MIMO OFDM PAPR Reduction Techniques

P. Sarthika[1]; S. Avanthika[2]; R. Karthikeya[3]; M. Abhinav Reddy[4];
Y. Prathyusha[5]; D. Ramadevi[6]

[5;6](Assistant Professor)
Teegala Krishna Reddy Engineering College and Technology

Publication Date: 2025/05/10

Abstract: Wireless communication plays a vital role in modern life. Over time, and with the rise in user demands, the field of communication has experienced significant advancements. To enhance transmission efficiency, single-carrier wave systems are increasingly being replaced by multi-carrier wave technologies such as MIMO-OFDM, which has become widely adopted. The growing need for high-speed and reliable wireless communication is being addressed through the deployment of multiple antennas at both the base station and the user end. This multi-antenna configuration significantly enhances system capacity, particularly for internet and multimedia services, while also improving coverage and reliability. In a Multiple Input Multiple Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) system, the Peak-to-Average Power Ratio (PAPR) presents several challenges that can negatively affect performance. This paper explores the concept of PAPR in OFDM systems, its impact on system efficiency, and reviews various methods designed to mitigate PAPR based on specific application requirements. These techniques aim to reduce PAPR without compromising bandwidth efficiency, Bit Error Rate (BER) performance, or the Complementary Cumulative Distribution Function .

Keywords: *Amplitude Clipping, Cyclic Prefix, Filtering IDFT, PAPR, MIMO OFDM.*

How to Cite: P. Sarthika; S. Avanthika; R. Karthikeya; M. Abhinav Reddy; Y. Prathyusha; D. Ramadevi (2025). MIMO OFDM PAPR Reduction Techniques. *International Journal of Innovative Science and Research Technology*, 10(4), 3119-3126. https://doi.org/10.38124/ijisrt/25apr1957

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a popular multicarrier modulation technique, highly regarded for its superior spectral efficiency, straightforward implementation, and excellent resilience to multipath fading and nonlinear distortions. These strengths have positioned OFDM as a foundational element in contemporary wireless communication systems. However, one of the main limitations of OFDM is its high Peak-to-Average Power Ratio (PAPR), which complicates both analog-to-digital (ADC) and digital-to-analog (DAC) conversions and negatively impacts the efficiency of RF power amplifiers.

To address this limitation, various regulatory and application-specific power constraints are enforced to prevent high signal peaks. While these constraints help reduce excessive peak emissions, they also limit the transmission range of multicarrier signals. Consequently, RF power amplifiers often operate in a non-linear region, leading to reduced energy efficiency, shortened battery life, and diminished system performance thus offsetting the benefits of using multicarrier modulation.

Several methods have been proposed to alleviate the impact of high PAPR. These include amplitude clipping, clipping combined with filtering, Partial Transmit Sequence (PTS), and interleaving techniques. While such strategies can effectively reduce PAPR levels, they typically introduce compromises such as increased power consumption, elevated bit error rates (BER), reduced data rates, and higher computational demands.

In real-world systems, power limitations are a key design concern. Since OFDM transmits data across numerous independently modulated subcarriers, their combination can generate large peaks in instantaneous signal power relative to the average. To accommodate these peaks, High Power Amplifiers (HPAs) must support a broad linear range, which adds to their cost, size, and complexity. When constrained to operate near saturation, HPAs may cause in-band distortion and out-of-band (OOB) radiation, the latter being particularly problematic in wireless applications due to strict adjacent channel interference (ACI) regulations.

Additionally, the large dynamic range required by OFDM signals increases the design complexity and cost of DACs and ADCs. As OFDM technology becomes increasingly integral to both current and future wireless systems, ongoing research focuses on developing advanced solutions to overcome these performance limitations.

Another challenge OFDM systems face is their sensitivity to frequency offsets, which makes them more vulnerable compared to single-carrier systems. Since OFDM

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr1957

relies on precise subcarrier spacing, even minor frequency mismatches caused by Doppler shifts or oscillator frequency discrepancies can disrupt the orthogonality of subcarriers. This results in Inter-Carrier Interference (ICI), making signal demodulation and detection more complex.

➢ *PAPR in OFDM Systems*

The Peak-to-Average Power Ratio (PAPR) quantifies the ratio between the highest instantaneous power and the average power of an OFDM signal. In multicarrier transmissions, high PAPR occurs when the phases of different subcarriers align, leading to constructive interference and the formation of sharp signal peaks.

Due to the involvement of many subcarriers with different phases, the OFDM waveform often exhibits peaks significantly higher than its average power level. When N subcarriers align in phase, the resulting peak power can reach up to N times the signal's average power. This makes OFDM signals highly susceptible to the nonlinear effects of RF power amplifiers.

In a typical OFDM transmission, a sequence of N symbols, denoted as $\{X_k \mid k = 0, 1, ..., N-1\}$, is used to modulate N orthogonal subcarriers $\{f_k \mid k = 0, 1, ..., N-1\}$. These subcarriers are spaced such that $f_k * f_k = \Delta f$, with $\Delta f = 1/NT$, where T is the base symbol duration. The time-domain OFDM signal is expressed as:

$$x(t) = \Sigma X_k \cdot e^{\wedge}(j2\pi f_k t) \text{ for } 0 < t < NT$$

Here, x(t) represents the complex baseband version of the signal. The PAPR is computed as the ratio of the signal's peak instantaneous power to its average power over a symbol period. For modeling nonlinear effects in RF systems, such as those introduced by Solid-State Power Amplifiers (SSPAs), specialized nonlinear models are employed.

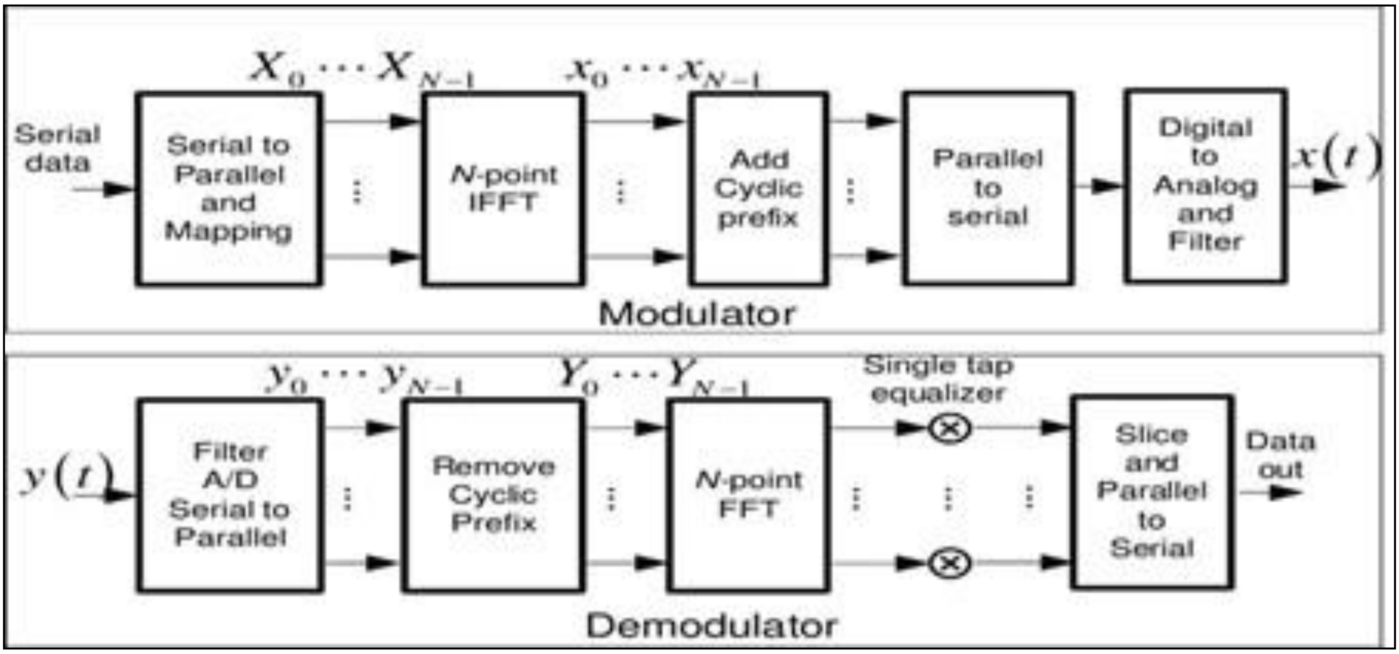

Fig 1 Block Diagram of OFDM

➢ *Peak-to-Average Power Ratio (PAPR) in OFDM Systems*

PAPR quantifies the difference between the highest instantaneous power and the average power of an OFDM signal. In multicarrier communication systems like OFDM, high PAPR arises due to the lack of phase alignment across subcarriers. Since each subcarrier's phase evolves independently, there are moments when all subcarriers align in phase, leading to constructive interference. This phenomenon produces significant spikes in the signal amplitude.

This problem is especially relevant in OFDM systems, which depend on numerous individually modulated subcarriers. When these subcarriers momentarily align, their amplitudes combine, producing power levels that can be significantly greater than the average. In the worst-case scenario, with perfect phase alignment across all N subcarriers, the peak power can be N times the average power. These power surges make OFDM signals vulnerable to nonlinear distortions, particularly when transmitted through power amplifiers.

In a standard OFDM framework, N data symbols $\{X_k \mid k = 0, 1, ..., N-1\}$ modulate N orthogonal subcarriers $\{f_k \mid k = 0, 1, ..., N-1\}$. To maintain orthogonality, the subcarriers are spaced such that $\Delta f = 1/(NT)$, where T is the symbol duration. The resulting time-domain composite signal can be described by:

$$x(t) = \Sigma X_k \cdot e^{\wedge}(j2\pi f_k t), \text{ for } 0 < t < NT$$

Here, x(t) denotes the complex baseband signal, and the PAPR is defined as the ratio of the signal's peak instantaneous power to its average power over this interval.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr1957

When transmitting through high-power amplifiers like Solid-State Power Amplifiers (SSPAs), nonlinear behavior becomes a concern. The amplifier's output can be modeled as:

V_out = V_in / (1 + (|V_in| / V_sat)^(2F))^(1/2F)

Where:

V_in and V_out represent the input and output voltages,

V_sat is the saturation voltage level,

F is a parameter that controls how gradually the amplifier shifts from linear to saturated operation.

II. TECHNIQUES FOR REDUCING PAPR

High PAPR forces amplifiers to operate in non-linear regions, causing spectral spreading and performance degradation due to increased Bit Error Rate (BER). While reducing the average transmission power is an option, it negatively affects the Signal-to-Noise Ratio (SNR), which can worsen the BER. Hence, strategies that reduce peak power without compromising signal quality are preferred.

A. Amplitude Clipping and Filtering

A straightforward and commonly applied technique is amplitude clipping, where the signal's amplitude is limited to a predefined Clipping Level (CL). Values exceeding this threshold are clipped, while lower amplitudes remain unchanged.

➢ *However, this Method Introduces:*

In-band distortion, which degrades BER and cannot be easily removed, Out-of-band radiation, which spills into adjacent frequencies and can be mitigated with filtering.

To address these distortions, oversampling is often utilized by applying a longer Inverse Fast Fourier Transform (IFFT), which pushes some of the distortion outside the essential frequency band. Filtering can then suppress this distortion while maintaining spectral integrity. Nonetheless, a side effect known as peak regrowth may occur, where the signal peaks slightly rise after filtering.

To improve this method, researchers have developed enhanced approaches such as iterative clipping and filtering or filter design via convex optimization. These advanced methods often achieve substantial PAPR reduction in just 1–2 iterations, in contrast to the traditional techniques that might require up to 16 iterations.

➢ *Simulation Findings show how Different Clipping Ratios (CRs) affect Performance:*

A lower CR (e.g., 1 dB) significantly reduces the Complementary Cumulative Distribution Function (CCDF), which indicates the probability of large peaks.

However, this also increases BER, showing a clear trade-off between effective PAPR reduction and maintaining good signal fidelity.

- *Peak Windowing Technique*

The peak windowing method offers a gentler alternative to hard clipping. Instead of abruptly limiting high amplitudes, this technique applies a tapering effect using windowing functions like Hanning, Hamming, or Kaiser windows, known for their favorable spectral characteristics.

This method identifies signal segments with high amplitude and applies the window function to smooth and attenuate those peaks. As a result, it introduces less distortion within the main frequency band and better preserves signal integrity. Compared to basic clipping, peak windowing leads to lower in-band noise and maintains higher signal quality.

B. Selective Mapping

Selective Mapping (SLM) is a widely adopted technique for addressing the issue of high Peak-to-Average Power Ratio (PAPR) in OFDM systems. The strategy involves generating multiple candidate signals from the same original data block and selecting the one with the lowest PAPR for transmission. This is possible because the PAPR depends on how the various subcarrier signals align and combine in the time domain.

To implement SLM, the original data block denoted as $X = [X_1, X_2, ..., X_{n-1}]$ is multiplied by a set of independently generated phase sequences. These sequences alter the phase of the data without affecting the core information. Each phase sequence can be defined as $P = [P_1(m), P_2(m), ..., P_n(m)]$, where m ranges from 0 to M−1, and M represents the total number of distinct sequences.

After the phase transformation, each modified data block undergoes an Inverse Fast Fourier Transform (IFFT) to convert the frequency-domain data into its time-domain form:

$$X(m) = [X_1(m), X_2(m), ..., X_{n-1}(m)]$$

This yields M different time-domain signals. The system then evaluates the PAPR of each and selects the one with the minimum value for transmission. While this process does introduce additional computational steps, it is highly effective in reducing peak power fluctuations.

The probability that a given signal's PAPR exceeds a specific threshold, z, is measured using the Complementary Cumulative Distribution Function (CCDF):

$$F^{z}_{max}(z) = P(Z_{max} > z) = 1 - F_{max}(z)$$

This function gives a statistical measure of how often a signal'speak exceeds the predefined threshold.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr1957

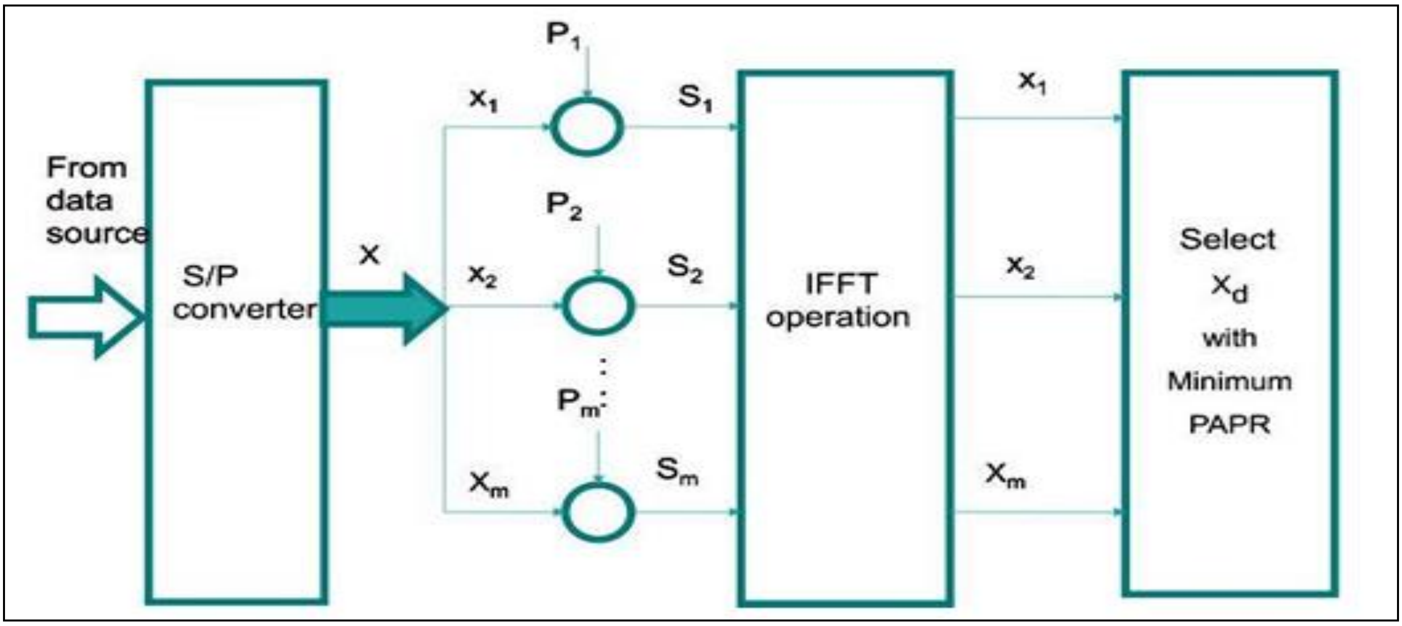

Fig 2 Block Diagram of Selective Mapping Model

C. Partial Transmit Sequence (PTS)

The Partial Transmit Sequence (PTS) technique offers another viable method for reducing PAPR, though it takes a different route than SLM. Rather than applying phase changes to the entire data block, PTS splits the input into several smaller, non-overlapping sub-blocks. Each sub-block is then individually rotated using a specific phase factor.

These phase factors are chosen in such a way that, when the sub-blocks are recombined, the resulting time-domain signal has a significantly reduced peak amplitude. Like in SLM, the phase rotation information must be transmitted to the receiver to ensure accurate signal reconstruction.

PTS generally offers better PAPR performance than SLM, especially when more sub-blocks and phase rotation options are utilized. However, this added effectiveness can come at the cost of increased computational load due to the need for exhaustive phase optimization.

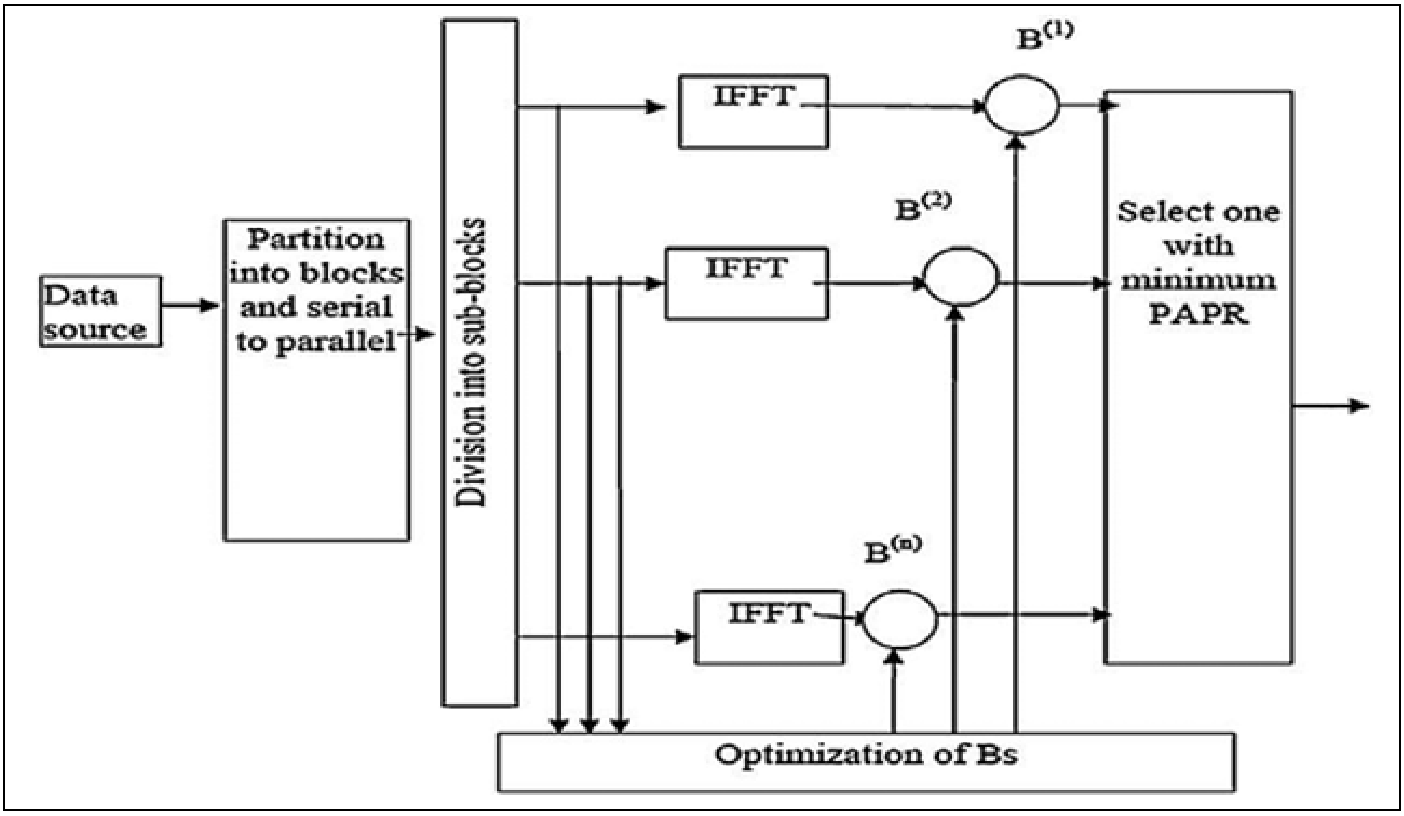

Fig 3 Block Diagram of Partial Transmit Sequence

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr1957

III. PROPOSED APPROACH

This study presents a new companding-based method that aims to strike a balance between two essential goals in wireless communication: lowering the Bit Error Rate (BER) and reducing out-of-band spectral emissions. The approach builds on the SLM framework to lower PAPR, while ensuring that the transmitter's modulator operates in a linear region thereby simplifying hardware requirements.

Traditional PAPR reduction techniques are less effective when applied directly to Universal Filtered Multi-Carrier (UFMC) systems, which differ structurally from standard OFDM. To overcome these limitations, the study introduces a hybrid approach that integrates a Maximal-Minimum (Max-Min) strategy with a Decomposed Selective Mapping (D-SLM) model, specifically tailored for 5G UFMC scenarios.

➢ *Adaptive PAPR Control via Max-Min Strategy:*

This adaptive system dynamically adjusts the PAPR threshold in real time, depending on the data rate requirements. The technique is resilient under varying channel conditions, including Rayleigh and Rician fading. The D-SLM mechanism supports flexible data block segmentation, enabling optimized performance based on network demands.

➢ *Performance Analysis Across Data Conditions:*

The system is tested under two scenarios when the data rate exceeds the permissible PAPR limit, and when it stays within acceptable bounds. Its performance is compared with standard approaches like conventional OFDM, traditional SLM, and UFMC-based D-SLM techniques.

➢ *Efficiency Without Extra Transmission Overhead:*

One of the standout features of the proposed model is that it enhances PAPR reduction while maintaining low computational complexity. Crucially, it avoids the need to transmit additional side information, which reduces latency and overall system overhead.

This section delves into the core principles behind reducing the Peak-to-Average Power Ratio (PAPR) through a hybrid strategy that combines the Max-Min approach with the Decomposition-based Selective Mapping (Decomp-SLM) technique. The simulated system mirrors a conventional Universal Filtered Multi-Carrier (UFMC) configuration, employing 'Nsc' subcarriers across a wide frequency range. Initially, the incoming data stream is modulated using M-ary Quadrature Amplitude Modulation (QAM) with modulation levels of 8, 16, 32, and 64, resulting in complex symbols.

These symbols are then divided into 'B' parallel segments, termed 'Sb', each comprising N-point sequences. The sequences are separated into their respective real and imaginary components, represented as Re{S} and Im{S}, each containing N-1 elements. To minimize PAPR, these components undergo phase vector-based processing optimized for this purpose.

To streamline computation, element-wise operations are expressed in matrix format: SUr = Re{S} ⊗ PU, and SUi =Im{S}⊗PU,where'⊗'denotes element-wise multiplication and 'PU' represents the matrix of phase vectors. These processed signals are passed through Finite Impulse Response (FIR) filters, yielding: XUr = FIR[SUr] and XUi = FIR[SUi].

Following this, the original PAPR value referred to as PAPR_original is determined using the formula: PAPR =10·$\log_{10}$(P_peak/P_avg),where P_peak is the peak instantaneous power and P_avg is the average signal power. Among the candidate signals generated, the one with the lowest PAPR is selected for transmission.

The effectiveness of the hybrid Max-Min and Decomp-SLM method is measured using the Complementary Cumulative Distribution Function (CCDF), which represents the probability that PAPR will exceed a particular threshold, noted as PAPR(p_0). Upon convergence, the system dynamically adapts the PAPR threshold based on the required data rate (denoted as D), where the resulting PAPR is labeled PDP_DPD.

A comparative analysis is also conducted, measuring the performance of the proposed approach against other established schemes such as Dcomp-UFMC-SLM, standard SLM, and traditional OFDM. The tolerable PAPR level is adjusted in line with specific data rate requirements, aided by the Decomp-SLM sub-blocking structure. Notably, a phase vector setting of U = 5 is found to significantly improve the Spectral Power Density (SPD), enabling reliable operation over Rayleigh and Rician fading channels. As it clearly demonstrates superior PAPR suppression at the 10^{-3} probability level when using the Max-Min Decomp-UFMC-SLM method. This improvement stems from a deliberate reduction in phase vector choices specifically U = 3, 5, 7, and 9 contrasted with the Dcomp-UFMC-SLM's usage of U = 4, 6, 8, and 10. Though the Dcomp-UFMC-SLM method performs particularly well at U = 6, it is consistently outperformed by the proposed hybrid solution.

IV. RESULT

The proposed Max-Min Decomp-UFMC-SLM technique exhibits superior performance in reducing PAPR, especially at the 10^{-3} probability level in the CCDF-PAPR domain. This improvement is largely due to the optimized selection of fewer, more effective phase vectors U = 3, 5, 7, and 9 compared to the conventional Dcomp-UFMC-SLM, which uses U = 4, 6, 8, and 10. While Dcomp-UFMC-SLM shows notable gains at U = 6, the proposed method consistently achieves better results.

➢ *Performance Highlights:*

Simulation tests with 1024 subcarriers and 32-QAM modulation revealed the following improvements using the proposed technique:

- A 0.2 dB gain over Dcomp-UFMC-SLM,
- A 0.5 dB gain over traditional SLM,

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr1957

- A substantial 8.2 dB improvement over standard OFDM when using U = 5.

➢ *When Phase Vector U = 7 is used, the Method Continues to Perform well, Offering:*

- A 0.5 dB increase over Dcomp-UFMC-SLM,
- A 2.5 dB boost over SLM,
- An impressive 10 dB enhancement compared to OFDM.

These findings confirm that the Max-Min Decomp-SLM approach is highly effective in suppressing PAPR, especially in high spectral efficiency scenarios with dynamic data rate demands.

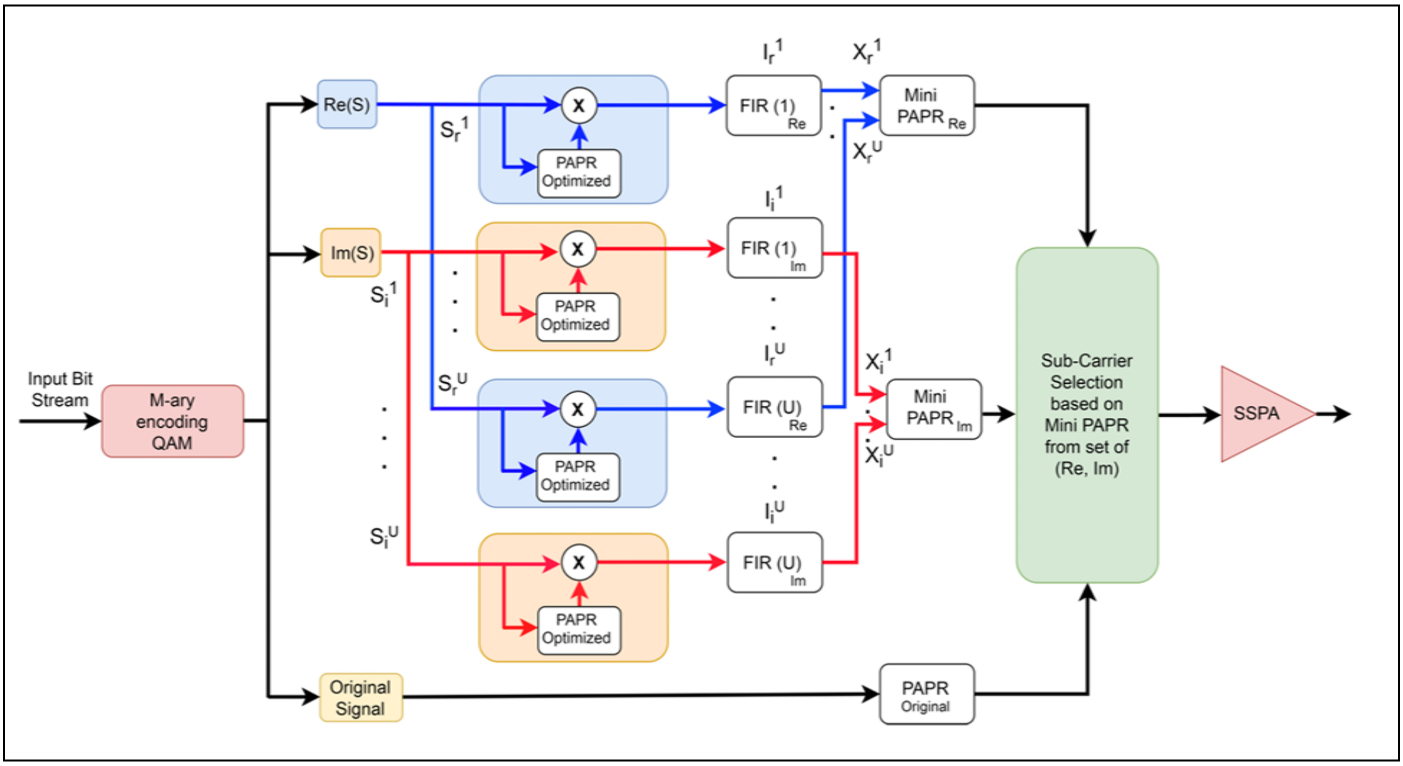

Fig 4 Maximal-Minimum approch Decomposed-SLM Technique

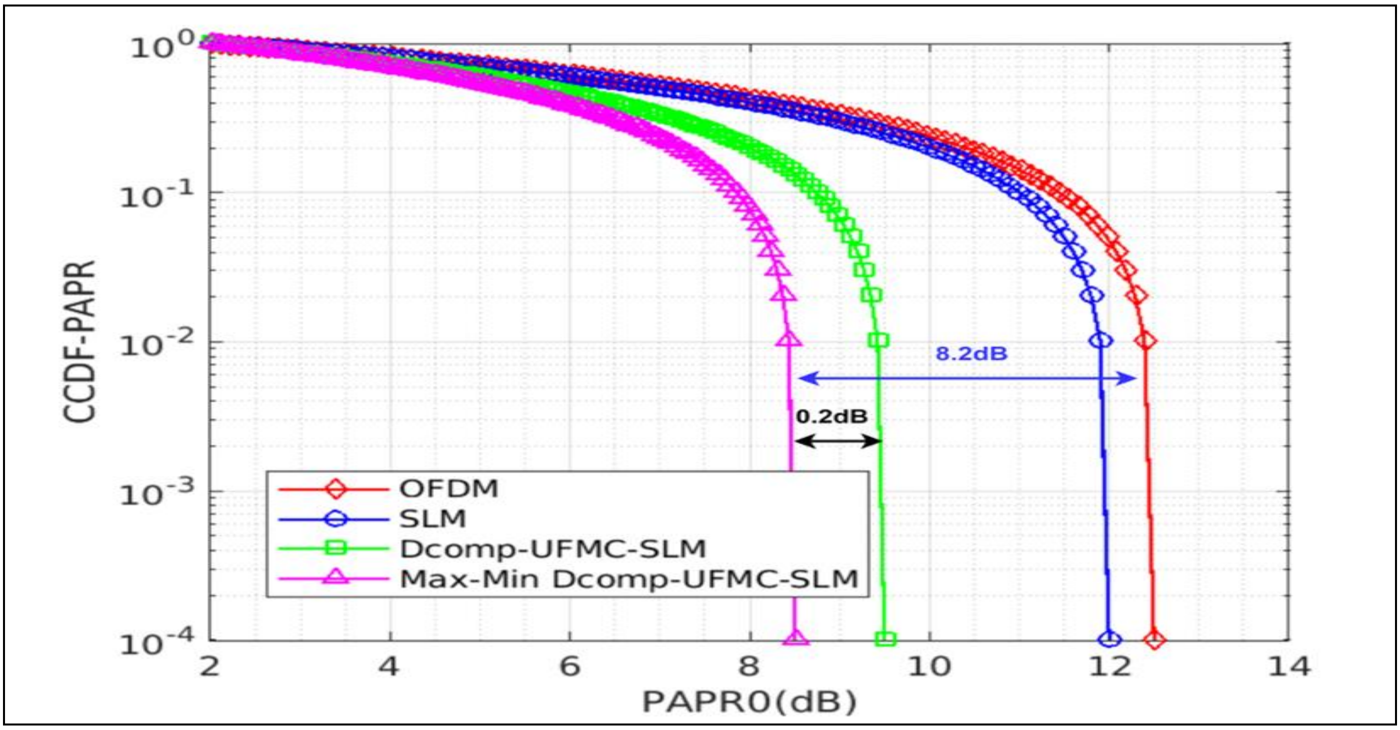

Fig 5 Visualizes the CCDF-PAPR Performance across Various Techniques Including the Proposed Max-Min Method, Dcomp-SLM, Traditional SLM, and OFDM. The Simulations are Conducted using 1024 Subcarriers, 32-QAM Modulation, and Phase Vector U = 5.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr1957

The CCDF-PAPR results for different values of U (specifically 3, 5, 7, and 9) show that U = 5 and U = 7 yield the most significant reductions within the 10^{-3} range of the CCDF-PAPR curve. These results highlight the importance of selecting the right phase vector to meet stringent PAPR thresholds, particularly within the 10^{-3} to 10^{-4} performance range.

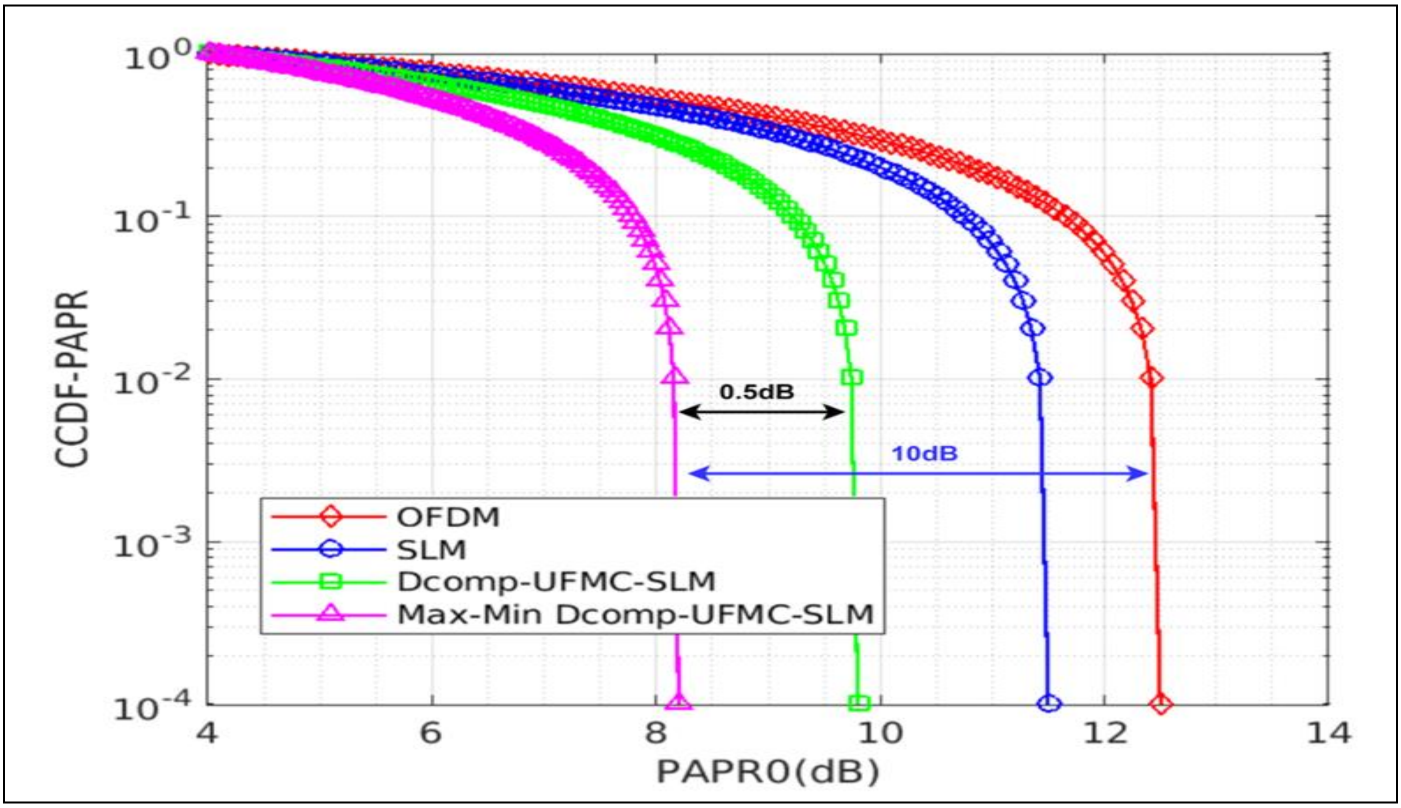

Fig 6 Presents the results under similar conditions, but with phase vector U = 7. The proposed technique continues to outperform the other methods in terms of PAPR reduction..

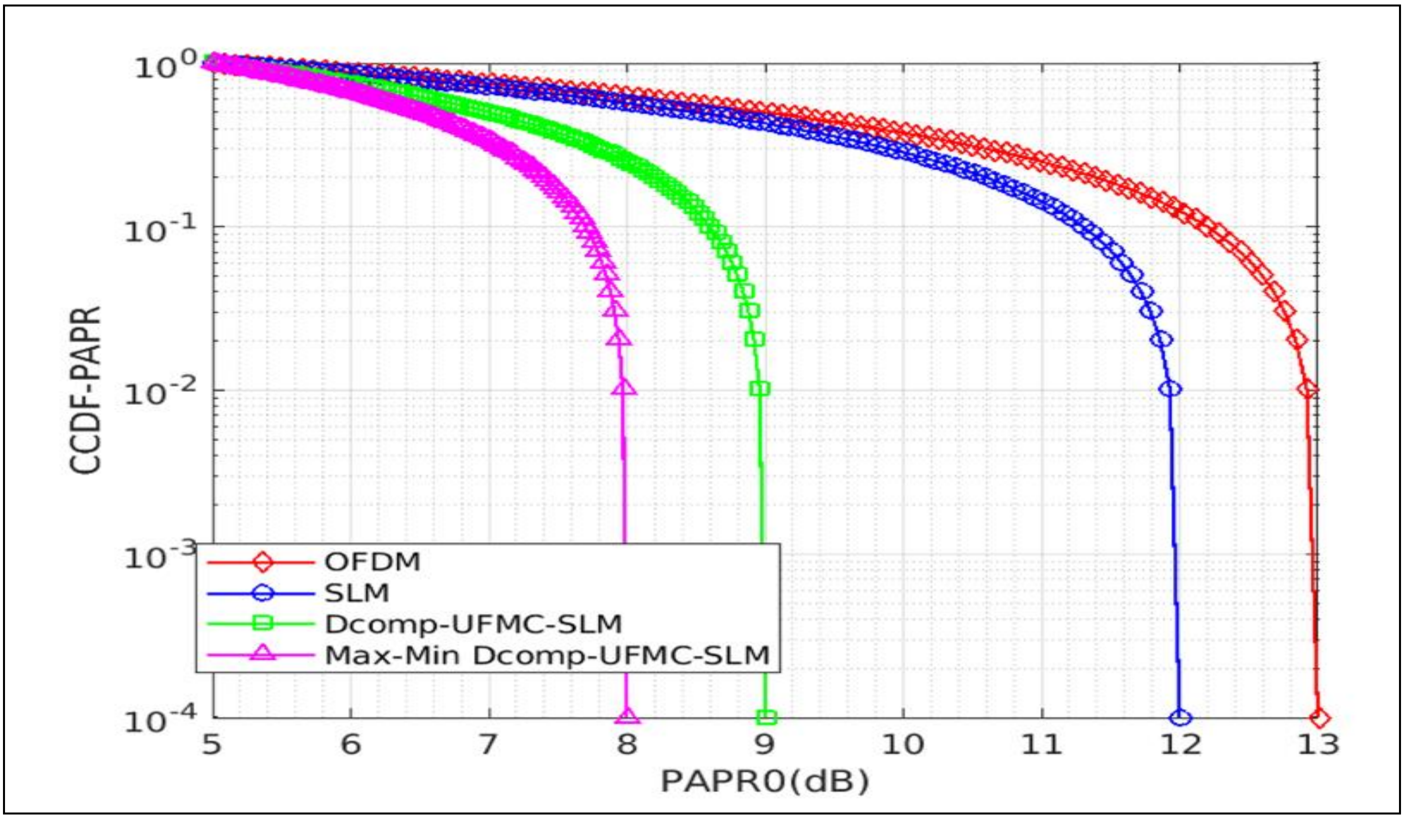

Fig7 Shows a Comprehensive Comparison using Multiple Phase Vectors U = 3, 5, 7, and 9.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr1957

V. CONCLUSION

Multicarrier transmission systems have demonstrated improved performance over single-carrier systems, particularly in terms of data delivery and spectral efficiency. Orthogonal Frequency Division Multiplexing (OFDM), a widely adopted digital multicarrier modulation technique, employs numerous closely spaced orthogonal subcarriers for data transmission. Despite its advantages, a significant drawback of OFDM systems is the high Peak-to-Average Power Ratio (PAPR), especially when input signals exhibit strong correlation.

This study explores critical aspects of PAPR and its influence on OFDM system performance, as well as various mitigation techniques tailored to specific application needs. While these methods can effectively reduce PAPR, they often introduce compromises such as reduced data throughput, increased transmission power requirements, degraded Bit Error Rate (BER) performance, and elevated computational demands.

The paper specifically reviews PAPR reduction strategies in MIMO-OFDM systems, with a focus on approaches that avoid the additional use of inverse Fast Fourier Transforms (IFFTs), which are a hallmark of conventional Partial Transmit Sequence (PTS) methods. Instead, the reviewed techniques emphasize optimized subcarrier and sub-block selection. The proposed filtering-based modification to the system illustrates a viable solution for achieving an improved trade-off between PAPR suppression and computational efficiency.

REFERENCES

[1]. H. Taub, D. L. Schilling, G. Saha, *Principles of Communication Systems by Taub*: Tata McGraw Hill, 2008.
and Practice (2nd ed.): Prentice Hall, 2002.

[2]. S. H. Han, J. H. Lee, “A Summary of Techniques for Reducing Peak-to-Average Power Ratio in Multicarrier Transmission,” IEEE Transactions on Wireless Communications, April 2005..

[3]. S. H. Han, J. H. Lee, "PAPR Reduction in OFDM Signals Using a Simplified PTS Technique," IEEE Signal Processing Letters, Vol. 11, No. 11, November 2004.

[4]. S. Y. L. Goff, B. K. Khoo, C. C. Tsimenidis, B. S. Sharif, "A Novel Technique for PAPR Reduction in OFDM Systems via Selected Mapping," IEEE Transactions on Communications, Vol. 56, No. 11, November 2008.

[5]. S. Y. L. Goff, S. S. Al-Samahi, B. K. Khoo, C. C. Tsimenidis, B. S. Sharif, "Selected Mapping Without Side Information for PAPR Reduction in OFDM," IEEE Transactions on Wireless Communications, Vol. 8, No.7, July2009.

[6]. J. Armstrong, "Reducing Peak-To-Average Power for OFDM by Clipping and Frequency Domain Filtering," IEEE Electronic Letters, Vol. 38, No. 5, pp. 246–247, February 2002.

[7]. A. Kubo, S. Tomisato, M. Hata, "Performance of Highly Efficient OFDM Signals with Iterative Peak Reduction," Proceedings of the Asia-Pacific Conference on Wearable Computing Systems (APWCS), August 2005, pp. 145–148.

[8]. S. K. Deng, M. C. Lin, "Recursive Clipping and Filtering with Bounded Distortion for PAPR Reduction," IEEE Transactions on Communications, Vol. 55, No. 1, pp. 227–230,January2007.

[9]. Y. C. Wang, Z. Q. Luo, "Optimized Iterative Clipping and Filtering for PAPR Reduction in OFDM Signals," IEEE Transactions on Communications, Vol. 59, No. 1, pp. 33–37,January2011.

[10]. P. Börjesson, H. G. Feichtinger, N. Grip, M. Isaksson, N. Kaiblinger, P. Ödling, L. Persson, "A Low-Complexity PAPR Reduction Method for DMT-VDL," Proceedings of the 5th International Symposium on Digital Signal Processing for Communications Systems (DSPCS), Perth, Australia,February1999,pp.164–169.

[11]. H. Xiao, L. Jianhua, C. Justin, Z. Junli, "Companding Transformation for Reducing PAPR of OFDM Signals," Proceedings of the IEEE Vehicular Technology Conference (VTC),2001,pp.835–839.

[12]. Lim D. W., Seon J., Lim C. W., "A New Low-Complexity SLM OFDM Scheme for PAPR Reduction," IEEE Signal Processing Letters, 2005, Vol. 12(2), pp. 93–96.

[13]. P. Cheng, Y. Xiao, L. Dan, S. Li, "Improved SLM for PAPR Reduction in OFDM Systems," Proceedings of the 2007 IEEE Symposium on Personal, Indoor, and Mobile RadioCommunications,pp.1–5.

[14]. S. A. Fathy, M. N. Ibrahim, S. S. Elagooz, H. M. El-Hennawy, "Efficient SLM Technique for PAPR Reduction in UFMC Systems," Proceedings of the 2019 36th National Radio Science Conference (NRSC), Port Said, Egypt, 16–18 April2019, pp.118–125.

[15]. A. Kumarbudati, T. Raopolipalli, "Performance Analysis of HFDI Computing Algorithm in Intelligent Networks," International Journal of Computer Applications, 41(4): IoT in Social, Mobility, Analytics & Cloud (ISMAC), 2019.

[16]. M. Pavani, P. Trinatha Rao, "Adaptive PSO with Optimized Firefly Algorithms for Secure Cluster-Based Routing in Wireless Sensor Networks," IET Wireless Sensor Systems,DOI:10.1049/iet-wss.2018.5227.

[17]. S. H. Han, J. H. Lee, "An Overview of PAPR Reduction Techniques for Multicarrier Transmission," IEEE Wireless Communications, Vol. 12(2), pp. 56–65, 2005.

[18]. V. Vijayarangan, Dr. R. Sukanesh, "Overview of Techniques for Reducing PAPR and Their Selection Criteria for OFDM Radio Systems," Journal of Theoretical and Applied Information Technology.