique as a simple approach for reducing the high peaks of OFDM signals. Their work showed that clipping can effectively lower PAPR with minimal implementation complexity. However, clipping may introduce in-band distortion, which can increase the Bit Error Rate.

Tellado the Tone Reservation scheme, where dedicated subcarriers are utilized to generate compensation signals that minimize excessive peaks in the OFDM waveform. Since these reserved tones do not carry user data, the original information is preserved. The method improves signal quality compared with clipping alone, although its performance depends on the effective selection of the reserved tones.

Kennedy and Eberhart proposed Particle Swarm Optimization, an optimization approach that imitates how groups of birds and fish move together while searching for better paths. PSO has been widely used for solve optimization problems because of its fast convergence and simple implementation. In OFDM systems, PSO can optimize the reserved tone values used in the TR method, leading to improved PAPR reduction without significantly affecting BER.

Recent research has shown that combining clipping, Tone Reservation and optimization algorithms can provide better overall performance than using a single technique. Such hybrid approaches provide greater PAPR reduction while maintaining acceptable BER and enabling more efficient amplifier operation.

Based on the reviewed studies, it observed that clipping is simple and computationally efficient but introduces signal distortion. Tone Reservation reduces this distortion, while PSO improves the optimization of the reserved tones. Therefore, this paper proposes a hybrid Clipping-Tone Reservation-Particle Swarm Optimization technique to achieve lower PAPR and improved BER performance in OFDM-based WLAN communication systems.

III. PROPOSED METHODOLOGY

A. Overview of the Proposed Method

In this work, a hybrid technique is proposed to reduce the high PAPR in OFDM-WLAN systems using Clipping, Tone Reservation, and Particle Swarm Optimization. The main objective is to reduce the high Peak-to-Average Power Ratio, which affects the efficiency of the power amplifier and the overall performance of the OFDM system. At the beginning of the proposed scheme, a clipping process is introduced to reduce excessive signal peaks, creating a more suitable input for the following Tone Reservation and Particle Swarm Optimization stages. Tone Reservation is then applied to reduce the distortion caused by clipping. Finally, PSO is used to optimize the reserved tones and improve the PAPR reduction. The proposed method aims to provide lower PAPR, better BER performance, and more efficient signal transmission.

B. System Architecture

The proposed system consists of several processing blocks, including data generation, 16-QAM modulation, IFFT, clipping, Tone Reservation, Particle Swarm Optimization, wireless channel transmission, FFT, and demodulation. These blocks work together to reduce the Peak-to-Average Power Ratio while maintaining good signal quality and BER performance.

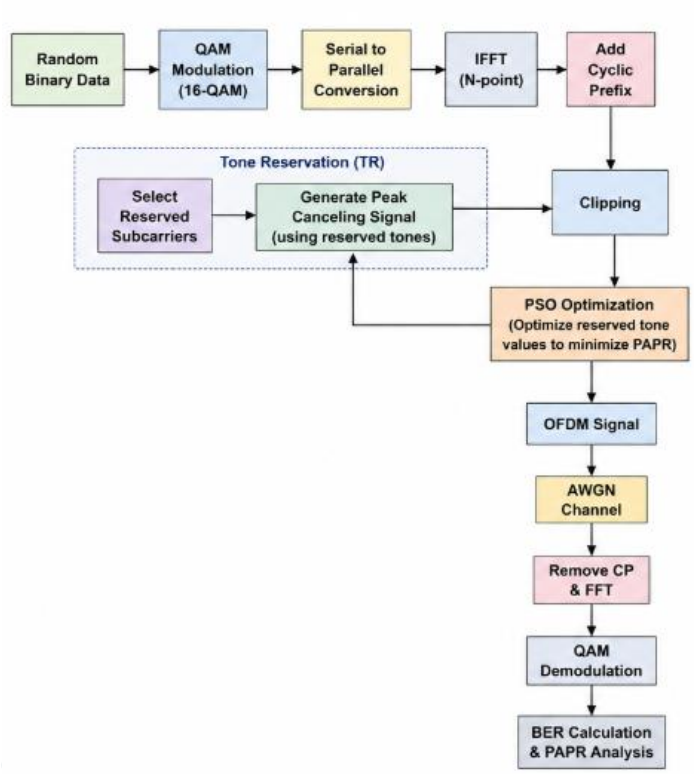

Fig.1. Architecture of proposed Clipping-TR-PSO Method

Fig.1 shows the proposed method used to reduce PAPR OFDM-WLAN systems. The proposed method begins by generating random input data, which are then modulated using 16-QAM before OFDM signal generation. The modulation data is converted from serial to parallel form. The IFFT to generate the time-domain OFDM signal and a cyclic prefix is added to reduce inter-symbol interference during transmission. The OFDM signal is processed through a hybrid PAPR reduction method, where clipping is first performed to limit high signal peaks. The Tone Reservation technique uses reserved subcarriers to create a peak-cancelling signal that compensates for clipping distortion. Particle Swarm Optimization is then employed to optimize the reserved tone values, resulting in improved PAPR reduction. The optimized OFDM waveform is evaluated under AWGN channel conditions. At the receiving end, the cyclic prefix is discarded, and the received signal is transformed into the frequency domain through the FFT operation. The recovered frequency-domain symbols are then processed using 16-QAM demodulation to obtain the transmitted information. System performance is finally assessed using the Peak-to-Average Power Ratio and Bit Error Rate.

C. Working Principle

The proposed systems work in a step-by-step process to reduce the PAPR in OFDM-WLAN systems. First, random binary data is generated and modulated using the 16-QAM technique. The modulated symbols are arranged into parallel streams before being processed by the IFFT to obtain the time-domain OFDM waveform. A cyclic prefix is appended afterward to reduce the effects of interference during signal transmission.

In the following step, the signal undergoes clipping to control high peak amplitudes and improves its power characteristics. Since clipping causes signal distortion, the Tone Reservation technique is used to reduce this distortion by generating a correction signal using reserved subcarriers. After that, Particle Swarm Optimization is applied to optimize the reserved tone values, which further improves PAPR reduction while maintaining good signal quality.

Finally, the performance of the proposed system is evaluated using PAPR and BER. Performance analysis confirms that the hybrid approach effectively lowers PAPR compared with conventional techniques, while supporting reliable signal transmission.

IV. MATHEMATICAL MODEL

A. OFDM Signal Model

Consider an OFDM system with N subcarriers, where the information symbols undergo 16-QAM modulation before forming input vector.

$$X = [X_0, X_1, \dots, X_{N-1}]^T \quad (1)$$

In this expression, X_k represents the complex data assigned to each Kth subcarrier, while N indicates the total count of subcarriers.

The OFDM symbols in the frequency domain are converted into a time-domain waveform using the Inverse Fast Fourier Transform (IFFT), as shown below,

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k^{e^{j\frac{2\pi kn}{N}}}, \quad 0 \le n \le N\text{-}1 \quad (2)$$

Here, x(n) denotes the OFDM signal in time-domain, where n ranges from 0 to N-1.

B. Peak-to-Average Power Ratio

The PAPR is one of the major drawbacks of OFDM systems. PAPR represents the relationship between maximum instantaneous signal power and its corresponding average power.

$$PAPR = \frac{max_{0\le n<N}\ |x(n)|^2}{E\{|x(n)|^2\}} \quad (3)$$

The PAPR in decibels is expressed as

$$PAPR_{dB} = 10log_{10}\ (\frac{max|x(n)|^2}{E\{|x(n)|^2\}}) \quad (4)$$

Reducing PAPR allows the power amplifier to operate more efficiently and helps minimize nonlinear effects in the transmitted signal.

C. Clipping Technique

The hybrid approach begins with clipping to suppress high peaks in the OFDM signal. The clipping threshold is determined by

$$A = CR \times \sigma \quad (5)$$

where

- CR is the clipping ratio,
- σ is the Root Mean Square (RMS) value of the OFDM signal.

The clipped OFDM signal is given by

$$x_c(n) = \begin{cases} A\, e^{j\angle x(n)}, |x(n)| > A \\ x(n), |x(n)| \le A \end{cases} \quad (6)$$

This operation limits the signal amplitude while preserving its phase information.

D. Tone Reservation (TR)

After clipping, Tone Reservation is employed to further reduce the remaining signal peaks. A selected group of subcarriers is set aside to generate a signal that suppresses high peaks.

The OFDM signal in the frequency domain can be expressed as

$$X = X_d + X_r \quad (7)$$

Where

- X_d denotes the data subcarriers,
- X_r represents the reserved-tone symbols.

The corresponding objective of Tone Reservation is

$$x = x_d + x_r \quad (8)$$

The optimization objective of Tone Reservation is

$$\min_{X_r} \max|x_d + x_r| \quad (9)$$

Which minimizes the peak amplitude without affecting the transmitted information symbols.

E. Particle Swarm Optimization (PSO)

PSO is employed to determine the optimal values of the reserved tones that achieve the minimum PAPR.

The particle velocity is updated using

$$v_i^{t+1} = \omega v_i^t + c_1 r_1 (p_i - x_i^t) + c_2 r_2\,(g - x_i^t) \quad (10)$$

Here,

- ω controls the contribution of the previous velocity to the current search step.
- c_1 and c_2 represent the individual the swarm learning factors, respectively.
- r_1 and r_2 denote randomly selected values between 0 and 1.
- p_i denotes the highest-quality solution obtained by the i^{th} particle.
- g denotes the best solution identified by the swarm during the optimization process.

The updated position of every particle is computed using the equation below.

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (11)$$

The optimization objective is

$$\min(\frac{max|x(n)|^2}{E\{|x(n)|^2} \quad (12)$$

The PSO algorithm iteratively searches for the reserved-tone values that provide the lowest PAPR while maintaining signal quality.

F. AWGN Channel and BER Analysis

The optimized OFDM signal is analyzed over an Additive White Gaussian Noise (AWGN) channel, as represented by the following model.

$$y(n) = x(n) + \omega(n) \quad (13)$$

Where

- y(n) is the received signal,
- ω (n) is additive white gaussian noise.

The Bit Error Rate is calculated as

$$BER = \frac{Number\ of\ Error\ Bits}{Total\ Number\ of\ Transmitted\ Bits} \quad (14)$$

A lower BER indicates better communication reliability.

G. CCDF Analysis

The Complementary Cumulative Distribution Function (CCDF) is used to evaluate the likelihood that the PAPR of an OFDM signal exceeds a specified level.

$$CCDF = P(PAPR > \gamma) \quad (15)$$

Where γ is the PAPR threshold expressed in decibels(dB).

In this work, the CCDF curve is used to compare the PAPR performance of the conventional OFDM system with the proposed Clipping-TR-PSO technique. A shift of the CCDF toward the left indicates that the proposed method achieves better PAPR reduction, meaning that lower PAPR values are obtained with a higher probability.

V. PARTICLE SWARM OPTIMIZATION ALGORITHM

PSO is a simple and effective optimization technique inspired by the way birds fly in groups while searching for food. Each particle is considered a candidate solution within the search space. During each iteration, every particle updates its movement based on its own best result and found by the swarm. This process continues until the algorithm finds the best possible solution. In the proposed OFDM-WLAN systems, PSO is used to optimize the Tone Reservation signal after clipping to reduce the Peak-to-Average Power Ratio. By selecting the optimal reserved tone values, PSO helps reduce PAPR with less signal distortion and maintains good Bit Error Rate performance, resulting in more efficient and reliable OFDM transmission.

Algorithm 1. Standard Particle Swarm Optimization (PSO)

Input: Population size N, T_{max}, ω, c_1, c_2
Output: Global best solution g_{best}
Step 1: Randomly initialize all particles and their velocity values
Step 2: Measure the performance of each particle using the fitness function
Step 3: Save the initial position of every particle as its personal best (p_{best})
Step 4: Determine g_{best}
Step 5: While ($t < T_{max}$) do
  5.1 Update velocity
  5.2 Update position
  5.3 Evaluate fitness
  5.4 Update p_{best}
  5.5 Update g_{best}
Step 6: End while
Step 7: Return g_{best}

VI. MATLAB SIMULATION PARAMETERS

The proposed Clipping-Tone Reservation-Particle Swarm Optimization technique was implemented and evaluated using MATLAB. The simulation parameters were selected to represent a typical OFDM-based WLAN system.

TABLE I

SIMULATION PARAMETERS

Parameter	Value
FFT Size (N)	64
Modulation Scheme	16-QAM
Number of OFDM Symbols	5000
Clipping Ratio (CR)	1.4
Reserved Tones	16
Optimization Technique	Particle Swarm Optimization (PSO)
Number of Particles	30
Maximum Iterations	80
Performance Metric	PAPR (CCDF)

A 16-QAM modulation scheme was used with 64 subcarriers. The PSO algorithm was configured with 30 particles and 80 iterations to optimize the reserved tones for PAPR reduction. The clipping ratio was set to 1.4, and the performance was evaluated in terms of PAPR and BER over an AWGN channel.

VII. RESULTS AND DISCUSSION

The proposed Clipping-TR-PSO technique was implemented in MATLAB to evaluate its performance in an OFDM-WLAN system. The results were compared with conventional OFDM, clipping, and clipping with TR, and PSO. The performance evaluated using PAPR and BER.

A. PAPR Performance Analysis

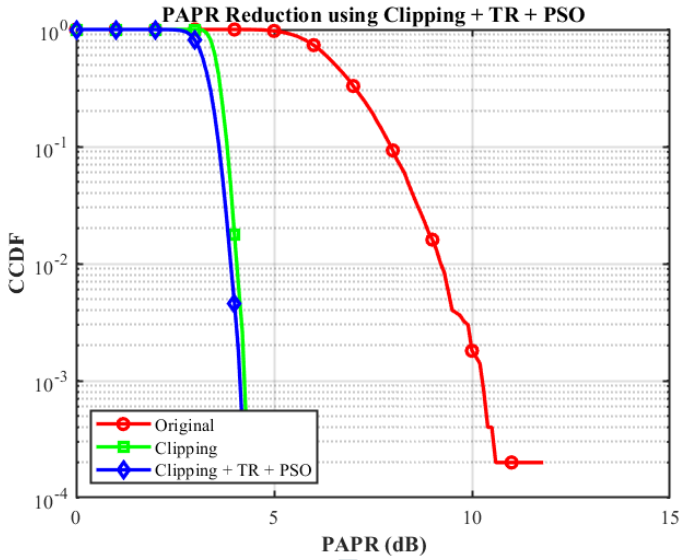

Fig.3. CCDF Analysis of PAPR Reduction Techniques

Fig. 3 presents the CCDF characteristics of conventional OFDM and the proposed Clipping–TR–PSO technique. The original OFDM signal has the highest PAPR because many subcarriers combine to produce high signal peaks. As a result, the PAPR is around 11dB at a CCDF of 10^{-4}.

After applying the clipping technique, the signal peaks are reduced, and the PAPR decreases to approximately 4dB. However, clipping introduces some signal distortion, which may affect system performance.

The proposed Clipping + TR + PSO method provides the best performance. By combining clipping with Tone Reservation and optimizing the reserved tones using Particle Swarm Optimization, the PAPR is further reduced to about 3.8dB. This shows that PSO effectively finds the optimal values for the reserved tones, resulting in better peak reduction with less distortion.

Overall, the proposed method achieves a significant improvement over the conventional OFDM system. The left shift of the CCDF curve indicates lower PAPR values, demonstrating the proposed hybrid technique is more efficient for OFDM-WLAN communication systems.

TABLE II

PAPR COMPARISON OF DIFFERENT TECHNIQUES

Method	Approximate PAPR (dB)
Original OFDM	10
Clipping	3.5
Clipping + TR+ PSO	4.0

B. BER Performance Analysis

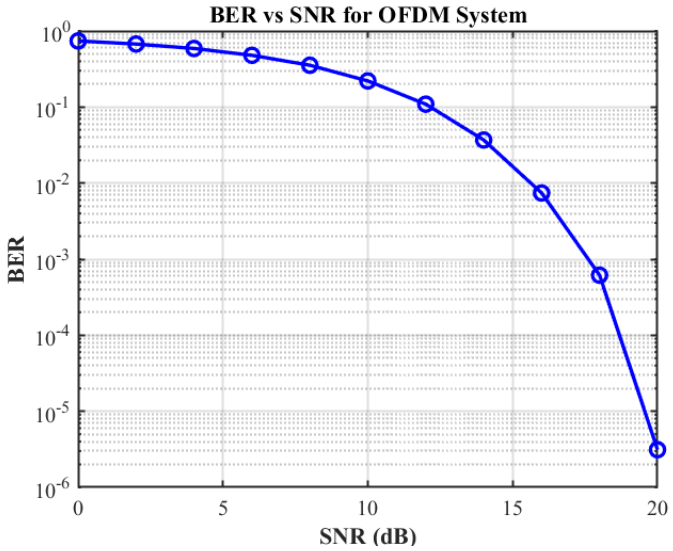

Fig.4. BER vs SNR for OFDM System

Fig.4 provides the BER characteristics obtained over a range of Signal-to-Noise Ratio values. Based on the graph, an increase in the SNR is accompanied by a decrease in the BER, indicating improved transmission performance. At low SNR values, the

received signal is more affected by noise, resulting in a higher number of bit errors. As the SNR increases, the effect of noise becomes smaller, allowing the receiver to detect the transmitted data more accurately.

At 0dB SNR, the BER is about 0.8, which means many bits are received with errors because the signal is affected by noise. As the SNR increases to 10dB, the BER reduces to about 0.22, showing better communication quality. At 20dB SNR, the BER becomes 3×10^{-6}, which means almost all the transmitted bits are received correctly.

These results show that the proposed Clipping-TR-PSO technique maintains reliable communication while reducing PAPR. The low BER at higher SNR values confirms that the proposed method improves transmission quality without significantly affecting error performance.

TABLE III

BER ANALYSIS OF THE PROPOSED OFDM SYSTEM

SNR (dB)	BER
0	0.85
5	0.60
10	0.22
15	0.02
20	3×10^{-6}

VIII. ADVANTAGES AND LIMITATIONS

Advantages:

- Enhances BER performance by minimizing clipping distortion using Tone Reservation.
- Improves the efficiency of the power amplifier by reducing signal peaks.
- Provides better performance by combining Clipping, Tone Reservation, and PSO.
- Suitable for OFDM-based WLAN communication systems.

Limitations:

- PSO increases computational complexity.
- Requires more processing time conventional OFDM.
- Tone Reservation reserves some subcarriers, reducing spectral efficiency.
- The system was tested only under an AWGN channel.

VIII. CONCLUSION

To improve the performance of OFDM systems, this work develops a hybrid framework that combines Clipping, Tone Reservation, and Particle Swarm Optimization for effective PAPR reduction. Clipping helps reduce the high peaks in the OFDM signal, while Tone Reservation reduces tones, which further improves the overall performance.

The developed hybrid approach achieves lower PAPR and better BER, particularly under high SNR conditions. Lower PAPR also increases the efficiency of the power amplifier, making the communication system more reliable. Overall, the proposed approach provides a simple and efficient solution for improving OFDM system performance and can be applied to modern wireless communication technologies such as Wi-Fi, 4G, and 5G networks.

X. FUTURE WORK

In the future, the proposed hybrid PAPR reduction method can be further improved by using advanced optimization techniques such as Genetic Algorithm, Artificial Bee Colony. The method can also be tested with larger OFDM systems, higher-order modulation schemes, and different wireless channel conditions to evaluate its performance. In addition, the proposed approach can be implemented on real-time hardware platforms such as FPGA or Software Defined Radio to verify its practical performance. Future research can also focus on reducing computational complexity while achieving even lower PAPR and better BER performance for next-generation wireless communication systems such as 5G and 6G.

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