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Hybrid PAPR Reduction Technique of OFDM based Cognitive Radio

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Abstract: **Cognitive radio technology allows unlicensed user to utilize the free licensed band intelligently to solve the problem of scarcity in the spectrum with the increase in use of wireless communication. Cognitive radio has the capability to learn and adapt their wireless transmission according to the surrounding radio environment. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique which is used in cognitive radio because of its capability of overcoming the problem of low data rate transmission. OFDM is high data rate transmission technique. The main issue of OFDM is high PAPR (peak to average power ratio). Various techniques such as clipping, coding, selective mapping (SLM), partial transmit sequence (PTS) and tone reservation, are available to reduce the PAPR. In this paper, a new approach of hybrid technique (combination of PTS and clipping technique) is proposed.**

Keywords: **Cognitive Radio, OFDM, PAPR, PTS, Clipping.**

I. INTRODUCTION

A radio spectrum is the most precious resource in wireless communication. With the increase in use of wireless technologies, need of spectrum increases and it becomes the scarce resource because the spectrum is assigned to the licensed users. The spectrum is not utilized all the time by the licensed user which leads to the spectrum holes (free licensed bands) in the spectrum. Cognitive radio is the best solution to overcome the scarcity problem. Cognitive radio is basically an intelligent and adaptive radio or a system that can sense its environmental condition and can change its radio operating parameters dynamically and autonomously to alter system operation such as frequency band, modulation mode, transmission power [1]. In cognitive radio network, unlicensed users (also known as cognitive users) can use free licensed band which is not used by licensed users at that time [2]. There are two issues of cognitive radio, namely Intersymbol Interference and slow data rate transmission because single high data rate carrier is used to transmit the data in cognitive radio system.

Orthogonal Frequency Division Multiplexing (OFDM) is the most favorable modulation technique which is used in cognitive radio systems to solve its problems. OFDM is also used in number of wireless communication technologies such as WiFi, WiMAX (Worldwide Interoperability for Microwave Access), Digital Audio and Video Broadcasting [3]. OFDM is a high data rate transmission technique because multiple subcarriers of low data rate are used to transmit the data which are orthogonal to each other. One of the main issues of OFDM is high PAPR of the transmitted signal. Because of high PAPR, the signal is distorted in non-linear region and the performance of bit error rate also degrades [4]. Therefore, to solve this problem, there are a number of techniques like clipping technique, selective mapping technique, partial transmit sequence technique etc. Among all the techniques, PTS technique is an attractive solution due to its good performance of PAPR reduction without any distortion in the signal [5]. This paper introduces the combination of PTS and clipping technique.

II. PAPR PROBLEM

The main issue in the OFDM is high PAPR. The power of some signals might increase instantaneously, when modulated subcarriers are merged coherently, which crosses the average power and it generates the problem of PAPR. As the name implies, PAPR (peak to average power ratio) is the ratio of peak power to the average power of transmit signal. The performance of the system also degrades due to high PAPR because it increases the Bit Error Rate (BER). PAPR can be defined by (1) as:

$$PAPR(f_n) = \frac{\max power\ of\ the\ OFDM\ symbol}{average\ power\ of\ the\ OFDM\ signal} \quad (1)$$

PAPR can be expressed as (2),

$$PAPR(f_n) = 10\log_{10}\frac{\max\{|x(t)|^2\}}{E\{|x(t)|^2\}} \quad (2)$$

Where x(t) is the original signal,
$|x(t)|^2$ is the peak signal power
$E[|x(t)|^2]$ is the average power signal where E[.] is the expectation operator
PAPR is the relation between the maximum power of a sample in a given OFDM symbol divided by the average power of that OFDM symbol [6]. So the best solution is to mitigate the PAPR before OFDM signals have been sent to nonlinear high power amplifier and DAC. PAPR must be reduced for lesser complexities, higher efficiency and greater stability [7].

Effect of PAPR

a. Signal peaks get into non-linear region of the power amplifier if power amplifier is not operated in linear region which will cause signal distortion.
b. In power amplifiers, high peaks cause saturation which leads to intermodulation products among the subcarriers and will also disturb out-of-band energy [8].

III. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION (CCDF)

The most commonly used method to evaluate the PAPR is to determine the probability that PAPR of the signal exceeds a certain threshold PAPR0 which is represented by CCDF [9]. It is the distribution of PAPR that shows the amount of time a signal spends above the average power level of the measure signal which is expressed as:
CCDF (PAPR(x)) = Pr [PAPR>PAPR0]

IV. PAPR REDUCTION TECHNIQUE

PAPR is the major issue of OFDM system. Different techniques are present to mitigate the PAPR such as Clipping, Coding, Selective Mapping (SLM), Partial Transmit Sequence (PTS) and Tone Reservation technique. In this paper, two techniques, that are, PTS and clipping techniques are used to reduce the PAPR. PTS technique is one of the most important methods to reduce the PAPR because it does not distort the data.

a. Partial Transmit Sequence technique

In this technique data signal is partitioned into m-sub blocks and a different phase factor is chosen for each subpart. Then each part is submitted to IFFT block which convert the frequency domain to time domain. After this, each sub portion is multiplied by a different phase factor and selects that phase factor for each subpart of the signal which has minimum PAPR value [13] as shown in Fig. 1.

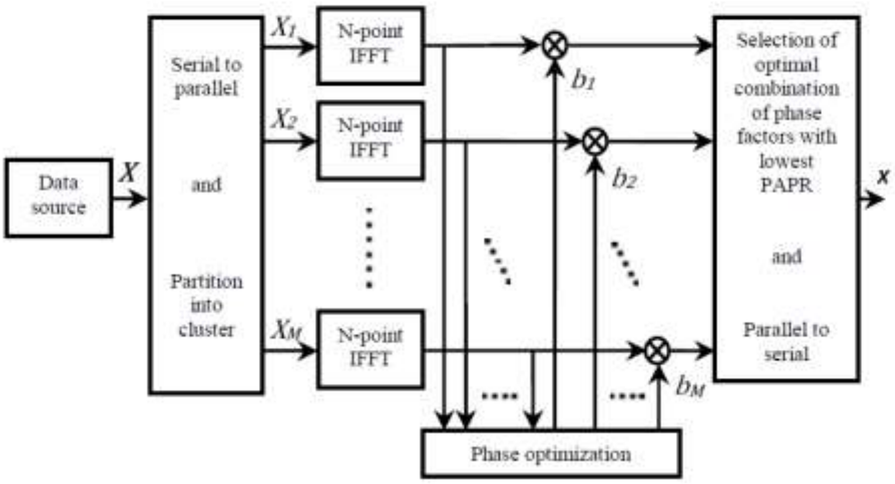


Figure 1: Block Diagram of PTS technique

Sub-blocks partitioning can be done by three methods: adjacent partition, pseudorandom partition and interleaved partition and each sub-block has equal size.

- **Interleaved sub-block partition:** It is the sub-block partitioning where every subcarrier signal is equally spaced apart at same sub-block.
- **Adjacent sub-block partition:** In this partial transmit sequence scheme, successive subcarriers are assigned into same sub-block.
- **Pseudorandom sub-block partition:** In this, each subcarrier signal is assigned randomly at any one of the sub-block.

Among all, interleaving sub-block partition is the best in terms of computational complexity but it has the least PAPR reduction. Pseudorandom sub-block partition is the best for PAPR reduction but it has high computational complexities [15].
The efficiency increases with the increase in number of phases and number of blocks used. But it requires large number of computations to select the appropriate phase factor for each subpart of the signal which has minimum PAPR value.

b. Clipping Technique

It is the simple and easiest technique to reduce PAPR. In this technique, high PAPR is reduced by cutting the amplitude of the modulated signal greater than the threshold value before the transmission at the transmitter end while the phase is saved. The part of the signal which is greater than the allowed region are to be clipped. The block diagram of clipping and filtering is shown in Fig. 2.

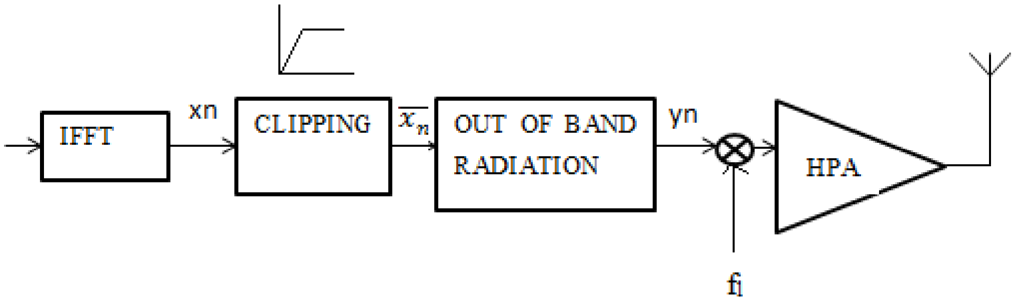


Figure 2: OFDM transmitter including clipping technique

The clipping ratio (CR) is defined by (3) as [10],

$$CR = \frac{A}{\sigma} \tag{3}$$

where A= Amplitude and σ= root mean squared value of the unclipped OFDM signal.
The output signal after clipping is expressed in (4) as,

$$x_n = \begin{cases} Ae^{j\phi n}, & (|x_n| > A) \\ x_n, & (|x_n| \leq A) \end{cases} \tag{4}$$

where ϕ_n= phase of baseband OFDM signal of x_n
A= Threshold value

The advantage of clipping and filtering technique is that it does not require side information to send along with the data signal to the receiver [11] and no operation is performed at the receiver to recover the original signal as well. It reduces the PAPR but it also produces the in-band radiation and out-band radiation which reduces the spectral efficiency [12].

V. PROPOSED TECHNIQUE

The proposed hybrid technique of PAPR reduction is the combination of partial transmit sequence technique and clipping technique which is used to reduce the high PAPR problem of OFDM signal at transmitted end. The key idea of hybrid technique is based on the observation that combination of two techniques reduces PAPR value more than individual technique and also increases the overall performance of the system.

PTS technique is an attractive technique because it reduces PAPR better without any distortion in the signal at the transmitting end. The main issue of PTS technique is increase in complexity due to increase in number of sub-blocks and amount of side information to be sent for recovery of original signal. Clipping technique is signal distortion technique which distorts large amount of signal but it reduces the high PAPR. So the combination of two, proposed hybrid technique reduces the PAPR.

The main focus of the proposed method is to reduce PAPR and the complexity which arises mainly due to number of sub-blocks. As the number of sub-blocks increases, more IFFT operations will be performed and the computational complexity increases. So, few numbers of sub-blocks are used to reduce the PAPR in proposed technique as comparison to obtain the PAPR using large number of sub-blocks in PTS technique. By using minimum number of sub-blocks, less amount of side information needs to be sent for recovering the original signal. So, the proposed technique obtains better results at minimum number of sub-blocks. Block diagram of hybrid technique is shown in Fig. 3.

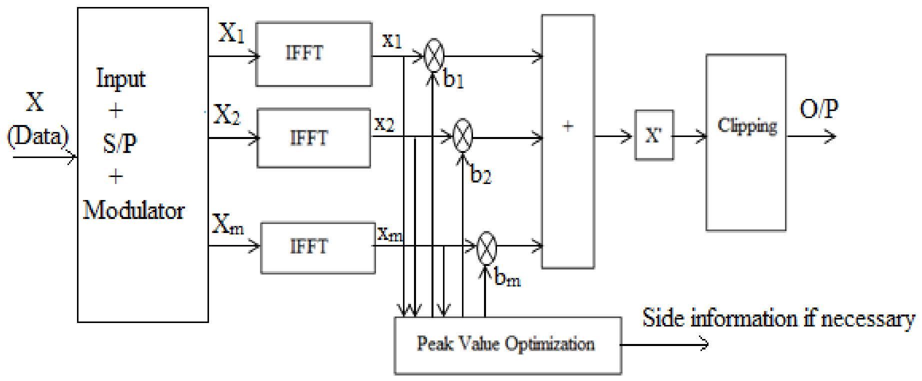


Figure 3: Block Diagram of Hybrid Technique

Following are the steps which are used to perform the process to mitigate the PAPR:

Step1: The input data is first modulated with different modulation schemes (BPSK, QPSK, QAM etc.). The signal is converted into parallel form by passing through serial to parallel conversion.
Step2: The PTS technique is applied first and in this technique, frequency vectors are partitioned into number of sub-blocks and to separate the sub-blocks combination of interleaved and adjacent sub-block partitioning methods are used.
Step3: The signal is then converted to time domain from frequency domain with the help of IFFT operation at the same time. The output of IFFT operation is then rotated by the set of complex phase factors to reduce the PAPR.
Step4: Then, the sub-blocks are combined to get the minimum PAPR. The PAPR transmitted signal is a combination of sub-blocks. Therefore, time domain signal after combination is expressed in (5) as,

$$X' = \sum_{m=1}^{m} x_m b_m \quad (5)$$

After combining the sub-blocks, the output is transmitted further for clipping technique.
Step7: A clipping ratio is selected intelligently so that it does not affect the bit error rate and reduces the high PAPR. Clipping operation is expressed in (6) as,

$$X' = \begin{cases} X' & if\ |X'| \leq A \\ A & if\ |X'| > A \end{cases} \quad (6)$$

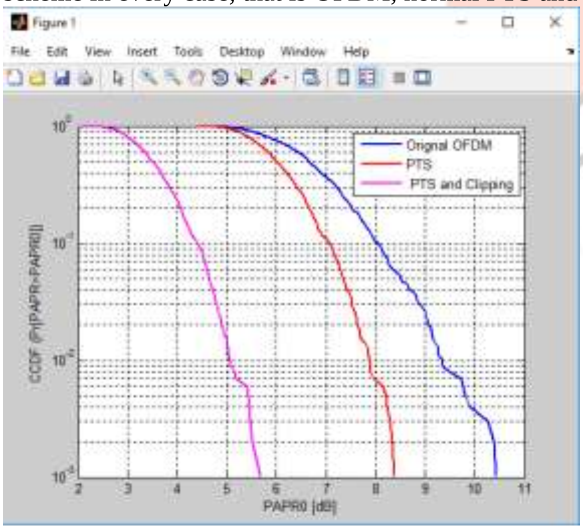
Where A= Clipping level is expressed in (7) as,

$$A = \max(X').\ \alpha \quad (7)$$

where α=clipping ratio. If α= 1, it means no clipping because A will be equals to the maximum value of OFDM signal. Clipping increases with the decrease in clipping ratio due to decrease in the value of A.
With the help of clipping ratio, signal will be clipped. With different sets of obtained phase rotation values, the process will be repeated. PAPR of the OFDM signal is obtained through each repetition. The lowest PAPR of OFDM signal is transmitted without much distortion in the signal.

VI. SIMULATION AND RESULT

The proposed method is simulated on MATLAB. In this section, numerical simulation for original OFDM signal, normal PTS technique and hybrid technique is presented. PAPR reduction performance is evaluated by the CCDF. Simulation uses different modulation scheme (QPSK, 16-QAM, 32-QAM), number of sub-blocks L=4, different input data block length (N=64, 128) and clipping ratio is 0.7. In order to generate CCDF, 1000 OFDM blocks are randomly generated.
In Fig. 4, CCDF of the PAPR for original OFDM signal, normal PTS technique and hybrid technique is shown at CCDF= 10^{-1}. The simulation uses number of subcarriers 64. For QPSK modulation, PAPR of proposed technique is 4.44dB while the PAPR of OFDM signal and normal PTS is 8.1 dB and 7.12 dB respectively. In Fig. 5, PAPR of proposed technique is 4.43 dB while the PAPR of OFDM signal and normal PTS is 8.01 dB and 7.12 dB respectively for 16-QAM modulation scheme. In Fig. 6, PAPR of proposed technique is 4.3 dB while the PAPR of OFDM signal and normal PTS is 8.01 dB and 6.96 dB respectively for 32-QAM modulation scheme. As compared to above results, PAPR value in 32-QAM is less than PAPR value of QPSK modulation scheme in every case, that is OFDM, normal PTS and proposed technique.



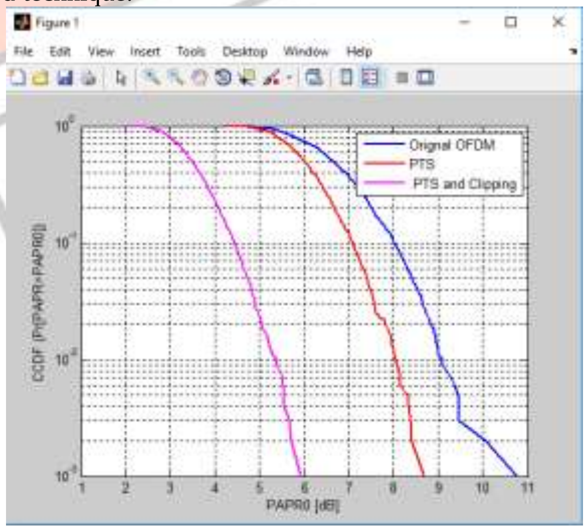
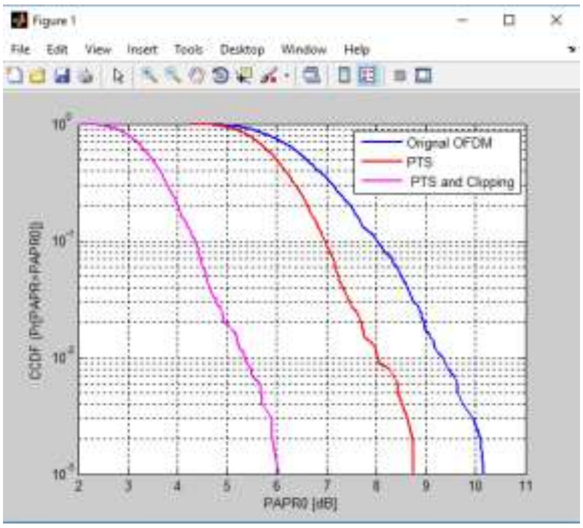


Figure 4: PAPR vs CCDF when N=64 for QPSK modulation
Figure 5: PAPR vs CCDF when N=64 for 16-QAM modulation



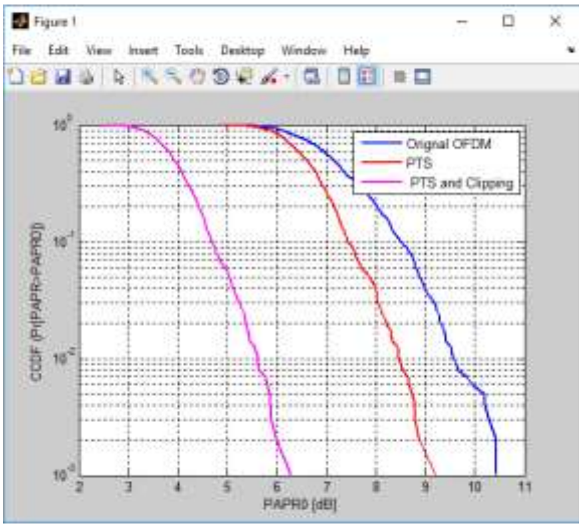
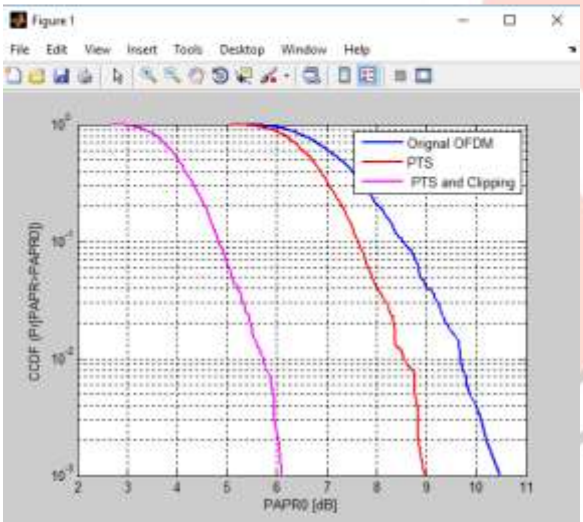


Figure 6: PAPR vs CCDF when N=64 for 32-QAM
Figure 7: PAPR vs CCDF when N=128 for QPSK modulation

The simulation uses number of subcarriers 128. Fig. 7 shows CCDF of the PAPR for original OFDM signal, normal PTS technique and hybrid technique at CCDF=10^{-1}. For QPSK modulation, PAPR of proposed technique is 4.65 dB while the PAPR of OFDM signal and normal PTS is 8.54 dB and 7.42 dB respectively. In Fig. 8, PAPR of proposed technique is 4.85 dB while the PAPR of OFDM signal and normal PTS is 8.51 dB and 7.62 dB respectively for 16-QAM modulation. In Fig. 9, PAPR of proposed technique is 4.62 dB while the PAPR of OFDM signal and normal PTS is 8.42 dB and 7.54 dB respectively for 32-QAM modulation.



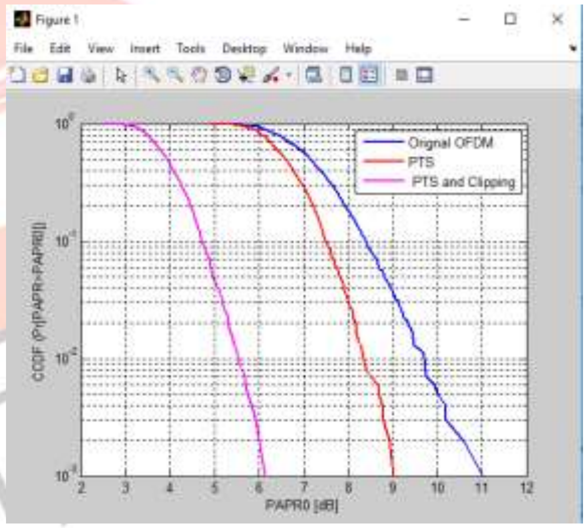


Figure 8: PAPR vs CCDF when N=128 for 16-QAM modulation
Figure 9: PAPR vs CCDF when N=128 for 32-QAM modulation

Comparison of CCDF of PAPR of proposed method, normal PTS technique and OFDM signal using different modulation scheme (QPSK, 16-QAM, 32-QAM) with different number of subcarriers (N=64,128) with clipping ratio 0.7 is shown in Table 1.

Table 1 PAPR values with clipping ratio=0.7

Size of N	Modulation Scheme	PAPR of OFDM signal(dB)	PAPR of PTS technique (dB)	PAPR of Proposed technique (dB)
	QPSK	8.1	7.12	4.44
64	16-QAM	8.01	7.12	4.43
	32-QAM	8.01	6.96	4.3
	QPSK	8.54	7.42	4.65
128	16-QAM	8.51	7.62	4.85
	32-QAM	8.42	7.54	4.62

VII. CONCLUSION

Cognitive radio is one of the best wireless technologies to manage the problem of shortage in the spectrum. OFDM is highly favorable modulation technique which is used in cognitive radio for high data rate transmission and spectral efficiency. By using OFDM in cognitive radio, interoperability can be provided among first responders (police, fire, safety departments). Various advantages and problems of OFDM are discussed here. But the major problem of OFDM is high PAPR at the transmission end because it affects the quality of performance of system.

To minimize the high PAPR, hybrid PAPR reduction technique is proposed by combining PTS and clipping technique. Simulation results shows that hybrid technique offers better PAPR reduction.

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