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# Development of an Improved Peak-to-Average-Power Ratio Reduction Technique and its Comprehensive Evaluation with admired Techniques in OFDM

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## ABSTRACT

The high value of Peak to Average Power Ratio (PAPR) is one of the primary limitations of the Orthogonal Frequency Division Multiplexing (OFDM). The PAPR has a direct impact on the performance of the high-power amplifier (HPA) of the transmitter and the complexity of the ADC & DAC. Thus, reducing PAPR in the OFDM system will not only just improves the power efficiency of the transmitter but also enhances the speed of operation. The quintessence of high PAPR in OFDM can be estimated from the fact that for many decade researchers are finding the solution for reducing it, every time the PAPR reduction technique is getting improver but not the best. Recent advancement in computer system gives a strong base for fastest signal processing. Numerous PAPR reduction methodologies have been proposed and implemented so far but these methods have adverse effects such as increased Bit Error Rate (BER), increased computational complexity, added in-band, and out-of-band distortions. This gives a strong motivation to work further on the reduction of PAPR with the least BER, reduced computational complexity, and no in-band distortion or out-of-band radiation. In this paper, we have proposed a novel approach to reduce PAPR in OFDM inherited from partial transmit sequence (PTS), selective mapping (SLM), and amplitude clipping & filtering (ACF) methods. The evaluation of the proposed novel method is done with Complementary Cumulative Distribution Function (CCDF) and Eb/N0 statistical models. OFDM WLAN standard 802.11a is referred for transmitter and receiver design, Software Defined Radio NI-USRP2922 and LabVIEW tools have been used to validate the signal design.

**Keywords:** *OFDM, PAPR, LabVIEW, NI USRP2922, SDR*

## 1. INTRODUCTION:

### *1.1. The OFDM:*

OFDM follows the fundamental principle of decomposing the high data rate stream into N lower data rate streams and then to transmit them simultaneously over many subcarriers. The sufficiently high value of N makes the individual bandwidth (W/N) of subcarriers narrower than the coherence bandwidth ($B_c$) of the channel. Consider $q$ OFDM symbol number each having N constellation point symbols, $X_{p,q}$ = [$X_{0,q}$, $X_{1,q}$,..., $X_{N-1,q}$] these are complex number symbols from a set of signal constellation points, {Ψ}, the OFDM signal can be represented with *equation 1* [1-2].

$$s_{r,q} = \frac{1}{\sqrt{N}} \sum_{p=0}^{N-1} X_{p,q} e^{j2\pi \frac{r}{N} p} \qquad \begin{array}{l} 0 \le r \le N-1 \\ 0 \le p \le N-1 \end{array} \qquad (1)$$

The $s_{r,q}$ = [$s_{0,q}$, $s_{1,q}$,..., $s_{N-1,q}$] are carrier amplitudes associated with the OFDM symbol, which is a formal expression for IFFT, $\mathfrak{F}^{-1}\{X_{p,q}\}$. *Equation 2* depicts an infinite sequence of OFDM symbols to be transmitted [1].

$$s(t) = \sum_{q=-\infty}^{\infty} s_q(t) = \sum_{q=-\infty}^{\infty} \sum_{p=0}^{N-1} X_{p,q} \phi_p(t - qT) \qquad (2)$$

The OFDM uses three transmission principles, multi-rate, multi-symbol and multicarrier. As compare to Frequency Division Multiplication the OFDM preserves almost 50% of channel bandwidth. It distributes the data over a large number of subcarriers that are separated apart at orthogonal frequencies [3].

*Figure 1* shows the fundamental principle of OFDM 4-QAM symbol formation from binary bits, and splitting of a frequency domain high-rate digitally modulation mapped data stream into several lower rate streams and transmitting them simultaneously on many of these low-rate subcarriers (SCs) by integrating them over a symbol period. These subcarriers are mutually orthogonal [2-3].

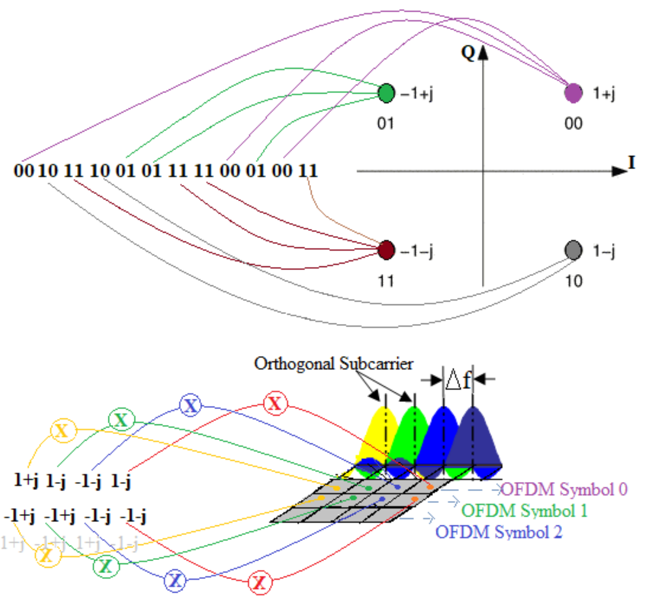


Figure-1: OFDM Symbol Formation for 4-QAM Scheme

### *1.2. Issue of High PAPR in OFDM*

In an OFDM signal, several subcarriers get aligned together in the time domain; this may cause significant peaks or faded samples; this effect or phenomenon is measured in terms of the

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difference between peak power and average power of the signal [3]. Two terminologies, Crest-Factor (CF) and Peak to Average Power Ratio (PAPR) or only Peak-to-Average Power (PAP) are used for measuring this effect in OFDM. CF is the ratio of peak power to the RMS value of the signal, whereas PAPR is the ratio of Peak power to the average power of the signal. PAPR as depicted in *equation 3*, is a square of the CF and has amplitude like a noise signal, with an extensive dynamic range and is sensitive to carrier frequency offset and drift. PAPR value is directly proportional to the number of subcarriers. For instance, if the number of subcarriers is 52, as in WLAN standard IEEE 802.11a/g, the instantaneous PAPR value may exceed 17 to 18 dB [4]. Mostly instantaneous PAPR goes up to approx. 9 to10 dB for this wireless standard. These uncertain values of PAPR makes the high-power amplifier (HPA) unstable. Power consumption of HPA of a transmitter increases as the steep peaks goes into the saturation region of the HPA, making non-linearity in signal amplification [5-7].

$$\xi = \frac{\max_{\forall\, q,r\in[0,N-1]} \left|s_{r,q}(t)\right|^2}{\mathrm{E}\left\{\left|s_{r,q}(t)\right|^2\right\}} \qquad (3)$$

## 2. Admired PAPR Reduction Techniques

For many decades numerous solutions have been proposed to deal with reducing the PAPR problem of OFDM. The first solution was proposed about ten years after its discovery. Although the basic issues are the same, the solutions differ to a great extent in the specific approach taken towards each of them. Furthermore, many researchers do not absolutely agree on the impact of high signal peaks on system performance [6][8]. Consequently, no general overview or consistent treatment of this problem is available in the literature to the best of our knowledge. Categorically, depending on the demand of the user and the system, the PAPR mitigation techniques can be classified as [9-15]:

i. Non-linear transformation
   a. Amplitude Clipping and Filtering (ACF)
   b. Companding
   c. Windowing
ii. Coding techniques
iii. Constellation modification method
   a. Tone Reservation (TR)
   b. Tone Injection (TI)
   c. Active Constellation Extension (ACE)
iv. Multiple signal representations
   a. Selective Mapping Scheme (SLM)
   b. Partial Transmit Sequence (PTS)
   c. Interleaving (INT)

Amplitude clipping and filtering is one of the most prominent techniques of nonlinear transformation. Clipping out the high amplitude peaks in the OFDM signal by applying threshold peak value is rather the easiest way of controlling PAPR. This gives least computational complexity but for the cost of increased BER. Frequency domain filtering may help to cope up to certain amount of BER degradation [6-7] . Constellation modification approach gives another one prominent PAPR reduction technique call ACE [8]. Here, the frequency domain constellation points re altered in a way that the subsequent signal gets the least PAPR value. Multiple signal representation, the three techniques are potential and prominent, viz. INT[9], SLM [10-12] ,PTS [13-15] and. in these methods a set of vectors are multiplied with signal and signal with least PAPR is shortlisted. Multiple signal representation method has issue of very high computational complexity, which increases processing overhead of transmitter. ACF is least computationally complex but suffering with degraded BER performance. An optimum solution is anticipated for reduction of PAPR in OFDM. Based on this survey the Novel approach is adapted with optimum solution as described in following section.

## 3. Proposed Work

*Figure 2* shows a typical block representation of the proposed method. A unique set of phase rotation vector set is used to multiply the signal vector. Which gives N replications of original signal, out of which one set with least PAPR is extracted and prepared to send along with the index number of shortlisted multiplying vector. The unique vector set is different from tradition PTS technique, additionally at the and the transmitter amplitude clipping, and filtering is applied to further fine tune the PAPR reduction. The number of phase rotation vector multiplied here are reduced to improve *computational complexity* and preprocessed signal when undergoes ACF it improved *BER degradation* compare to traditional BER. Thus, both the critical issues of prominent PAPR reduction techniques are addressed here [6][10][15].

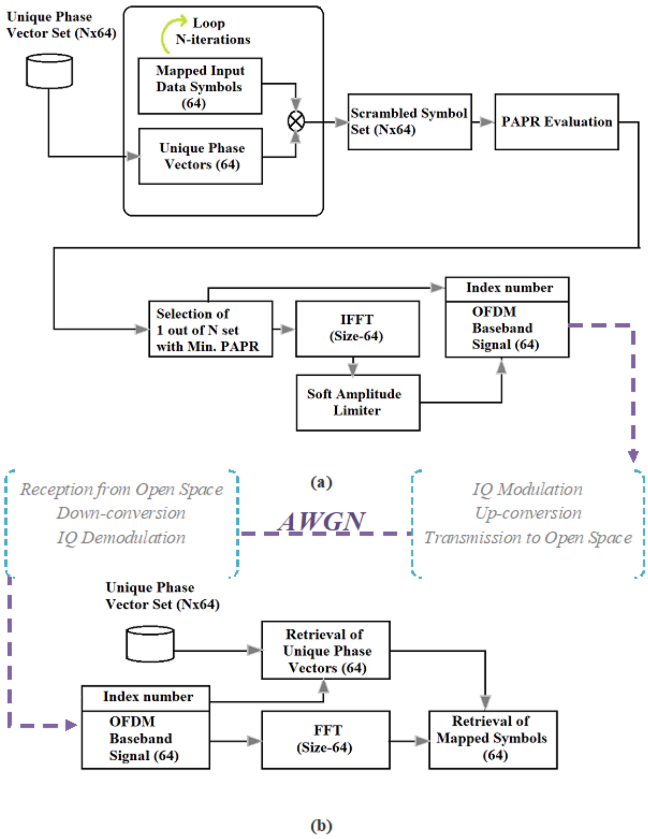


Figure-2: Block Diagram of Proposed Technique (a) Tx (b) Rx

### *3.1 Mathematical Model of Proposed Technique*

Let $x$ represents the signal set having N symbols split into v disjoint blocks and a matrix $x_{disj}$. After performing IFFT operation, $x_{disj}$ will become $X_{disj}$.

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This matrix having a size *(NXV)*, is then multiplied with phase rotation factors matrix of size (***V***x*N*) to reduce highly uncorrelated data caused by IFFT. Let $X_{V,N}^{SET}$ represent the resultant matrix (***N***x*N*) of this multiplication as shown in *equation 4* [13][15].

$$X_{V,N}^{SET} = \left[ \begin{bmatrix} X_1^1 & X_2^1 & \cdots & X_N^1 \\ X_1^2 & X_2^2 & & X_N^2 \\ & \vdots & & \\ X_1^V & X_1^V & & X_N^V \end{bmatrix}^T \begin{bmatrix} X_1^1 & X_2^1 & \cdots & X_N^1 \\ X_1^2 & X_2^2 & & X_N^2 \\ & \vdots & & \\ X_1^V & X_1^V & & X_N^V \end{bmatrix} \right]^T \quad (4)$$

Now this $X_{V,N}^{SET}$ is representing N copies of the original signal having different PAPR caused due to the multiplication of phase rotation vectors. The one out of N set is selected ($X_{PTS}$) for minimum PAPR based on rigorous evaluation as depicted in *equation 5*.

$$X_{PTS} = \arg min_{X_V^{SET}} \left( \max_{v=1,2,..V} |X_{V,N}^{SET}| \right) \quad (5)$$

The selected set $X_{PTS}$ is transmitted as data along with side information $\breve{X}$, represented by *equation 6.*

$$\breve{X} = \arg min_V \left( \max_{v=1,2,...V} |X_{V,N}^{SET}| \right) \quad (6)$$

Repeated Amplitude clipping and filtering is performed on $X_{PTS}$ to a predefined amplitude level A, the resultant signal is stored in $x_{prop}$ as shown in *equation (7)*. This seems similar to conventional amplitude clipping and filtering but rather different in actual with the fact that it is done post phasor rotation and hence the selection of the value of A is quite different than as that of the conventional scheme. This causes the least in-band distortion or out-of-band radiation in the signal [6-7][10-15].

$$x_{prop} = \begin{cases} X_{PTS} & |X_{PTS}| \le A \\ Ae^{j\theta(t)} & |X_{PTS}| > A \end{cases} \quad (7)$$

$x_{prop}$ along with $\breve{X}$ is sent to recover the original signal at the receiver. The receiver has a similar set of phase rotation factors, so only information (indices) of these phase sequence needed to be sent from the transmitter side.

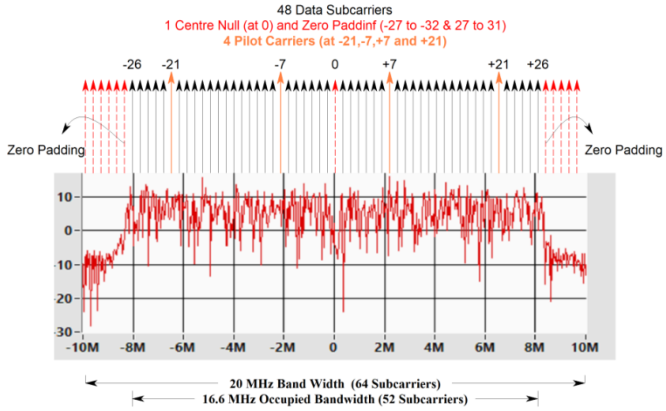

Figure-3: IEEE 802.11a Signal Bandwidth

Table 1: Description of various modulation scheme in IEEE 802.11a

| Mode | Data Rate MBPS | Modulation | Coded bits per Subcarrier | Coded bits per OFDM Symbol | Data bits OFDM Symbol |
|---|---|---|---|---|---|
| 1 | 6-9 | BPSK | 1 | 48 | 24-36 |
| 2 | 12-18 | 4-QAM | 2 | 96 | 48-72 |
| 3 | 24-36 | 16-QAM | 4 | 192 | 96-144 |
| 4 | 48-54 | 64-QAM | 6 | 288 | 192-216 |

## 4. SYSTEM MODEL

System Development is modeled based on the IEEE 802.11a WLAN standard, its PHY uses an unlicensed 5 GHz band, to transmit frames at a data rate up to 54 Mbps, enabling high-speed data transmissions over WLAN networks. It uses 52 subcarriers that can be modulated with BPSK, QPSK, 16QAM, or 64QAM [16-17]. The Description of various modulation schemes in IEEE 802.11a shown in *Table 1*. IEEE 802.11a Signal Bandwidth is shown in *Figure 3*, and the block schematic shown in *Figure 4* is referred in the development of a test model for OFDM transmitter and receiver, here the highlighted blocks of PAPR reduction techniques at transmitter and the receiver is already described with *Figure 2*, in detailed manner. The error-correcting code is not used for current implementation to simplify the design and focus on evaluating the core problem of the Peak-to-Average-Power Ratio of OFDM [16-17].

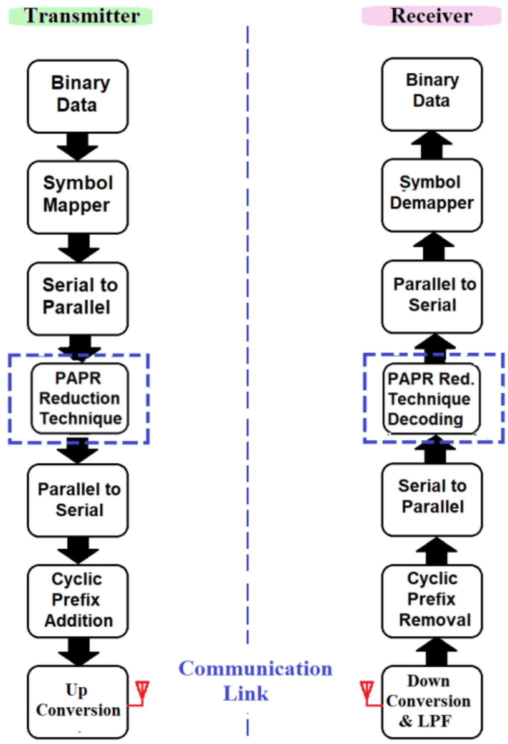

Figure-4: Block schematic of OFDM Transmitter and Receiver

## 5. METHODOLOGY

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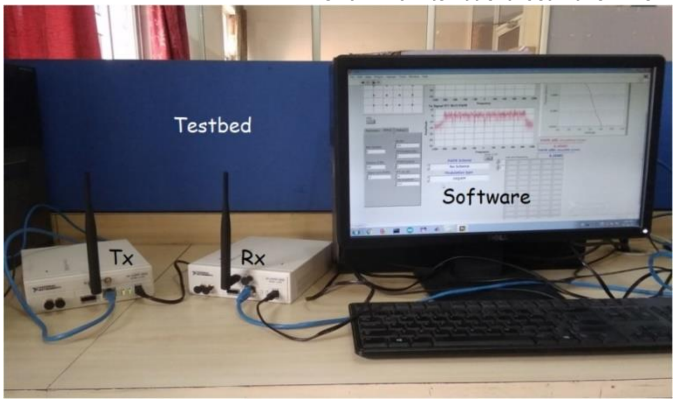



Figure-5: Test Bed with Software Defined Radio- NI USRP 2922

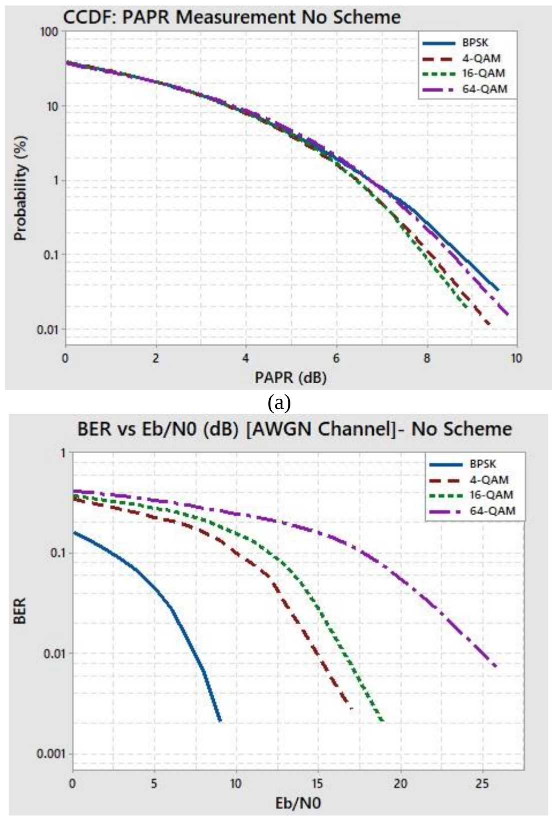
The OFDM signal design is validated with NI USRP as shown in *figure 5*, based on this design the PAPR algorithm is appended in this signal. Simulation model of Transmitter and Receiver with IEEE 802.11a system specifications are implemented for the AWGN channel model with LabVIEW development. The comprehensive evaluation of the proposed technique is done with the various admired PAPR reduction techniques in OFDM viz. ACF, ACE, INT, SLM, and PTS. have been implemented for 802.11a along with proposed technique. The performance of the transmitted signal is evaluated with the CCDF tool for different PAPRs of the signal. The CCDF tool is used to know how often the random variable-here PAPR, is above a particular level. CCDF computes the power from a time-domain signal it is also known as tail distribution or 'exceedance' [18]. The CCDF curve shows, the probability of the signal power to remain above the average power level. The occurrence of false bits in the received signal is measured in terms of Bit Error Rate, and its statistical distribution over symbol power is analyzed via a tool which is plotted with BER Vs., the ratio of Energy per Bit (Eb) to the Spectral Noise Density (No), called Eb/N0. The BER vs. Eb/N0 plots are used to evaluate impact of various PAPR reduction schemes at receiver side[16][18].

## 6. RESULTS

Results include performance evaluation of five PAPR reduction schemes viz. ACF, ACE, INT, SLM and PTS with four modulation schemes viz. BPASK, 4-QAM, 16-QAM and 64-QAM as per 802.11a standard. Firstly, these evaluations are performed on the OFDM signal without any PAPR reduction scheme and lastly the evaluations are performed for proposed technique.

Figure 6 to Figure 12, part (a) shows the CCDF Plots and part (b) shows BER Vs Eb/N0 Plots for all the four Modulation schemes. The interpretation of these results is as follows.

a) Firstly, as depicted in figure 6, the OFDM signal is test for without any PAPR reduction technique where the exceedance reached up to 10dB. The variance of all the modulation techniques is not remarkable. Received signal show the BER vs Eb/N0 varying from 8 to 30 dB, here with the increase in constellation size BER degrades linearly.
b) The Amplitude Clipping and Filtering is the least complex method that has minimum computational complexity but has in-band distortion and out of the band radiation. ACF causes signal degradation and the worst BER Vs Eb/N0 performance. It is classified under the signal distortion PAPR reduction technique. The exceedance of the PAPR value can be observed up to 7 dB as shown in *figure 7*.
c) In ACE the outer constellation points in the data block are dynamically extended further out. Note that, this technique requires additional power to regulate the peak-to-average power ratio unlike with the previous techniques. ACE has lesser computational complexity and the CCDF value with this technique lies in between 7 to 8 dB As Illustrated in *Figure 8*.
d) In the Interleaving (INT) method a random permutation matrix is used which is known at both the transmitter and receiver side. The exceedance of the PAPR values can be reduced in the range of 6-9 dB as shown in the CCDF plot in *figure 9*.
e) With the SLM technique, the CCDF plot can be seen much improved with The exceedance of the PAPR value up to 6-7dB for the cost of increased computational complexity as shown in *Figure 10*.
f) The PTS Technique is also taking high computational complexity due to a large number of multiplications, as in PTS the modulated symbols are partitioned into several sub-blocks, and then there is the multiplication of the weighted phase vectors with these sub-blocks, as described in section 3. But PTS complexity is not as much the SLM requires. *Figure 11* shows the CCDF plot of PTS that exceedance is up to 7 dB.




(a)

(b)

Figure-6: (a) CCDF Plot for PAPR at Transmitter
(b) BER Vs Eb/N0 Plot for AWGN Channel at Receiver

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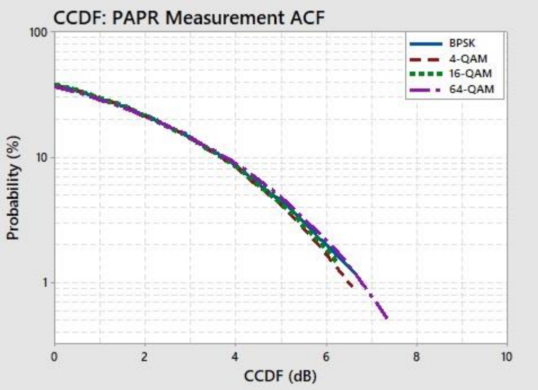
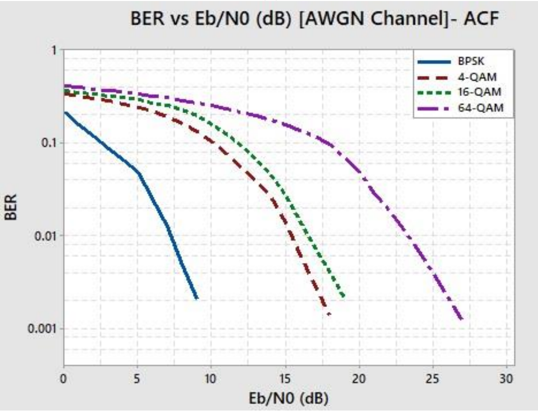
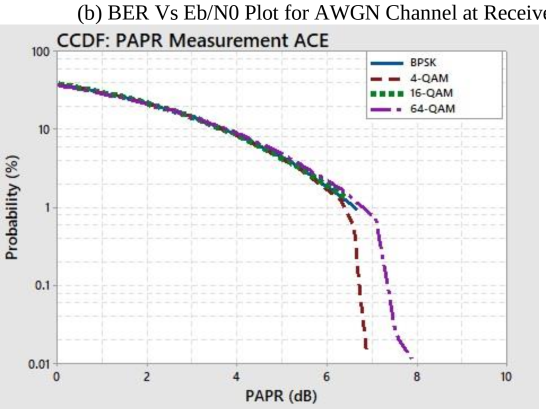


(a)

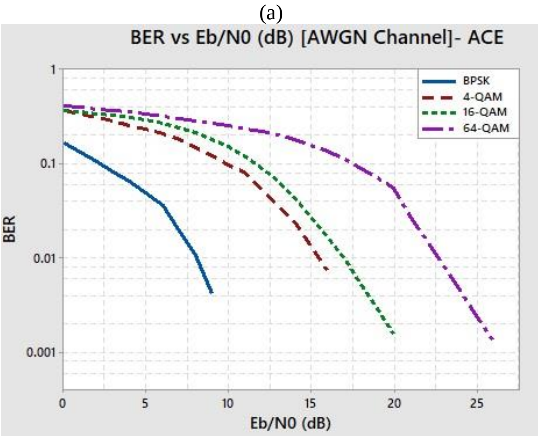


(b)

Figure-7: ACF: : (a) CCDF Plot for PAPR at Transmitter
(b) BER Vs Eb/N0 Plot for AWGN Channel at Receiver

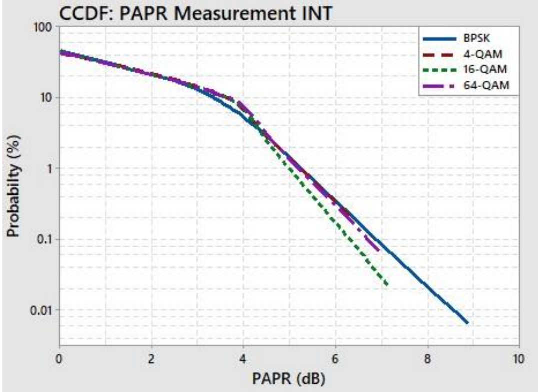


(a)

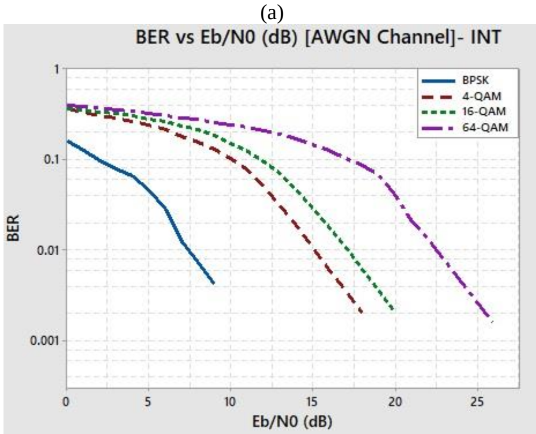


(b)

Figure-8: ACE : (a) CCDF Plot for PAPR at Transmitter
(b) BER Vs Eb/N0 Plot for AWGN Channel at Receiver

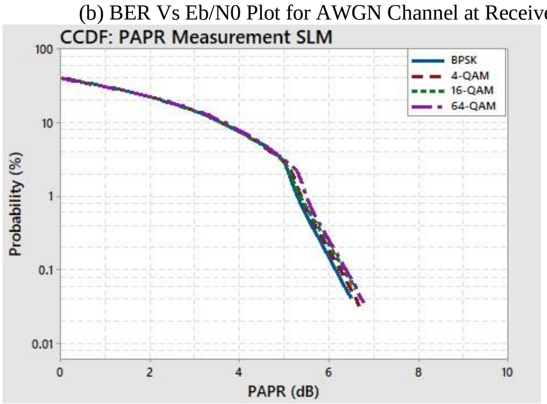


(a)

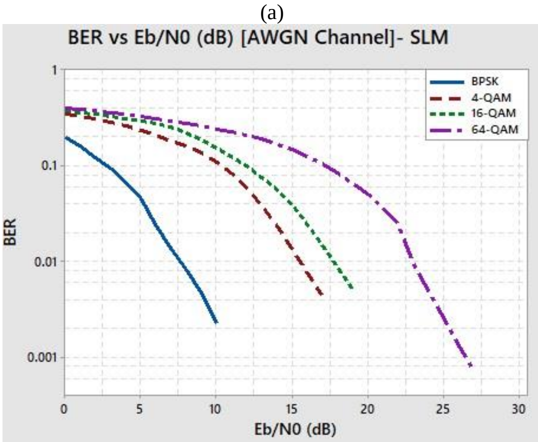


(b)

Figure-9: INT: : (a) CCDF Plot for PAPR at Transmitter
(b) BER Vs Eb/N0 Plot for AWGN Channel at Receiver



(a)



(b)

Figure-10: SLM Technique : : (a) CCDF Plot for PAPR at Transmitter
(b) BER Vs Eb/N0 Plot for AWGN Channel at Receiver

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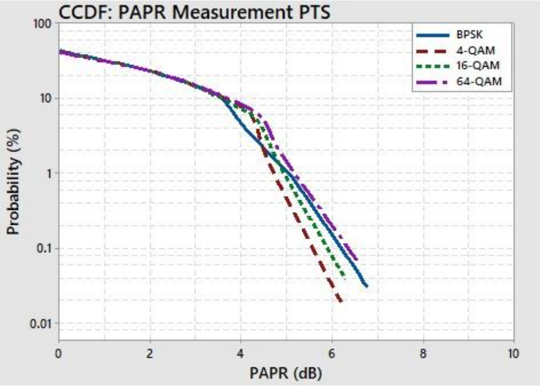
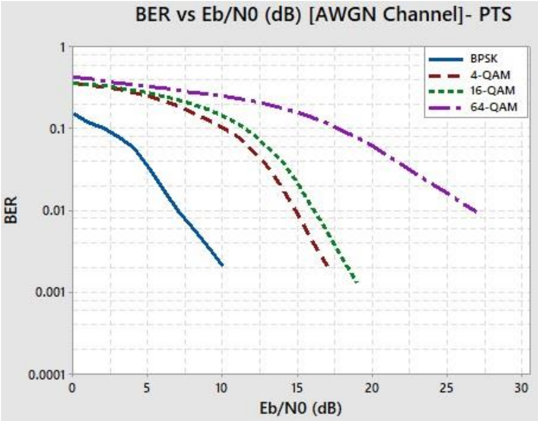
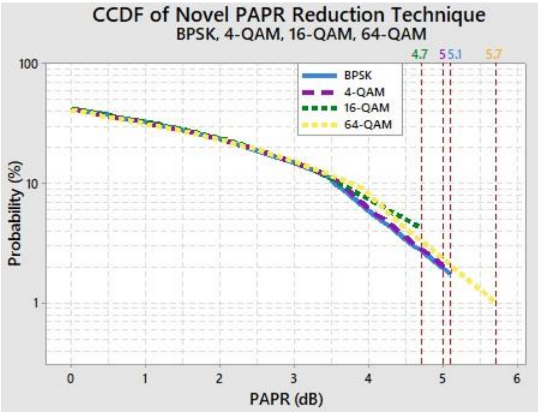



(a)

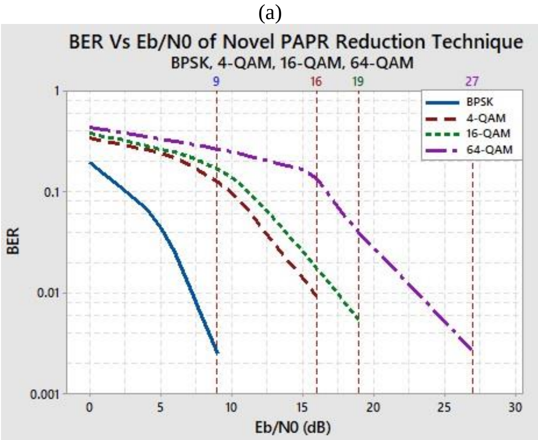



(b)

Figure-11: PTS: : (a) CCDF Plot for PAPR at Transmitter
(b) BER Vs Eb/N0 Plot for AWGN Channel at Receiver




(a)




(b)

Figure-12: Proposed Method: (a) CCDF Plot for PAPR at Transmitter
(b) BER Vs Eb/N0 Plot for AWGN Channel at Receiver

The proposed method has adequate computational complexity and BER performance with reduced PAPR value as shown in *Figure 12*. PAPR value lies in between 4 to 6 dB for various modulation schemes. *Table 2* shows the comparative analysis of exceedance PAPR values of different PAPR schemes with various modulation techniques with which we may conclude the proposed method is an improved version of existing PAPR reducing techniques

Table 2: Comparative analysis of PAPR values of different PAPR schemes with various modulation techniques

| PAPR SCHEMES | (Max Exceedance PAPR Value (dB) for Different Modulation Techniques | | | |
|---|---|---|---|---|
| | BPSK | 4-QAM | 16-QAM | 64-QAM |
| No Scheme | 9.6 | 9.4 | 8.9 | 9.8 |
| Proposed Scheme | 5.1 | 5.1 | 4.7 | 5.7 |
| SLM | 6.5 | 6.7 | 6.6 | 6.8 |
| PTS | 6.8 | 6.2 | 6.3 | 6.6 |
| ACF | 6.7 | 6.6 | 6.3 | 7.4 |
| INT | 8.9 | 6.3 | 7.2 | 7 |
| ACE | 6.7 | 6.9 | 6.4 | 7.9 |

## 7. CONCLUSION

A Rigorous evaluation of some of the prominent PAPR reduction techniques viz. ACF, ACE, INT, SLM and PTS is done by implementing them in LabVIEW environment. All these techniques along with OFDM signal and without PAPR reduction and with Proposed PAPR reduction techniques are evaluated with CCDF at transmitter and BER vs Eb/N0 at receiver over AWGN. Evaluation is done as per IEEE 802.11a WLAN standard, thus all four Modulation Technique viz. BPSK, 4-QAM, 16-QAM and 64-QAM are tested. Based on these implementations we have come up with following outcomes:

i. Computational complexity has been significantly reduced by reducing the number of phase rotation vectors, thus number of multiplications.
ii. Applying ACF post phase rotation helped to reduce PAPR exceedance further without compromising BER degradation.
iii. Present method is inherited from PTS, SLM and ACF, but compare to all these three methods we could get less *computational complexity* and *better BER degradation*.

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## FUTURE SCOPE

The algorithm is designed and tested for the IEEE 802.11a Wi-Fi standard, furthermore, it can be used to improve the performance of other W-Fi standards as well also Digital Video Broadcasting, IEEE 802.16 WiMAX, LTE, etc There is a scope of development and deployment of the Multiple Input Multiple Output (MIMO) antenna technique.

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