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SLM-Based PAPR Reduction in OFDM System Using Four Distinct Matrices

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Abstract:

Orthogonal Frequency Division Multiplexing (OFDM) has been extensively used in contemporary wireless communications because of its high spectral efficiency. However, high peak to average power ratio (PAPR), which increases system complexity in OFDM. Selected mapping (SLM) - based methods are promising solutions to reduce the high PAPR in OFDM signals. In SLM, phase sequences are used to generate alternative signals from the input sequence. Then, the signal with low PAPR is selected for transmission. In the present work, four distinct matrices, such as the Parter matrix, Lotkin matrix, Lehmer matrix, and Riemann matrix are employed in conventional SLM techniques. These matrices generate alternative signals from the input data sequence. Then, PAPR of all modified signals is computed, and the signal, exhibiting low PAPR is transmitted. The proposed method achieved 9 dB of PAPR reduction gain over the conventional SLM method. The performance of the present work was evaluated using the complimentary cumulative distribution function (CCDF), and the results confirm that the PAPR reduction performance outperformed existing methods.

Keywords: OFDM, PAPR, SLM, DCT.

1. Introduction

Fifth generation (5G) networks face substantial challenges in efficiently exploiting limited spectrum resources due to the exponential growth of wireless devices [1]. OFDM has emerged as a pivotal solution for 5G wireless applications, offering higher spectral efficiency by partitioning the available bandwidth into multiple orthogonal subcarriers. Compared to traditional single- carrier modulation techniques, OFDM confirms effective spectrum utilization, making it essential for meeting the high data rate demands of 5G networks. However, when multiple subcarriers with different phases are added into a single signal, the PAPR of rises. This makes the OFDM more susceptible to non-linear distortions in power amplifiers, reducing power efficiency. Hence, reducing high PPAR has become a challenging research area. SLM is a promising solution as it does not introduce distortion into the signal, unlike other techniques like clipping In SLM scheme, independent phase sequences are used to generate alternative signals, and the signal with low PAPR is chosen for transmission. Gupta et. al. [2] proposed a DCT-based SLM method to control the PAPR. The method also yields significant gains in PAPR reduction, as demonstrated in Section III. The Hadamard matrix-based SLM technique [3] presented similar performance with efficient implementation. Based on the insights provided in the literature, we proposed an SLM technique in which the alternative signals are generated using four distinct matrices, such as the Parter matrix, Lotkin matrix, Lehmer matrix, and Riemann matrix.

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2. Research Problem

The research problem focuses on developing effective working technology approaches for the social engineering attacks mitigation using AI (artificial intelligence). Traditional cybersecurity strategies, such as firewalls, antivirus software, and IPS (Intrusion Prevention Systems) are often ineffective in identifying and blocking social engineering attacks as they limit themselves to static rules and signatures. The human factor becomes the weakest point in the security walls, as the technical protections are bypassed through the manipulation of an individual by the attacker who uses the user's psychological vulnerabilities to achieve their aims [3]. Thus, the study identifies the problem at hand that is creating offensive and defensive strategies that make use of artificial intelligence to discover normal behavior, notice abnormalities and impede social engineering attacks in immediate time. Through tackling this research issue, AI Sentry strives to bring about changes in cyber invasive engineering practices and to make communities, organizations and critical infrastructure resistant to social engineering attacks.

A. OFDM System Model

An OFDM signal, x(t), derived from multiple orthogonal subcarriers, each modulated by a symbol from the input data sequence X(n), can be represented as [2].

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X(n) e^{j\frac{2\pi nt}{N}}, 0 \le t \le T-1 \quad (1)$$

Where, N = number of subcarriers, spaced by $\Delta f = \frac{1}{NT}$ and symbol period = T. The Eq. (1) can be produced using the N-point Inverse Fast Fourier Transform (IFFT).

B. Peak to Average Power Ratio

According to Eq. (1), the OFDM signal is the addition of several sinusoids with varying phases. If all signals are combined with the same phases, it can lead to high PAPR. PAPR is the ratio of the max. instantaneous power to avg. power of the signal [4].

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

When the OFDM signal with high PAPR is received at the receiver, it needs high dynamic range power amplifiers. If such power amplifiers are not used at the receiver, it can lead to nonlinear distortions.

C. Analysis of PAPR using CCDF

CCDF is the probability of OFDM signal's PAPR exceeds a threshold γ [5].

$$Pr(PAPR > \gamma) = 1 - (1 - e^{-\gamma})^N \quad (3)$$

The PAPR reduction performance is computed using Eq. (3).

Selected Mapping-based Method

As depicted in Fig. 1, initially, the input serial data is converted into a 'U' number of parallel streams. Each data stream is multiplied by a unique phase factor, generating a U number of modified signals of the input.

Later, each modified signal undergoes an N-point IFFT. The PAPR of all modified signals are computed, and the signal, having minimum value, is chosen for transmission [5-10].

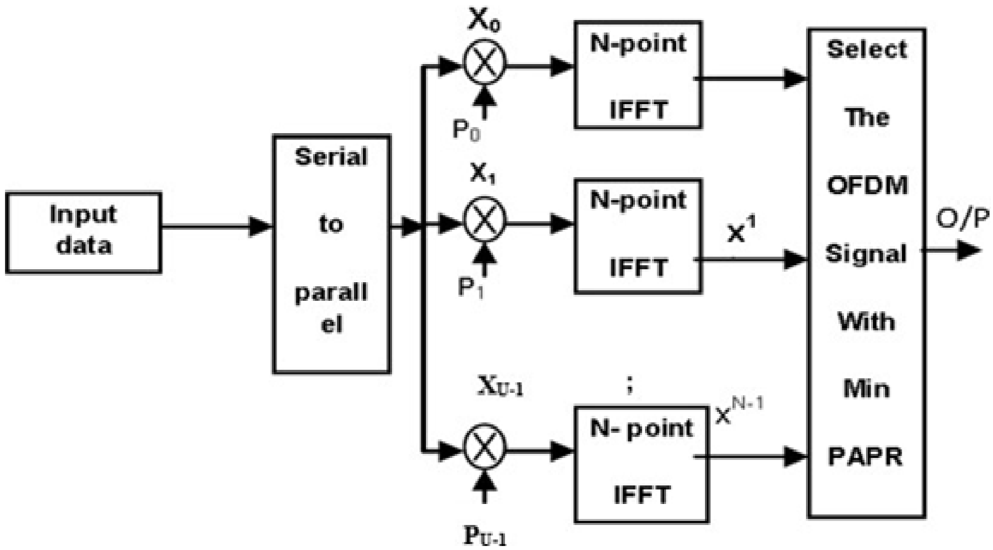


Figure-1 Block diagram of SLM Technique

The rest of this paper is arranged as follows. Section II presents the proposed SLM based OFDM system. The results are presented, and the performance of the proposed method is discussed in Section III. Finally, Section IV concludes the present work

3. Proposed SLM-Based OFDM System

The proposed SLM - based method in OFDM system is portrayed in Fig. 2. It employs four distinct matrices, such as the Parter matrix, Lotkin matrix, Riemann matrix, and Lehmer matrix, within the SLM technique to achieve the objective of the present work.

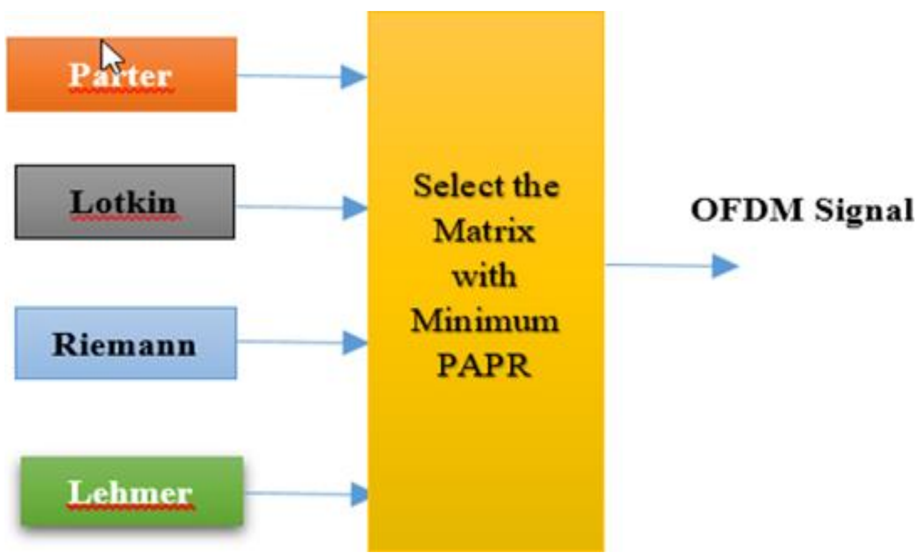


Figure-2 Block Diagram of the Proposed Method SLM based method in OFDM System

Each row of the matrix in the present work generates a different version of the signal according to Eq. (1). The PAPR of all alternate signals is computed according to Eq. (2). Then, the signal with the lowest PAPR is selected for transmission.

1. Parter Matrix

In the Parter matrix, each element can be defined as [11].

It is basically a variant of Cauchy Matrix. Most of the singular values of P are very close to pi. An 8x8 Parter matrix is shown below.

$$P(i,j) = \frac{1}{(i-j+0.5)} \tag{4}$$

$$\begin{bmatrix} 2.0000 & -2.0000 & -0.6667 & -0.4000 & -0.2857 & -0.2222 & -0.1818 & -0.1538 \\ 0.6667 & 2.0000 & -2.0000 & -0.6667 & -0.4000 & -0.2857 & -0.2222 & -0.1818 \\ 0.4000 & 0.6667 & 2.0000 & -2.0000 & -0.6667 & -0.4000 & -0.2857 & -0.2222 \\ 0.2857 & 0.4000 & 0.6667 & 2.0000 & -2.0000 & -0.6667 & -0.4000 & -0.2857 \\ 0.2222 & 0.2857 & 0.4000 & 0.6667 & 2.0000 & -2.0000 & -0.6667 & -0.4000 \\ 0.1818 & 0.2222 & 0.2857 & 0.4000 & 0.6667 & 2.0000 & -2.0000 & -0.6667 \\ 0.1538 & 0.1818 & 0.2222 & 0.2857 & 0.4000 & 0.6667 & 2.0000 & -2.0000 \end{bmatrix}$$

2. Lotkin Matrix

The Lotkin matrix can be obtained using Hilbert matrix with its first row changed to all '1'. The formula for Hilbert Matrix is given by [12].

$$H_n = H_{ij} \tag{5}$$

Where, $hij = \frac{1}{i+j-1}$

An 8x8 Lotkin matrix is shown below.

$$\begin{bmatrix} 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 \\ 0.5000 & 0.3333 & 0.2500 & 0.2000 & 0.1667 & 0.1429 & 0.1250 & 0.1111 \\ 0.3333 & 0.2500 & 0.2000 & 0.1667 & 0.1429 & 0.1250 & 0.1111 & 0.1000 \\ 0.2500 & 0.2000 & 0.1667 & 0.1429 & 0.1250 & 0.1111 & 0.1000 & 0.0909 \\ 0.2000 & 0.1667 & 0.1429 & 0.1250 & 0.1111 & 0.1000 & 0.0909 & 0.0833 \\ 0.1667 & 0.1429 & 0.1250 & 0.1111 & 0.1000 & 0.0909 & 0.0833 & 0.0769 \\ 0.1429 & 0.1250 & 0.1111 & 0.1000 & 0.0909 & 0.0833 & 0.0769 & 0.0714 \\ 0.1250 & 0.1111 & 0.1000 & 0.0909 & 0.0833 & 0.0769 & 0.0714 & 0.0667 \end{bmatrix}$$

3. Riemann Matrix

Riemann matrix can be obtained by eliminating the first row and column of the matrix A [13].

$$A(i,j) = \{i - 1; if\ i\ divides\ j - 1; otherwise \tag{6}$$

An 8x8 Riemann matrix is shown below.

$$\begin{bmatrix} 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 2 & -1 & 2 & -1 & 2 & -1 & 2 \\ -1 & -1 & 3 & -1 & 3 & -1 & 3 & -1 \\ -1 & -1 & -1 & 4 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 5 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & 6 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & 7 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & 8 \end{bmatrix}$$

4. Lehmer Matrix

In the Lehmer matrix, each element can be defined as [14,15, 16]

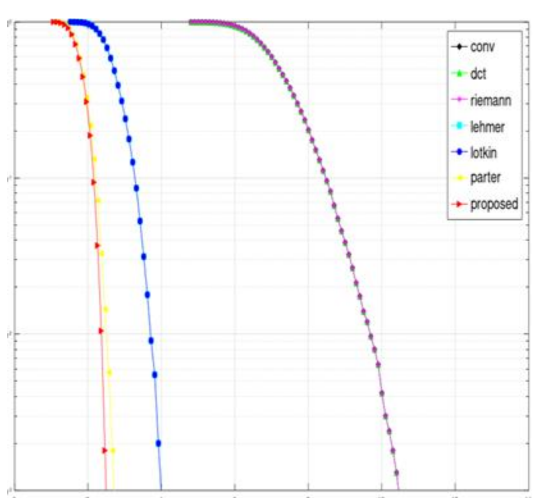
$$A(i,j) = \{\frac{i}{j}; j \geq i\, \frac{j}{i}; j < i \tag{7}$$

An 8x8 Lehmer matrix is shown below.

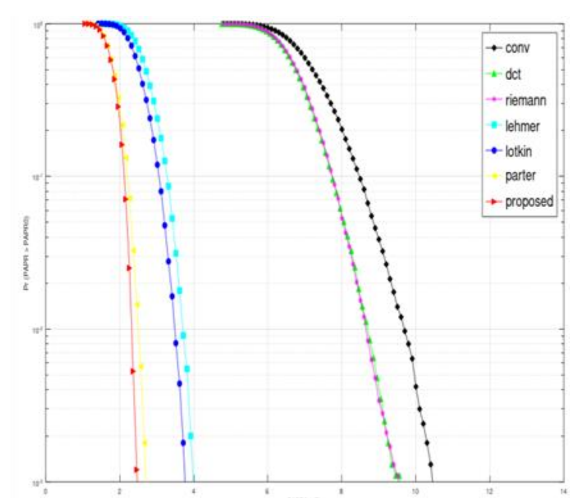
$$\begin{bmatrix} 1.0000 & 0.5000 & 0.3333 & 0.2500 & 0.2000 & 0.1667 & 0.1429 & 0.1250 \\ 0.5000 & 1.0000 & 0.6667 & 0.5000 & 0.4000 & 0.3333 & 0.2857 & 0.2500 \\ 0.3333 & 0.6667 & 1.0000 & 0.7500 & 0.6000 & 0.5000 & 0.4286 & 0.3750 \\ 0.2500 & 0.5000 & 0.7500 & 1.0000 & 0.8000 & 0.6667 & 0.5714 & 0.5000 \\ 0.2000 & 0.4000 & 0.6000 & 0.8000 & 1.0000 & 0.8333 & 0.7143 & 0.6250 \\ 0.1667 & 0.3333 & 0.5000 & 0.6667 & 0.8333 & 1.0000 & 0.8571 & 0.7500 \\ 0.1429 & 0.2857 & 0.4286 & 0.5714 & 0.7143 & 0.8571 & 1.0000 & 0.8750 \\ 0.1250 & 0.2500 & 0.3750 & 0.5000 & 0.6250 & 0.7500 & 0.8750 & 1.0000 \end{bmatrix}$$

5. Results and Discussion

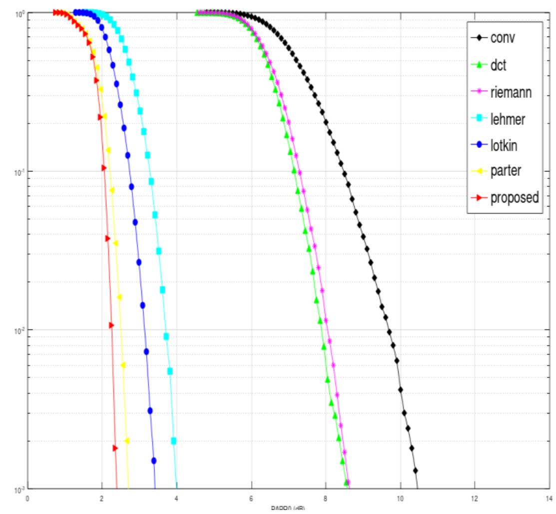
The present work was conducted using MATALB software. We considered 128 subcarriers with an up-sampling factor of 4, resulting in a matrix size of 512. Binary phase shift keying is employed in the present work. The PAPR reduction performance is evaluated using CCDF plots.



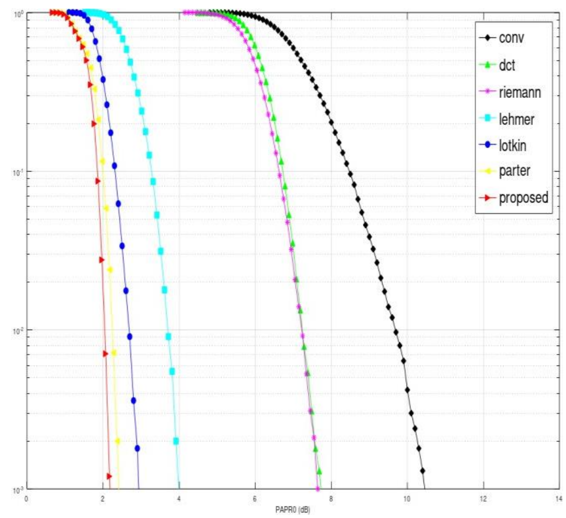
(a)



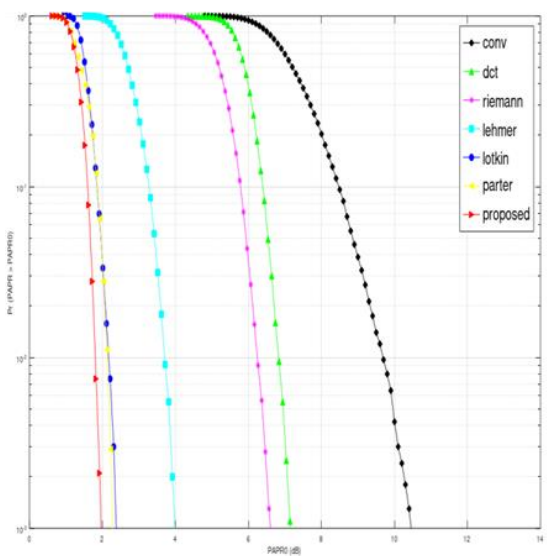
(b)



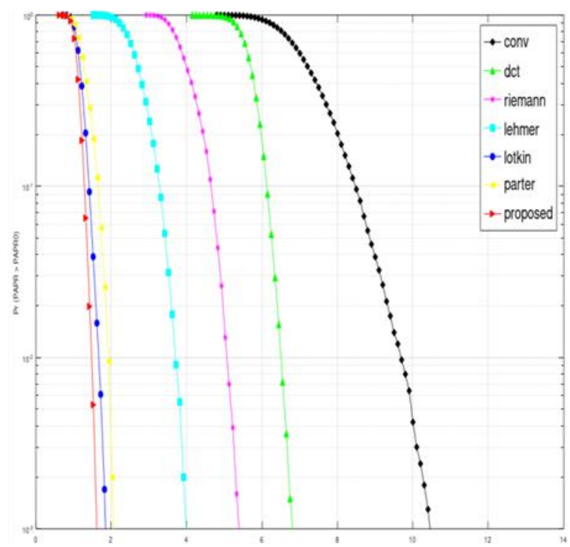
(c)



(d)



(e)



(f)

It can be seen that for all values of U, the curve corresponding to the present work (red color) is shifted downward, which indicates that the PAPR reduction performance is outperformed by all methods. The results of the CCDF plots are summarized in Table 1.

Table-1 PAPR (in dB) performance of the proposed method for various values of U

U	Conventional	[2]	Proposed Method
1	10.5	10.5	2.4
2	10.5	9.5	2.4
4	10.5	8.6	2.3
8	10.5	7.7	2.2

16	10.5	7.2	2.0
32	10.5	6.8	1.5

It can be seen that as the U increases, the proposed method consistently achieves lower PAPR values. For instance, when U = 1, the PAPR is dramatically reduced from 10.5 dB (both in the conventional and DCT methods) to 2.4 dB. Therefore, PAPR reduction gain of 8.1 dB (10.5 dB-2.4 dB) is achieved for U = 1, when compared with conventional method. When the U increases to 32, the reduction gain reaches 9 dB. It is also perceived that the present work outperforms the DCT method [2]. The PAPR reduction performance can be perceived in bar graphs (Fig. 4).

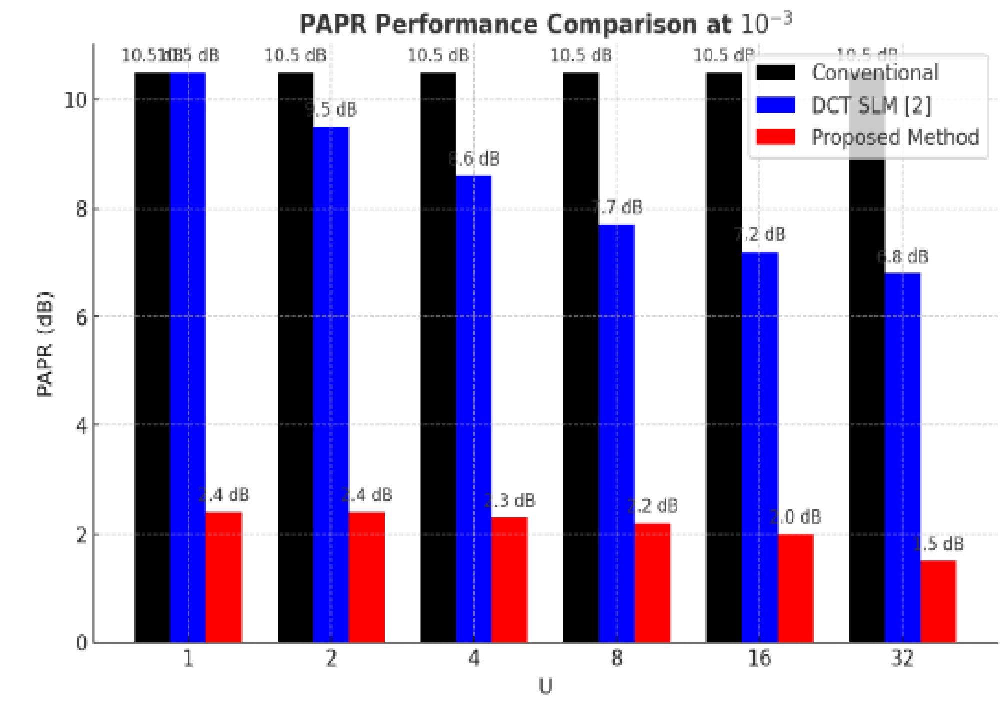


Figure-4 PAPR values for Conventional Method, DCT and Proposed Method

PAPR reduction gain performance of the DCT and the proposed method over conventional method is depicted in Fig. 5.

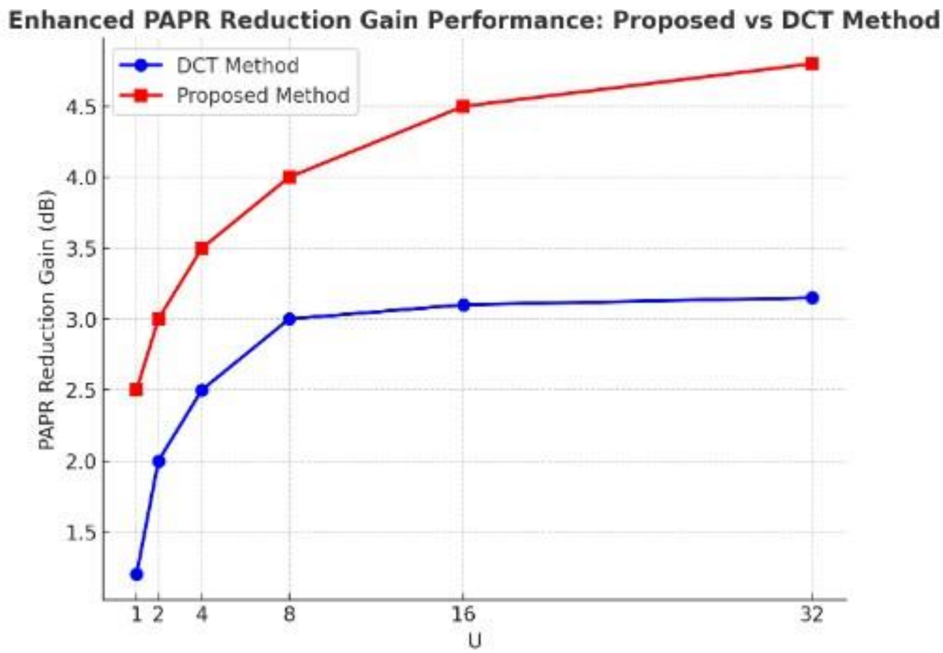


Figure-5 PAPR Reduction Gain Values of DCT and Proposed Method over Conventional Method

According to Figs. 4 and 5, the PAPR performance of the proposed method, is superior when compared with the conventional method, and the DCT-SLM for different values of U [2].

6. Conclusion and Future Scope

The proposed SLM - based OFDM system was implemented by using four distinct matrices, such as the Parter matrix, Lotkin matrix, Riemann matrix, and Lehmer matrix, to reduce the PAPR in an OFDM system. The performance of the present work was discussed using CCDF plots. The proposed method demonstrates a significant reduction in PAPR across all values of U when compared to both the conventional and DCT-based SLM method. The proposed method consistently achieves lower PAPR values, particularly as the U increases. For U = 32, the PAPR is reduced to 1.5 dB, which is a substantial improvement over the conventional method, achieving a reduction gain of 9 dB. Moreover, the DCT-based method also improves PAPR but still lags behind the proposed method. This determines that the proposed method is highly efficient for minimizing PAPR in OFDM. The future scope of this work can be extended, integrating with deep learning methods, such as convolutional neural networks to further enhance PAPR reduction in OFDM systems. The networks may be trained to select optimal matrices, enhancing PAPR performance. Implementing deep learning architecture for PAPR reduction in real-time processing, lead to substantial advancements in 5G applications.

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8.Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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