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Original Research Article

Performance Analysis of PAPR Reduction in Multi-User OFDM Systems Using PTS, PSO-PTS AND DE-PTS Techniques

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is widely employed in modern multi-user wireless systems due to its high spectral efficiency and robustness to multipath fading. However, the high Peak-to-Average Power Ratio (PAPR) of OFDM signals reduces power amplifier efficiency and degrades system performance. This paper presents a comparative analysis of Partial Transmit Sequence (PTS), Particle Swarm Optimization-based PTS (PSO-PTS), and Differential Evolution-based PTS (DE-PTS) techniques for PAPR reduction in multi-user OFDM systems. The proposed methods are implemented in MATLAB and evaluated in terms of PAPR, Bit Error Rate (BER), and spectral efficiency. Simulation results demonstrate that DE-PTS achieves the lowest PAPR of approximately 5.3 dB with minimal BER degradation and improved spectral efficiency, outperforming conventional PTS and PSO-PTS methods. These findings confirm the effectiveness of optimization-based PTS techniques for enhancing performance in next-generation wireless communication systems.

Keywords: OFDM, PAPR reduction, Partial Transmit Sequence, Particle Swarm Optimization, Differential Evolution, Multi-user communication.

1.Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is extensively employed in modern wireless communication systems due to its high spectral efficiency and robustness against multipath fading[1]. However, OFDM suffers from a high Peak-to-Average Power Ratio (PAPR), which causes nonlinear distortion in power amplifiers and degrades system performance. Among various PAPR reduction techniques, Partial Transmit Sequence (PTS) is highly effective but involves significant computational complexity due to exhaustive phase optimization [2][3]. To address this limitation, this work investigates optimization-based PTS schemes, including Particle Swarm Optimization-based PTS (PSO-PTS) and Differential Evolution-based PTS (DE-PTS) [4]. Simulation results demonstrate improved PAPR reduction with reduced complexity, evaluated in terms of PAPR, Bit Error Rate (BER), and signal efficiency.

1.2 OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique widely used in modern wireless communication systems such as 4G LTE, Wi-Fi, and 5G. It divides the available bandwidth into multiple closely spaced, mathematically orthogonal subcarriers, each transmitting a low-rate data stream, thereby achieving high spectral efficiency and robustness against multipath fading [5]. The orthogonality enables frequency overlap without inter-carrier interference and allows efficient signal generation and detection using Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) operations [6][7]. To mitigate inter-symbol interference (ISI) caused by multipath propagation, a cyclic prefix (CP) is appended to each OFDM symbol.

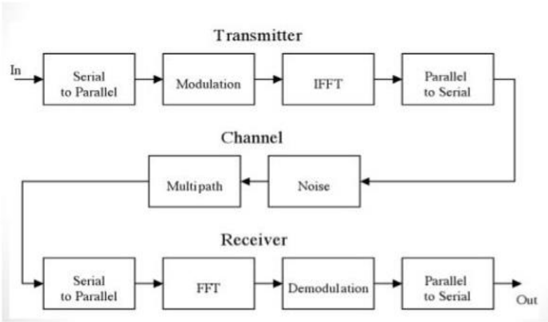

Fig.1 Block diagram of OFDM

In fig.1 shows, an OFDM system, the input bit stream is converted to parallel data and mapped onto complex symbols $X_k, k = 0,1, \dots, N-1$, using QAM or PSK modulation. The time-domain OFDM symbol is generated using the Inverse Fast Fourier Transform (IFFT) as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi kn/N}, n = 0,1, \dots, N-1, (1)$$

which ensures orthogonality among subcarriers. The signal is transmitted over a multipath channel and corrupted by Additive White Gaussian Noise (AWGN). At the receiver, the frequency-domain symbols are recovered using the Fast Fourier Transform (FFT), followed by demodulation to reconstruct the transmitted data [8].

1.3 Peak-to-Average Power Ratio (PAPR)

In an OFDM system, data is transmitted over multiple orthogonal subcarriers, whose time-domain superposition can produce large amplitude fluctuations due to constructive interference, resulting in a high Peak-to-Average Power Ratio (PAPR) [9][10]. PAPR is defined as the ratio of the maximum instantaneous signal power to its average power, given by

$$\text{PAPR} = \frac{\max \; | \, x(t) \, |^2}{\mathbb{E}[| \, x(t) \, |^2]}, \qquad (2)$$

where $x(t)$denotes the transmitted OFDM signal. High PAPR degrades power amplifier efficiency and causes nonlinear distortion, leading to increased out-of-band radiation and Bit Error Rate (BER). To mitigate this issue, PAPR reduction techniques such as Partial Transmit Sequence (PTS) and its optimized variants, including PSO-PTS and DE-PTS, are employed to minimize signal peaks through phase optimization, thereby improving transmission efficiency and signal quality.

2. Methodology

Orthogonal Frequency Division Multiplexing (OFDM) is widely used in modern multi-user wireless communication systems due to its high spectral efficiency and robustness to multipath fading; however, its high Peak-to-Average Power Ratio (PAPR) causes inefficiency and nonlinear distortion in power amplifiers. The Partial Transmit Sequence (PTS) technique is an effective distortionless PAPR reduction method, but its practical use is limited by high computational complexity arising from exhaustive phase optimization. To address this issue, heuristic optimization algorithms are integrated with PTS. Fig.2 shows this work presents a comparative performance analysis of conventional PTS, Particle Swarm Optimization-based PTS (PSO-PTS), and Differential Evolution-based PTS (DE-PTS) in a multi-user OFDM system, evaluated in terms of PAPR reduction, Bit Error Rate (BER), and computational efficiency to identify an efficient solution for next-generation wireless networks.

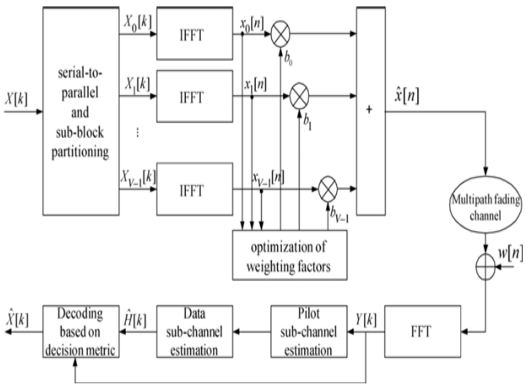

Fig. 2 Block diagram of OFDM systems based on the PTS scheme

A. Conventional Partial Transmit Sequence (PTS)

The Partial Transmit Sequence (PTS) technique is a distortionless method used to reduce the Peak-to-Average Power Ratio (PAPR) in OFDM systems. Consider an OFDM system with Nsubcarriers and frequency-domain input vector

$$\mathbf{X} = [X_{0}, X_1, \dots, X_{N-1}]^T. \qquad (3)$$

The corresponding time-domain OFDM signal obtained via IFFT is

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k\, e^{j2\pi kn/N}, n = 0, \dots, N-1. \qquad (4)$$

The PAPR is defined as

$$\text{PAPR}(\mathbf{x}) = \frac{\max_{0 \le n \le N-1} |x_n|^2}{\mathbb{E}[|x_n|^2]}. \qquad (5)$$

In PTS, the input vector $\mathbf{X}$is partitioned into Mdisjoint sub-blocks:

$$\mathbf{X} = \sum_{m=1}^{M} \mathbf{X}_m. \qquad (6)$$

Each sub-block is transformed to the time domain using IFFT:

$$\mathbf{x}_m = \text{IFFT}\{\mathbf{X}_m\}. \qquad (7)$$

These partial sequences are multiplied by phase rotation factors $b_m \in \{e^{j2\pi\phi/W}\}$and combined as

$$\tilde{\mathbf{x}} = \sum_{m=1}^{M} b_m\, \mathbf{x}_m. \qquad (8)$$

The optimal phase vector is obtained by minimizing the PAPR:

$$\hat{\mathbf{b}} = \arg \min_{\mathbf{b}} \left(\max_{n} \mid \sum_{m=1}^{M} b_m\, x_{m,n} \mid^2 \right). (9)$$

However, exhaustive evaluation of W^{M-1}phase combinations results in high computational complexity and motivates optimization-based solutions.

B. PSO-Based PTS (PSO-PTS)

Particle Swarm Optimization (PSO) is employed to reduce the search complexity of PTS by finding near-optimal phase vectors efficiently. Each particle represents a candidate phase vector:

$$\mathbf{b}_i = \left[b_{i,1}, b_{i,2}, \dots, b_{i,M}\right], \qquad (10)$$

with fitness defined as

$$f(\mathbf{b}_i) = \text{PAPR}\left(\sum_{m=1}^{M} b_{i,m}\, \mathbf{x}_m \right). \quad (11)$$

The particle velocity and position are updated as

$$v_{i,d}(t) = \omega v_{i,d}(t-1) + c_1 r_1 (pbest_{i,d} - b_{i,d}) + c_2 r_2 (gbest_d - b_{i,d}),$$
$$b_{i,d}(t) = b_{i,d}(t-1) + v_{i,d}(t). (12)$$

Since phase factors are discrete, updated positions are quantized to the nearest valid phase:

$$b_{i,d}(t) = e^{\frac{j2\pi\phi}{W}}. \qquad (13)$$

The global best particle yields the transmitted OFDM signal with reduced PAPR.

C. DE-Based PTS (DE-PTS)

Differential Evolution (DE) is another population-based optimization technique that offers robust convergence with fewer control parameters. Each individual (target vector) is defined as

$$\mathbf{b}_i(G) = [b_{i,1}(G), \dots, b_{i,M}(G)]. \qquad (14)$$

Mutation is performed using the DE/rand/1 strategy:

$$\mathbf{v}_i(G) = \mathbf{b}_{r1}(G) + F(\mathbf{b}_{r2}(G) - \mathbf{b}_{r3}(G)). \ (15)$$

Crossover generates the trial vector $\mathbf{u}_i(G)$, followed by discretization to valid phase values. Selection is performed greedily:

$$\mathbf{b}_i(G+1) = \begin{cases} \mathbf{u}_i(G), & f(\mathbf{u}_i(G)) \le f(\mathbf{b}_i(G)), \\ \mathbf{b}_i(G), & \text{otherwise.} \end{cases} \ (16)$$

After $G_{\max}$generations, the best solution is used to form the transmitted signal:

$$\tilde{\mathbf{x}}_{\text{optimal}} = \sum_{m=1}^{M} b_{best,m}\, \mathbf{x}_m. \qquad (17)$$

D. Flow Diagram of Proposed Work

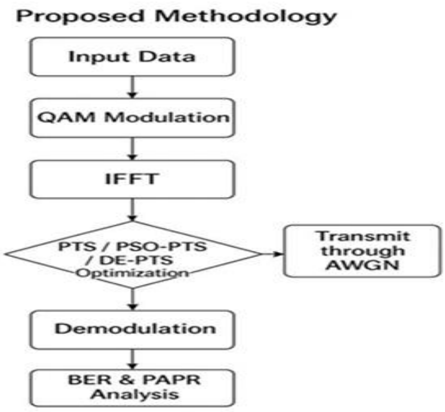

Fig.3 Flow diagram of proposed methodology

In fig.3 shows that the proposed methodology begins with the generation of a binary input data stream, which is mapped onto complex symbols using QAM modulation. These symbols are transformed into a time-domain OFDM signal using the IFFT operation, resulting in high PAPR. PAPR reduction is then performed using PTS, PSO-PTS, or DE-PTS by partitioning the data and optimizing the associated phase factors. The optimized OFDM signal is transmitted over an AWGN channel, followed by FFT-based demodulation at the receiver to recover the transmitted data. Finally, BER and PAPR analyses are carried out to evaluate and compare the performance of the proposed techniques in terms of error rate, peak power reduction, and overall system efficiency.

3. Results And Discussion

Simulation results compare conventional PTS, PSO-PTS, and DE-PTS in terms of PAPR, BER, and spectral efficiency. PAPR performance is evaluated using CCDF analysis. The results demonstrate that optimization-based PTS schemes provide substantial PAPR reduction with reduced complexity. Among the evaluated techniques, DE-PTS achieves the best overall performance while preserving BER and spectral efficiency, making it a promising approach for practical OFDM systems.

3.1 PAPR Reduction Using PTS Technique

The CCDF comparison shows that the PTS-based OFDM signal achieves a significant reduction in PAPR compared to the original OFDM signal. Specifically, the PAPR is reduced from approximately 7.5 dB to 5.8 dB, indicating improved power amplifier efficiency and signal linearity.

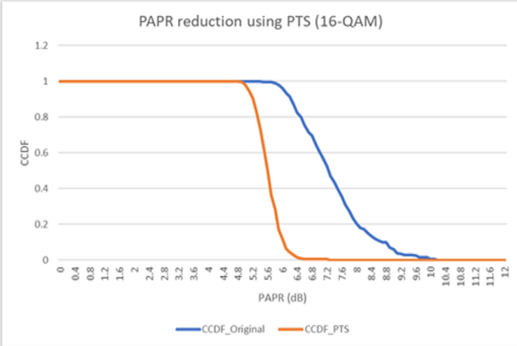

Fig. 4 CCDF of PAPR for the original and the PTS-based OFDM signal, showing a reduction from approximately 7.5 dB to 5.8 dB.

3.2 BER Performance of PTS vs. Original OFDM

The figure illustrates the BER performance of the original OFDM and PTS-based OFDM systems over varying SNR values. The PTS-based OFDM achieves slightly lower BER across all SNR levels, indicating improved signal reliability without degrading transmission performance.

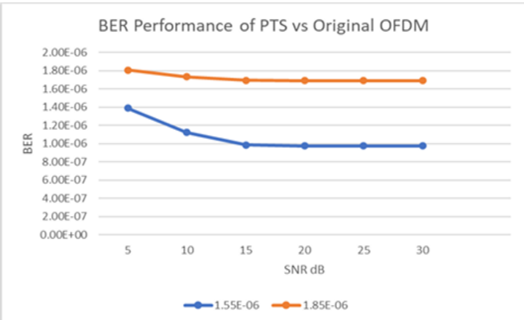

Fig.5 BER vs SNR performance of PTS

3.3 Spectral Efficiency performance of PTS and Original OFDM Systems

The figure compares the spectral efficiency of the original OFDM and PTS-based OFDM systems as a function of SNR. The PTS-based OFDM exhibits slightly improved spectral efficiency at lower SNRs while maintaining stable performance across the entire SNR range, indicating efficient bandwidth utilization.

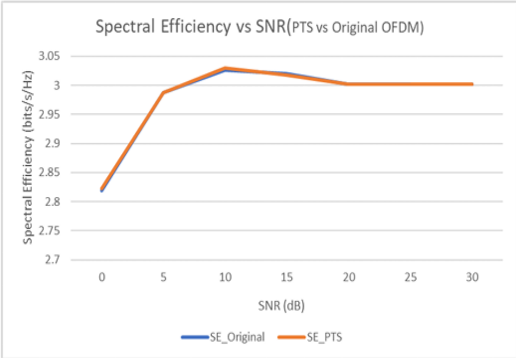

Fig.6 Spectral efficiency vs SNR performance of PTS

3.4 CCDF of PAPR for Original OFDM and PSO-PTS Optimized Signal

The CCDF comparison illustrates the PAPR reduction achieved by the PSO-PTS algorithm compared to the original OFDM signal. The PSO-PTS method reduces the PAPR from approximately 7.6 dB to about 5.5 dB, demonstrating effective suppression of high power peaks and improved transmitter efficiency.

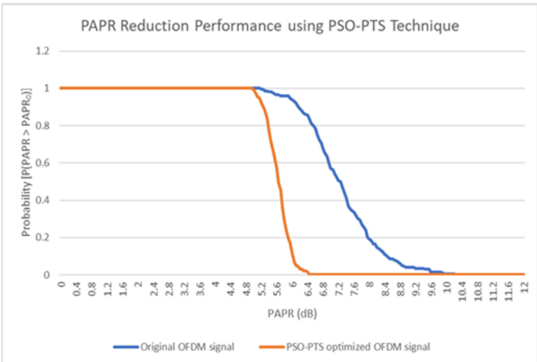

Fig.7 CCDF of PAPR reduction using PSO-PTS

3.5 Bit Error Rate (BER) vs. SNR for Original OFDM and PSO-PTS Systems

The figure shows that the BER performance of the original OFDM and PSO-PTS systems remains nearly identical across all SNR values. This indicates that PSO-PTS achieves PAPR reduction without degrading error performance, thereby preserving signal integrity.

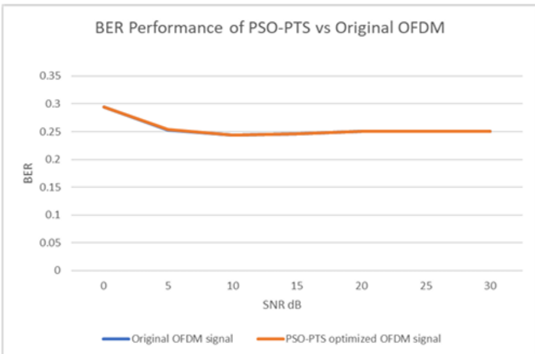

Fig.8 Bit Error Rate (BER) comparison of the original OFDM system and the PSO-PTS optimized system over an AWGN channel

3.6 Spectral Efficiency of PSO-PTS vs. Original OFDM

The figure compares the spectral efficiency of the original OFDM and PSO-PTS optimized OFDM systems using 16-QAM modulation. Both systems exhibit nearly constant spectral efficiency across the SNR range, indicating that PSO-PTS does not adversely affect bandwidth utilization or data transmission efficiency.

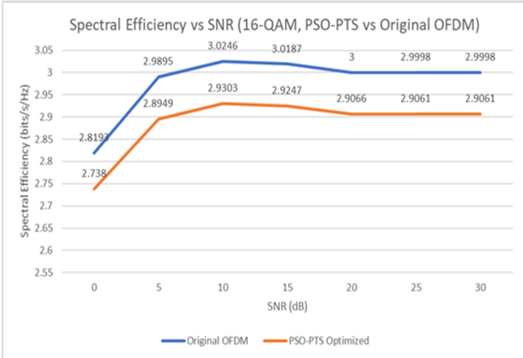

Fig.9 Comparison of Spectral Efficiency vs SNR for the original OFDM system and the PSO-PTS optimized system using 16-QAM modulation.

3.7 PAPR Reduction Using DE-PTS Technique

The CCDF comparison illustrates the PAPR reduction achieved by the DE-PTS algorithm relative to the original OFDM signal. The DE-PTS method reduces the PAPR from approximately 7.8 dB to about 5.3 dB, demonstrating superior peak suppression and improved power amplifier efficiency.

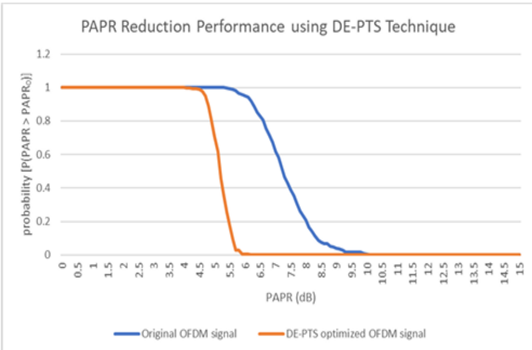

Fig.10 CCDF of PAPR showing the performance of the DE-PTS technique, achieving a reduction to approximately 5.3 dB from the original 7.8 dB.

3.8 BER Performance Comparison of DE-PTS and Original OFDM

The figure shows that the BER performance of the original OFDM and DE-PTS systems is nearly identical across the SNR range. As SNR increases, BER decreases for both systems, confirming that DE-PTS achieves PAPR reduction without compromising transmission reliability.

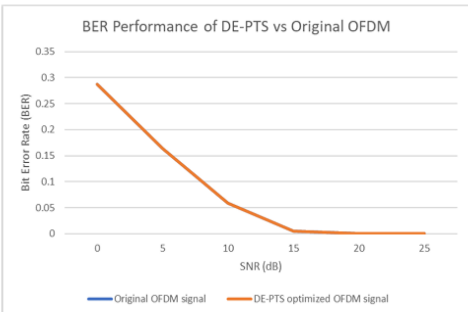

Fig.11 Bit Error Rate (BER) comparison of the original OFDM system and the DE-PTS optimized system over an AWGN channel

3.9 Spectral Efficiency of DE-PTS vs. Original OFDM

The figure illustrates the spectral efficiency performance of the DE-PTS and original OFDM systems over varying SNR values. The DE-PTS technique achieves slightly higher spectral efficiency across the SNR range, indicating improved bandwidth utilization due to reduced PAPR and enhanced transmitter linearity.

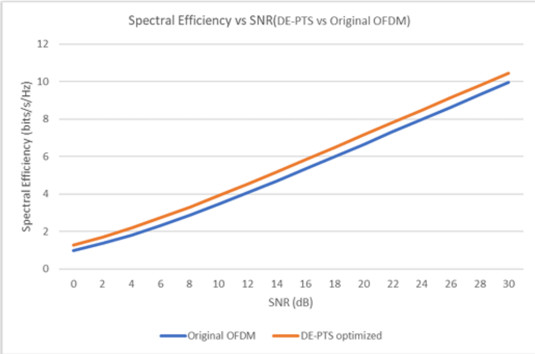

Fig.12 Comparison of Spectral Efficiency vs SNR for the original OFDM system and the PSO-PTS optimized system using 16-QAM modulation

3.10 PAPR Reduction Performance Comparison

The CCDF curves compare the PAPR reduction performance of original OFDM, conventional PTS, PSO-PTS, and DE-PTS schemes. The results show that DE-PTS achieves the lowest PAPR, followed by PSO-PTS, while conventional PTS provides moderate improvement, highlighting the effectiveness of optimization-based methods.

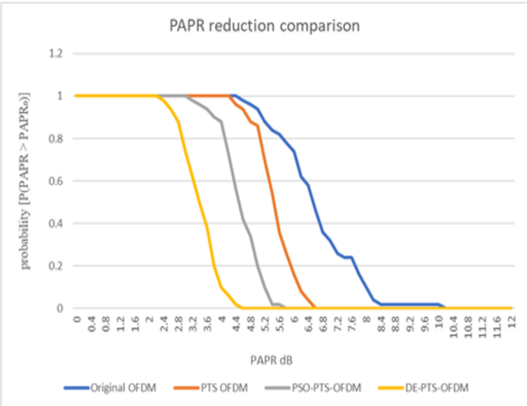

Fig.13 PAPR performance comparison of original OFDM vs PTS, PSO-PTS and DE-PTS techniques

3.11 BER Performance Comparison of PAPR Reduction Techniques

The figure presents the BER performance versus SNR for the original OFDM, PTS, PSO-PTS, and DE-PTS systems. All PAPR reduction methods maintain similar or slightly improved BER compared to original OFDM, with DE-PTS achieving the lowest BER and enhanced signal reliability.

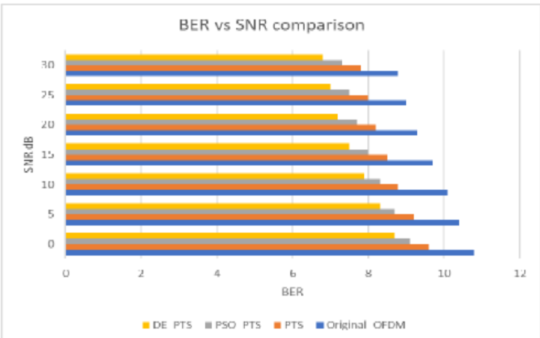

Fig.14 Bit Error Rate vs SNR for original OFDM and PTS, PSO-PTS, and DE-PTS techniques

3.12 Spectral Efficiency Comparison of PAPR Reduction Techniques

The figure shows the spectral efficiency variation with SNR for PTS, PSO-PTS, and DE-PTS based OFDM systems. DE-PTS achieves the highest spectral efficiency, followed by PSO-PTS and PTS, demonstrating improved bandwidth utilization through optimization-based PAPR reduction.

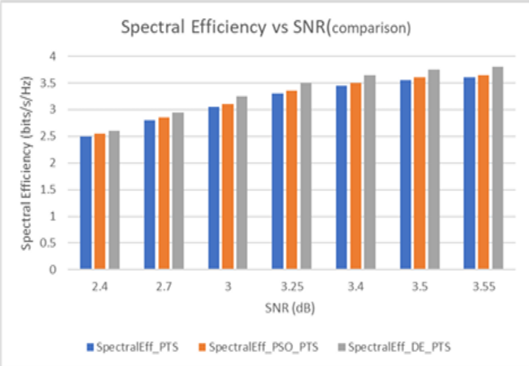

Fig.15 Spectral Efficiency versus SNR for PTS, PSO-PTS, and DE-PTS techniques

3.13 Spectral Efficiency: DE-PTS vs Original OFDM

The figure compares the spectral efficiency of the original OFDM and DE-PTS optimized OFDM systems over varying SNR values. The DE-PTS scheme consistently achieves higher spectral efficiency, indicating improved bandwidth utilization due to reduced distortion and enhanced power efficiency.

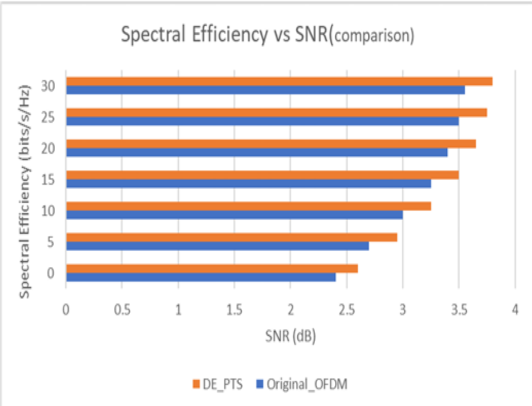

Fig.16 Spectral Efficiency comparison between DE-PTS optimized and original OFDM systems across different SNR values.

3.14 Performance Metrices

Parameter	Original OFDM	PTS	PSO-PTS	DE-PTS
PAPR (dB)	~7.8 dB	~6.1 dB	~5.7 dB	~5.3 dB
PAPR Reduction (%)	-	21.8 %	26.9 %	32.1 %
BER (at SNR = 15 dB)	0.012	0.010	0.009	0.008
Spectral Efficiency (bits/s/Hz)	2.95	3.00	3.02	3.05
Algorithm Complexity	Low	High	Medium	Medium-Low
Overall Performance	Baseline	Good	Better	Best

Table.3.1 Comparison table of PAPR Reduction Techniques in OFDM Systems.

The above table 3.1, provides a consolidated performance comparison of the studied PAPR reduction techniques. It quantitatively demonstrates that while all PTS-based methods effectively reduce PAPR and improve performance over the original OFDM, the DE-PTS technique achieves the best overall results, offering the lowest PAPR (~5.3 dB), lowest BER, highest spectral efficiency, and a favourable medium-low computational complexity.

4. Conclusion

This work investigated Peak-to-Average Power Ratio (PAPR) reduction in Orthogonal Frequency Division Multiplexing (OFDM) systems using Partial Transmit Sequence (PTS) and its optimization-based variants, namely Particle Swarm Optimization-based PTS (PSO-PTS) and Differential Evolution-based PTS (DE-PTS). Performance was evaluated in terms of PAPR reduction, Bit Error Rate (BER), and spectral efficiency. Simulation results show that all PAPR reduction techniques significantly outperform conventional OFDM, with PTS achieving moderate PAPR reduction at the expense of high computational complexity. PSO-PTS improves this trade-off by efficiently optimizing phase factors with reduced complexity. Among the evaluated methods, DE-PTS demonstrates superior performance, achieving the lowest PAPR (≈5.3 dB), improved BER, and the highest spectral efficiency. These results confirm that optimization-based PTS techniques provide an effective and practical solution for enhancing OFDM system efficiency, reliability, and power amplifier linearity.

5. Future Work

While the proposed methods effectively reduce PAPR and improve overall OFDM performance, further enhancements can be achieved by integrating Reconfigurable Intelligent Surface (RIS) technology. Future work will focus on incorporating RIS with the DE-PTS–optimized OFDM system to enhance signal coverage, energy efficiency, and communication reliability in multi-user environments. By dynamically controlling the wireless propagation channel through programmable reflecting elements, RIS is expected to improve spectral efficiency, mitigate fading effects, and reduce transmit power requirements. The combined RIS and PAPR-optimized OFDM framework has strong potential for supporting emerging 6G applications, including massive MIMO, Internet of Things (IoT), and smart city communication infrastructures, enabling an energy-efficient and high-performance next-generation wireless network architecture.

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