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Efficient PAPR reduction technique in OFDM system using amplitude clipping and selective filtering

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ABSTRACT

One of the most important transmission methods for the next generation of wireless communication systems is orthogonal frequency division multiplexing (OFDM). Transmitting an OFDM signal in a noisy environment with a low bit error rate (BER) is the primary goal. High peak-to-average power ratio (PAPR) at the transmitter, which lowers the transmission peak power, is one of OFDM's biggest drawbacks. In this paper, we propose efficient PAPR reduction technique in OFDM system using amplitude clipping and selective filtering. The efficient multi-efficiency PAPR reduction strategies with pulse amplitude modulation (PAM) and quadrature amplitude modulation (QAM) modulation are employed with selective filtering and evaluated in terms of percentage reduction level to lowest PAPR of 3.841 db. It is observed that QAM modulation produces better results compared to PAM modulation with less BER of 0.003 for signal-to-noise ratio (SNR) of 20 db.

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1. INTRODUCTION

A technique for encoding digital data on several carrier frequencies is called orthogonal frequency division multiplexing (OFDM) [1]. It is mostly employed in wireless communications to reduce signal interference and allow for more effective data transfer. The primary feature of OFDM is its use of orthogonally separated carrier frequencies that do not interfere with one another. As a result, many carriers can broadcast simultaneously and without interference. Data is carried on many narrowband subcarriers with OFDM as opposed to a single wideband carrier. The fast fourier transform (FFT) technique is used by OFDM for both modulation and demodulation, translating time domain signals into representations in the frequency domain and vice versa. OFDM adds a guard interval (usually a cyclic prefix to maintain signal continuity) between signals to prevent inter-symbol interference (ISI). Several modifications and extensions of traditional OFDM systems [2], [3] have been developed. One such variation is coded OFDM (COFDM), which incorporates error correction coding to enhance the resilience of the signal in hostile environments. By adding this coding, COFDM can detect and correct errors in the received data, making it particularly useful in environments with high interference or signal degradation, such as urban areas or underwater communications. Adaptive OFDM (A-OFDM) is an additional extension that modifies transmission parameters in real time based on the state of the channel, including power levels, modulation schemes, and coding rates. Through adaptive responses to variables like signal strength and interference levels, A-OFDM improves data transmission reliability and efficiency. Another form of OFDM, called wideband OFDM (W-OFDM), is made to accommodate high mobility scenarios like vehicle communications. Rapid movement in these settings might result in noticeable frequency shifts, or "Doppler effects," that can impede communication. W-OFDM addresses this by using wider subcarrier spacing, making the system more resilient to frequency shifts caused by motion. This wider spacing helps maintain signal integrity and ensures reliable communication even in fast-changing environments, such as high-speed trains or vehicles in motion. Combining the ideas of OFDM with multiple input multiple output (MIMO) technology— which employs multiple antennas for signal transmission and reception—allows for OFDM with MIMO [4]. By enhancing spectral efficiency (SE) and offering spatial diversity, MIMO improves the performance of OFDM. In addition, it strengthens the system's resistance to interference and signal fading, which makes it an effective option for 4G and 5G wireless networks, where high capacity and dependability are critical requirements. OFDM has a number of important benefits, by keeping subcarriers orthogonal and grouping them near together, it maximizes bandwidth utilization and improves SE. Because each subcarrier undergoes flatter, easier-to-manage fading, the system is also well suited to counter multipath fading. Furthermore, inter-carrier interference is decreased by the sturdy architecture of OFDM. Compared to broadband signals, the equalization procedure is simpler and easier to manage because each subcarrier is narrowband. Additionally flexible in terms of resource distribution, OFDM enables users to be assigned subcarriers dynamically, allowing it to adapt to a range of transmission circumstances. OFDM has disadvantages. Its high peak-to-average power ratio (PAPR) is a major problem that necessitates more complex transmitter designs and complicates power amplification. Furthermore, Doppler effects and oscillator instability can create frequency shifts in OFDM that can result in inter-carrier interference. Although using a cyclic prefix helps prevent ISI, it adds overhead that lowers the data rate overall. In conclusion, even though the FFT makes certain tasks easier, complicated signal processing is still needed for the overall implementation of OFDM, particularly for synchronization and equalization [5], which increases system complexity.

Bemani *et al.* [6] talks about a new waveform for next-generation wireless networks called affine frequency division multiplexing, or AFDM. AFDM offers reliable performance in high-mobility and high-frequency conditions by modulating numerous chirp signals using the discrete affine fourier transform (DAFT). According to simulation data, AFDM is a viable modulation technique for future wireless networks, outperforming other techniques like OFDM [7] and orthogonal time frequency space (OTFS) modulation.

Inspired on OTFS modulation, this study [8] offers orthogonal delay-doppler division multiplexing (ODDM), a unique multicarrier (MC) modulation for DD planes. By establishing the foundation for the creation of effective detection algorithms for ODDM in the future, this study positions ODDM as a superior solution for managing doubly-selective channels in wireless communication. Xu *et al.* [9] investigates the use of the discrete hartley transform (DHT) in CO-OFDM with index modulation (O-OFDM-IM) for visible light communications (VLC). Spectral efficiency (SE) is increased by transferring more index bits since the discrete fourier transform (DFT) is substituted with DHT, which does away with the requirement for Hermitian symmetry. In comparison to DFT-based systems, the suggested DHT-based O-OFDM-IM likewise delivers superior bit error rate (BER) performance and a lower PAPR, particularly at the same SE. The same BER as conventional maximum likelihood (ML) detectors is offered by a revolutionary reduced complexity ML detector, which has less computing complexity. The results of simulations verify that DHT-based systems perform better in terms of signal-to-noise ratio (SNR) than its DFT-based counterparts. They are a viable substitute for VLC systems, providing increased efficiency without the need for extra hardware. Zhang *et al.* [10] presents a hybrid chaos-based three-dimensional (3-D) constellation scrambling strategy to improve coherent CO-OFDM systems' transmission performance as well as physical layer security. While a 5-D hybrid chaotic system combining a 3-D hyperchaoticHénon map and two 1-D logistic maps creates a wide key space ($\sim 10^{133}$) for encryption, enhancing system security, a 3-D regular hexahedron signal constellation is proposed to increase error performance. An experimental test is conducted using 100 km of fiber to encrypt 144 Gbps 16QAM OFDM data.

The outcomes demonstrate a 2 dB improvement in BER over conventional 3-D constellations. This indicates that the method is promising for upcoming CO-OFDM systems since it greatly improves security and transmission performance. The versatility of orthogonal chirp division multiplexing (OCDM) [11] modulation in producing different waveforms, such as precoded OFDM and OFDM, is examined in this work. It shows that a transmission chain made up of an Inverse DFT (IDFT), a chirp multiplication, and a DFT matrix may generate OCDM signals. The study demonstrates how this chain may be divided into six sub-blocks, and by turning these blocks on or off, one can create an infinite number of inherited waveforms. It is stated that OCDM is a viable option for multi-radio access technology (multi-RAT) and 6G flexible communication systems. Future studies will tackle the technological difficulties related to OCDM. In order to improve the spectrum efficiency of OFDM, a novel method called joint-mapping OFDM with subcarrier number modulation (JM-OFDM-SNM) is proposed in this study. By taking constellation symbols and subcarrier activation patterns into account simultaneously, this method [12] enhances conventional OFDM systems and achieves a constant bit length for data transmission. In addition, compared to ML detection, it provides a low-complexity detection technique based on log-likelihood ratios to lessen the computational load. The authors also suggest two improvements: JM-OFDM-IQ-SNM, which expands indexing to in-phase and quadrature domains, and Adaptive JM-OFDM-SNM, which modifies constellation ordering for varying active subcarrier counts. Both systems achieve better spectrum efficiency and BER than the standard JM-OFDM-SNM. These enhancements are validated by simulation results, which provide notable performance advantages over traditional OFDM systems. This work [13] introduces a new method of optimizing optical wireless communication (OWC) through the combination of OFDM and two-level Laser Diode Color-Shift-Keying. This technique is appropriate for secure and fast data transmission since it makes use of RGB laser diodes to modify the apparent color of illumination.

The technology accomplishes non-flickering effects, reducing health risks, and greatly boosting data speeds. The system met forward-error-correction thresholds in an experimental setting, demonstrating a data throughput of 28.4 Gbit/s over a 1.25-meter distance. This indicated the system's potential for use in next-generation OWC systems. In order to improve implementation efficiency and performance, this work [14] offers a cross-correlation technique for correcting common phase error (CPE) in OFDM systems. Because of the constraints of the pilots, traditional phase offset compensation utilizing pilots frequently results in low BER. The drawbacks of conventional techniques are addressed by the suggested algorithm, which makes greater use of preamble sequences for phase offset correction in both the time and frequency domains. According to numerical assessments, at 10 dB SNR, the new technique decreases mean square error (MSE) to 10^{-3} from 10^{-2}, and at 12 dB SNR, it achieves a BER of about 10^{-5}. In comparison to current techniques, the suggested solution offers notable gains in BER and MSE and is simple to implement with minimal hardware complexity. The correctness and efficacy of the algorithm are confirmed by the experimental findings. The online dimensioning and survivability of OFDM-based optical grids [15] are discussed in this research, which is important since it will enable grid applications in the future generation of optical networks. It uses shared path protection to guard against single link failures and applies the anycast concept to network dimensioning, which permits job relocation to resources that are comparable. Online dimensioning with shared path protection (ODSPP), a heuristic algorithm that solves the problem in polynomial time, is introduced together with an integer linear program (ILP) formulation in this study. In comparison to conventional approaches, ODSPP achieves a 20.07% reduction in connection blockage probability, demonstrating its great capacity efficiency. Through simulations on the 24-node US network, the study stresses the need for appropriate dimensioning and survivability solutions in OFDM networks and shows how successful the suggested heuristic is. In 6G machine-type communication (MTC) applications, this work [16] presents a code-division orthogonal frequency division multiplexing (CD-OFDM) system for joint communication and sensing (JCS). By combining communication and radar sensing, the proposed CD-OFDM JCS system uses a novel successive-interference-cancellation (SIC) approach and code-division multiplex (CDM) gain to solve mutual interference.

It is designed a unified JCS channel concept for both transmission and reception. Comparing CD-OFDM to conventional OFDM JCS systems, simulation findings show that CD-OFDM provides stronger radar sensing and better communication reliability, especially under low signal-to-interference-and-noise ratio (SINR) circumstances. Even though CD-OFDM uses more processing power, it performs better in low SINR regimes than OFDM JCS and is on par with time-division duplex (TDD) OFDM systems in terms of sensing. Depending on particular MTC needs and real-time SINR, CD-OFDM or OFDM JCS should be chosen. In high-mobility settings, OTFS modulation [17] performs better than OFDM. Because there are so many base station antennas, downlink channel estimate is one of the challenges with OTFS massive MIMO. In order to address this issue, we provide in this study a channel estimation method based on a 3D-structured orthogonal matching pursuit algorithm. First, we demonstrate the presence of 3D-structured sparsity in the OTFS MIMO channel: block sparsity along the Doppler dimension, burst sparsity along the angle dimension, and normal sparsity along the delay dimension. We next define the downlink channel estimation problem as a sparse signal recovery problem based on the 3D-structured channel sparsity. The suggested technique can provide accurate channel state information with little pilot overhead, according to simulation findings.

The OFDM has a number of drawbacks and difficulties based on the literature survey as follows: (i) High PAPR: OFDM signals can have peaks that are significantly higher than the average power level because to their high PAPR. (ii) Mitigation: Performance can be harmed and complexity increased by employing techniques like clipping, coding, or selective mapping. (iii) carrier frequency offset (CFO) Sensitivity: OFDM is extremely vulnerable to phase noise and carrier frequency mismatches between the transmitter and receiver. Inter-carrier interference (ICI), which impairs system performance by overlapping neighboring subcarriers, can be brought on by slight frequency shifts. To reduce this effect, frequency synchronization techniques are needed, which makes system design more complicated. (iv) Cyclic Prefix Overhead: The cyclic prefix (CP), added to combat ISI, introduces redundancy. This reduces the SE of OFDM, as a portion of the transmitted data is used for the CP rather than actual information. The remaining portions of the paper are arranged as follows: Section 2 presents background information on the topics covered in this study and then delves into a survey of similar works. Section 3 presents an overview of the suggested approach along with the steps. An account of the experimental design and results analysis is given in section 4. As the report draws to an end, the Conclusion points out its shortcomings and makes recommendations for more study.

2. METHOD

The proposed OFDM has been tested with following types of clipping model. The proposed OFDM has been tested with the following types of clipping model. The amplitude clipping process is shown in Figure 1.

Figure 1. Amplitude clipping

2.1. Amplitude clipping

We have used Nyquist rate clipping with different modulation scheme [18]-[21]. When the signal amplitude is more than threshold, the amplitude value is clipped and the corresponding phase value is saved. If φ_n is the phase of a baseband signal of any OFDM system with 'a' threshold, then the clipped signal can be represented as:

$$x_n = \left\{ \begin{matrix} A\, e^{j\varphi_n}, & |x_n| > A \\ x_n, & |x_n| > A \end{matrix} \right\} \quad (1)$$

Since the clipping is a nonlinear operation, as a result it introduces distortions in the clipped signal (both in-band and out-of band) components. The in-band distortions increase the BER and out-of band distortions increases neighboring channel interfaces. The interferences are reduced by the use of band limiting filters. Also to reduce BER we can use any error correcting techniques. In the proposed technique, clipping and filtering are applied repeatedly to reduce the peak of the signal to gradually reduce PAPR. This method can reduce PAPR effectively but with increment of the cost of the calculation. As a result, a trade-off is necessary.

2.2. Partial transmit

Let 'X' denote random input signal in frequency domain with length 'N'. 'X' is partitioned into 'V' disjoint sub blocks as shown in Figure 2.

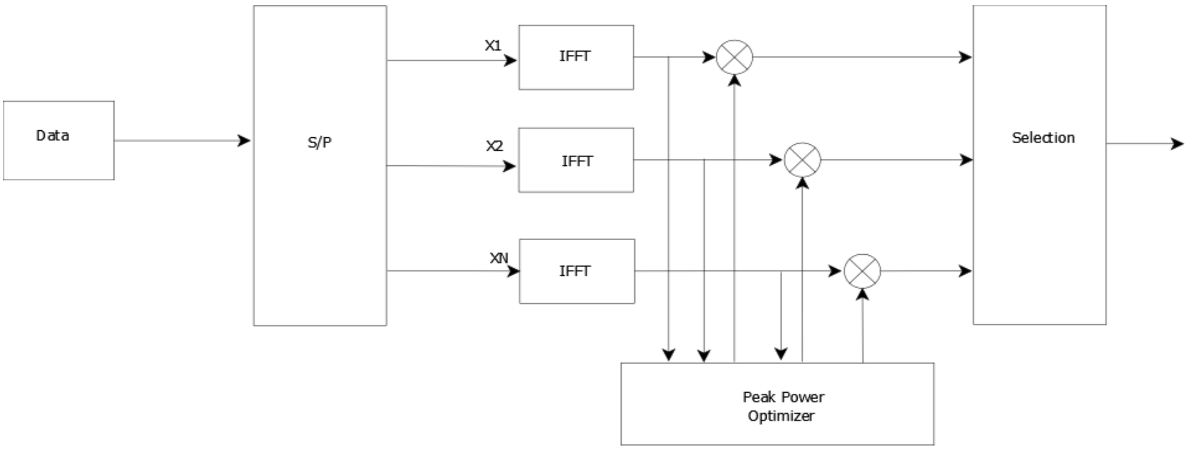

Figure 2. Partial transmit technique

This division is must such that $\sum_{v=1}^{V} X_v = X$ which makes those sub blocks are combined to minimize the PAPR in time domain. By applying the phase rotation factor as $b_v = e^{j\emptyset_v}$ where v=1, 2…V to the IFFT of the v^{th} sub block X_v.

$$X_V = [X_{v,0}, \quad X_{v,1}, \dots \dots \dots \quad X_{v,N-1}] \tag{2}$$

The time domain signal is

$$X'(b) = \sum_{v-1}^{V} b_v X_v \tag{3}$$

Where $X'(b) = [X'_0(b), \quad X'_1(b), \dots \dots \dots \quad X'_{NL-1}(b)]$
L – Oversampling factor
To minimize the PAPR we can write both ‘b’ and ‘X’ as

$$b = \begin{bmatrix} b_1 & b_1 \dots \dots \dots & b_1 \\ \vdots & \vdots & \vdots \\ b_v & b_v \dots \dots \dots & b_v \end{bmatrix} X = \begin{bmatrix} X_{1,0} & X_{1,1} \dots \dots \dots & X_{1,NL-1} \\ \vdots & \vdots & \vdots \\ X_{v,0} & X_{v,0} \dots \dots \dots & X_{1,NL-1} \end{bmatrix}$$

As the oversampling of X, add zeros to the vector which implies that the number of phase sequence to multiply to matrix ‘X’ will remain same. So, the optimized parameter.

$$\tilde{b} = \arg\min(\max 0 \ \leq K \ \leq NL - 1 \, |\textstyle\sum_{v-1}^{V} b_v X_v|) \tag{4}$$

2.3. Partial transmit

The selective mapping technique is one OFDM technique which is used to reduce PAPR. Let us consider an OFDM system with N-Subcarrier which uses data block having ‘U’ number of independent vector where ‘X’ data block is mapped as X(k) with finite number of sub symbols with k=0,1, 2,…… , N-1. Let us consider the total phase vector denoted by B^u where u = {1, 2… u}. So, an element at k^{th} position can be given as:

$$X^u(k) = X(k) \,.\, B^u(k) \tag{5}$$

Then by applying IFFT we can obtain u number of alternative OFDM signal which can be written mathematically as:

$$x^u(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X^u(k) e^{j\frac{2\pi nk}{N}} \tag{6}$$

The selective mapping technique, which is used to reduce PAPR, is shown in Figure 3. Figure 3 depicts the selective mapping technique.

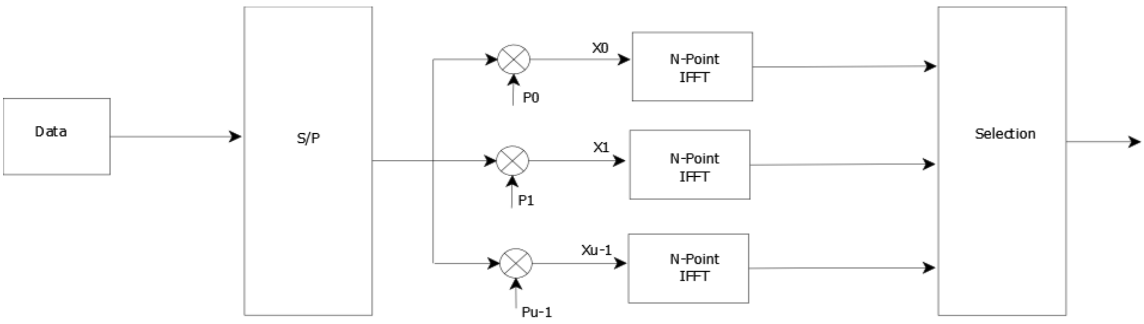

Figure 3. Selective mapping technique

3. RESULTS AND DISCUSSION

The proposed advanced OFDM (AOFDM) to reduce PAPR have used nonlinear companding transform (CT) with Cyclic Prefix is simulated and the results are verified using MATLAB tool for GSM

Global system for mobile communication and IEEE 802.11a/b/g standards. The parameters are used to implement this AOFDM is:
- FFT length: 512
- Carrier Count: 16
- Bits per symbol: 8
- Symbols per Carrier: 24
- Channel models: Lossy (Gaussian AWGN)
- Data modeling: Rounding the elements to the nearest integers less of a random value
- SNR: 90

3.1. Simulation results for PAPR techniques

The results for all the three methods of clipping are simulated in MATLAB software with 128 sub carriers with the size of FFT as 512. The OFDM time domain signal with elaborated version of it for one time period is given in Figure 4 The comparison plot of all the three techniques with original signal in a single graph is as shown in Figure 5. The amplitude clipping provides better result than any other PAPR reduction techniques. The PAPR value for different reduction techniques were calculated and are given in Table 1. It is observed that the Amplitude clipping for subcarriers N=128 gives better results compared to other reduction technique.

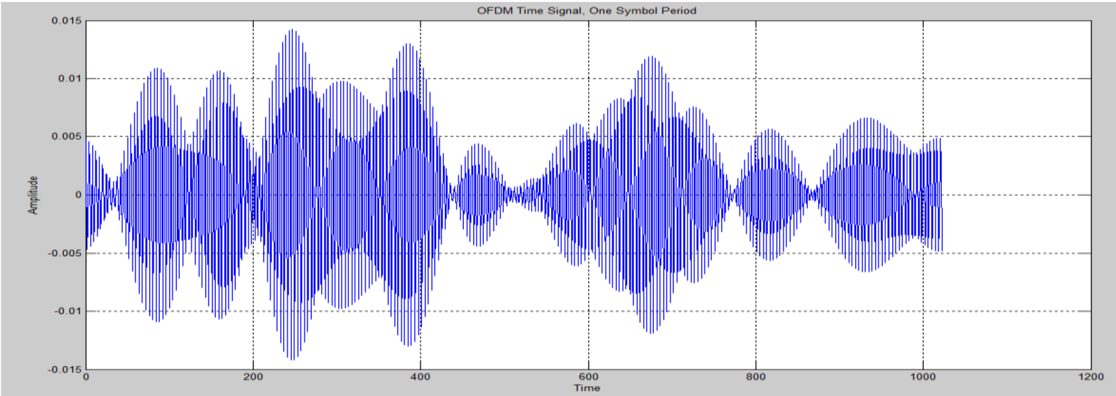

Figure 4. OFDM time signal one symbol period

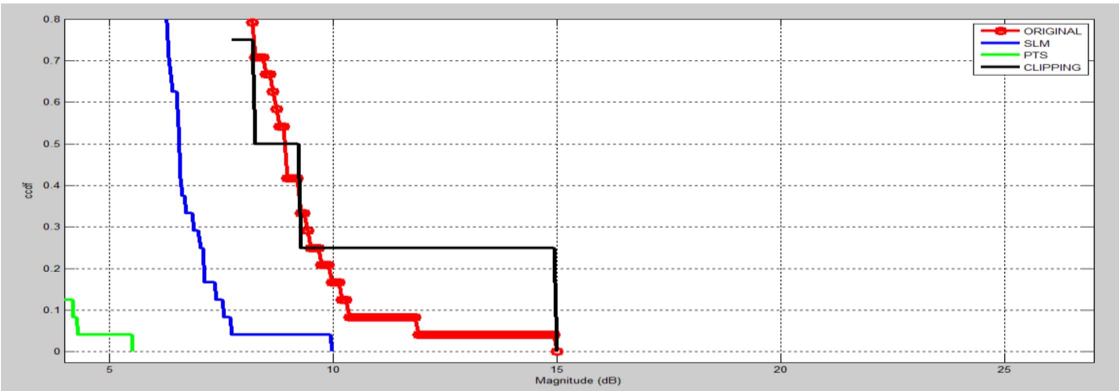

Figure 5. Performance of several PAPR schemes in terms of complementary cumulative distribution function (CCDF)

Table 1. PAPR values for different reduction techniques

SNR (dB)	Original signal (dB)	Partial transmit (dB)	Selective mapping (dB)	Amplitude clipping (dB)
15	7.923	15.051	15.051	5.549
20	8.171	7.429	8.426	2.748
25	8.171	7.461	8.376	2.499
30	6.954	8.603	8.641	3.841

3.2. Bit error rate comparison

In amplitude clipping, we compared with quadrature amplitude modulation (QAM) and pulse amplitude modulation (PAM) modulation with BER. The final output for the comparison is performed with the symbol error rate and SNR calculation for PAM Modulator. The graph is shown in the Figure 6.

The final output for the comparison is done with the symbol error rate and SNR calculation for QAM Modulator. The graph is shown in Figure 7. In amplitude clipping, we further analyzed by using QAM and PAM modulation with respective BER as shown in Table 2. It is observed that the QAM modulation provides better symbol error rate compared to PAM modulation.

The various existing techniques were compared with our proposed approach as shown in Table 3. It is observed that in [22]-[25] which employed Tone reservation, PTS and iterative clipping had some limitations with respect to non linear distortions and this was improved in our method by employing amplitude clipping with selective filtering which improved the PAPR and also reduced the BER value.

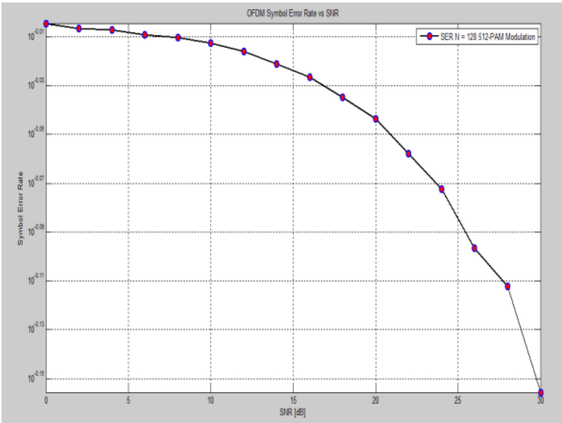

Figure 6. OFDM symbol error rate vs SNR for PAM

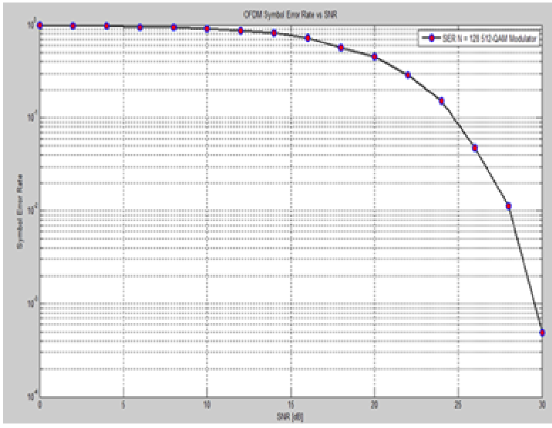

Figure 7. OFDM symbol error rate vs SNR for QAM

Table 2. Symbol error rate for QAM and PAM modulation

SNR (dB)	Symbol error rate	
	PAM modulation	QAM modulation
5	0.979	0.000
10	0.957	0.891
15	0.929	0.891
20	0.883	0.158
25	0.828	0.115
30	0.708	0.003

Table 3. Comparison with existing techniques

Parameters	[22]	[23]	[24]	[25]	Proposed method
PAPR reduction technique	Tone reservation	PTS	Iterative clipping	Iterative clipping and filtering	Amplitude clipping with selective fltering
PAPR in dB	10.5	8.5	5.878	4.9	3.841

4. CONCLUSION

The efficient technique of OFDM with respect to PAPR reduction, symbol error rate and SNR is proposed in this paper. To reduce PAPR, CCDF is used with Amplitude clipping, partial transmit and selective mapping technique. By comparing the symbol error rate of all three techniques with actual OFDM we can conclude that amplitude mapping with selective filtering is better than other techniques used to reduce PAPR. Now by using different modulation techniques (QAM and PAM), we also compared the performance of amplitude mapping OFDM technique. The result shows that QAM is giving better performance than PAM in terms of lowest BER.

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Supriya M	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Sukumar R		✓				✓		✓	✓	✓	✓	✓		

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

I'm Supriya M corresponding author of this paper and my co-author Sukumar R would like to say that there is no conflict of interest for this paper publication.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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