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Peak-to-Average Power Ratio Reduction of OFDM Signals by Applying Low Complexity SLM and Clipping Hybrid Scheme

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Abstract: This paper presents performance analysis of Peak to Average Power Ratio (PAPR) Reduction techniques in Orthogonal Frequency Division Multiplexing (OFDM) System such as Clipping, Partial Transmit Sequence (PTS), Selective Mapping (SLM) and SLM with Clipping (Hybrid Scheme) .Complementary Cumulative Distribution Function (CCDF) is calculated for each technique with different number of sub carriers in order to analyze PAPR reduction performance and also compared with pure OFDM signal. According to our simulation results, SLM with clipping (Hybrid) technique has good PAPR reduction performance than other conventional methods, with less computational complexity.

Key words: CCDF, Clipping, OFDM, PAPR, PTS.SLM

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is one of the multi carrier transmission systems. Due to its interference rejection capability, high data rate it is mainly used in next generation (3G) wireless communication systems. However this system introduces high PAPR that is inherent in the transmitted signal. Large signal peak occur in the OFDM signal when the signals in the 'N' sub channels are added constructively in the phase. Such high Peak amplitude will saturate the power amplifier at the transmitter and results in inter modulation distortion, this can be reduced by reducing the transmit power of the amplifier in order to operate the power amplifier in linear range. This leads to inefficient in terms of power. Hence, many PAPR reduction techniques are proposed to reduce PAPR such as Distortion, Signal Scrambling and coding methods.

Clipping [2] is one of the simplest method, but this introduces clipping noise to the transmit signal and will degrade Bit Error Rate (BER) performance. So the clipped signal is passes through filter.

Clipping and Filtering [3] eliminates out of band radiation at the cost of peak re-growth. So, the filtered signal again will exceed the clipping threshold. To reduce the peak re growth problem the paper [8]-[9] proposed a method called iterative clipping at many times. However, the more clipping, degrades the BER performance of the system.

The statistical algorithms, such as Selective Mapping (SLM)[4],Partial Transmit Sequence(PTS) [6] has relatively good PAPR reduction performance than distortion techniques. However computational complexity is high. In this approach the OFDM signal phase is rotated till PAPR reaches the minimum value.

The idea behind this paper is to further reduce PAPR of OFDM signal with less complexity by applying SLM and clipping method with appropriate modulation technique with smaller number of subcarriers without affecting BER performance of the system.

This paper is organized as follows. In sec.2 the definition of PAPR is given .In sect.3 existing PAPR reduction algorithm is given. The Numerical Result is given in sec.4.Then conclusion is given in sec.5.

2. PAPR in OFDM signal

Let us consider the total number of subcarriers in the OFDM system is 'N', and X (k), $0 \leq k \leq N$ represents the input Sequence. Then IFFT is taken for X (k) and the output is time domain

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complex signal x(t) which is expressed as

$$x(t) = \sum_{k=0}^{N-1} X(k)\exp(j2\pi f_k t), t \in [0,T]. \quad (1)$$

and x(t) is sampled at t=T/N, then sampled time domain signal x(n) can be written as

$$x(n) = \sum_{k=0}^{N-1} X(k)\exp\left(j\frac{2\pi}{N}nk\right), 0 \le k \le N, \quad (2)$$

Where X (k) is the signal on the K^{th} sub- channel and x (n) is OFDM signal.

The PAPR (dB) of the OFDM signal x(n) is defined as the ratio between Maximum power at a particular sampling instant and average power of the OFDM signal.

$$\text{PAPR (dB)} = \frac{\max[|x(n)|^2]}{E[|x(n)|^2]} \quad (3)$$

PAPR is a random variable .Therefore PAPR can be measured using Complementary Cumulative Distribution Function (CCDF).It is defined as Probability that PAPR greater than the threshold value ($PAPR_o$).

$$CCDF=Pr(PAPR>PAPR_o) \quad (4)$$

Figure 1 shows the CCDF of OFDM signals for different number of sub carriers i.e. N=64,128,256,512 respectively. In the graph bold line represent theoretical (T), dotted line represent the simulated values(S). The results demonstrate that given the threshold value of PAPR, the CCDF will increase when the number of subcarriers (N) becomes larger in the OFDM system.

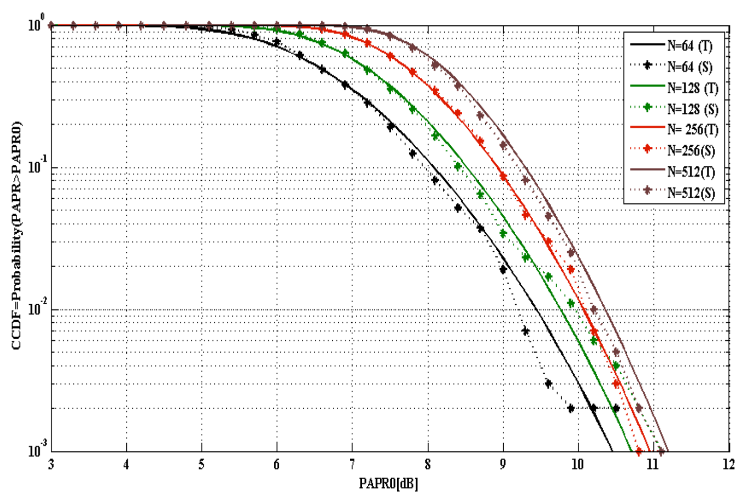

Figure 1. CCDF of OFDM signals with N=64,128,256,512

3. PAPR Reduction Techniques

A.1. Clipping Method

Figure.2 shows the block diagram of OFDM system with clipping. The randomly generated input sequences are fed to the BPSK/QPSK/QAM modulator, then it is converted into 'N' parallel symbols and N-point IFFT is taken for the input symbols. After that clipping is performed, in the process of clipping, a clipping level (A) is set to perform clipping before digital to analog (D/A) conversion. The sample value which exceeds clipping level (A) is directly clipped and the values below the threshold are kept unchanged.

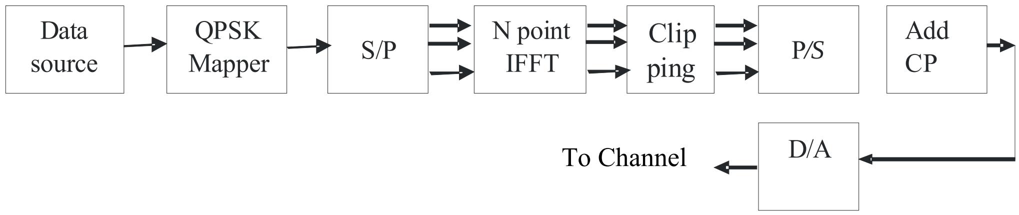

Figure 2. OFDM system model with clipping

Let us consider, the input signal is x (n), the output signal is y (n) then the clipped version of output signal can be expressed as

$$\tilde{y}(n) = \begin{cases} A, & |x(n)| \succ A \\ x(n), & |x(n)| \leq A \end{cases} \tag{5}$$

Clipping ratio can be defined as the ratio between clipping level (A) and RMS value of OFDM signal(σ)

$$\text{CR=}\ \frac{A}{\sigma} \tag{6}$$

A.2. Partial Transmit Sequence (PTS) Algorithm

In conventional PTS algorithm the randomly generated input sequences of length 'N' is partitioned into 'V' number of disjoint sub blocks i.e. v=1, 2, 3… V. There are three sub block partitioning methods i.e Pseudo-random, interleaving and adjacent partition. Then IFFT is taken. Subcarriers in each sub block are weighted with set of complex phase factors i.e.$b^v=e^{j\varphi v}$,v=1, 2,.., V and the one with minimum PAPR is selected for transmission.

$$\text{X=IFF}\left\{\sum_{v=1}^{V} b^v X^v\right\} = \sum_{v=1}^{V} b^v x^v \tag{7}$$

In the PTS algorithm, exhaustive search is made to get the optimum phase set. Hence computational complexity is high. The search complexity exponentially increases with number of subcarriers. Pseudo random partition exhibits good PAPR reduction performance, and interleaving method provides low computational complexity in the OFDM system.

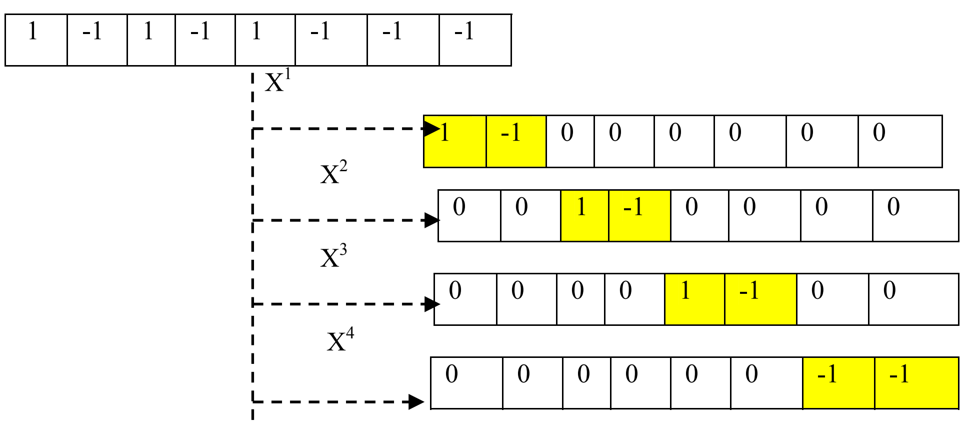

Figure 3. Input sequence' X' is partitioned in to v=4subblocks(X^1, X^2 ,X^3, X^4)

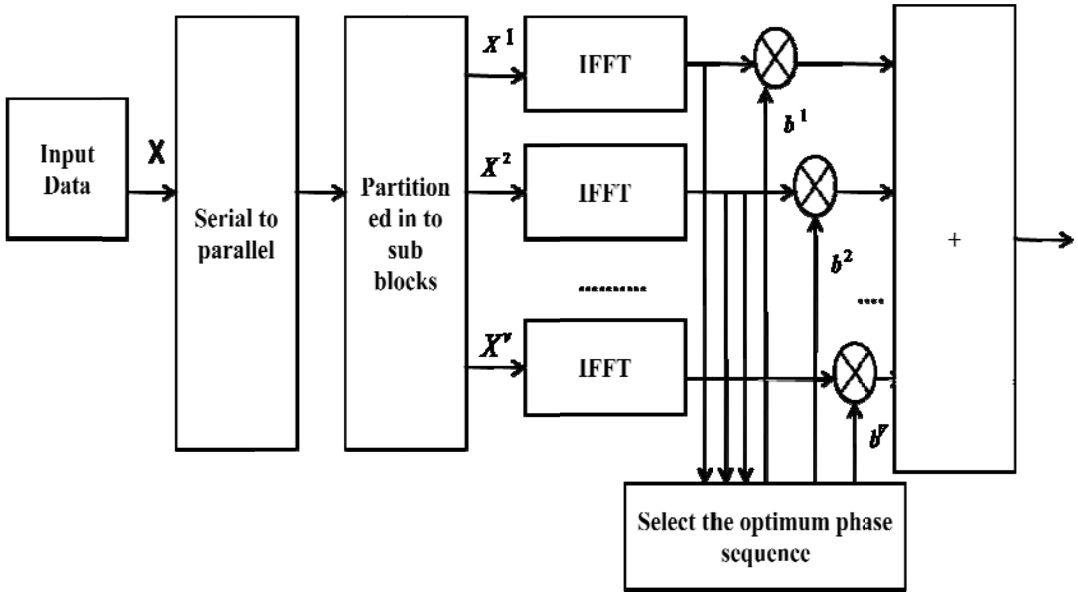

Figure 4. Block Diagram of OFDM system with PTS

Figure 4 illustrates the block diagram of OFDM with PTS. In this input sequence' X' is partitioned in to v=4 sub blocks(X^1,X^2 ,X^3,X^4) as shown in Figure 3. Where'X^v' is the Partial Transmit Sequence (PTS).These PTS are independently rotated by the phase vector 'b^v'. Then the phase vector corresponding to minimum PAPR is selected for transmission. This is given as

$$\left[\tilde{b}^1,,,,\tilde{b}^V\right] = \underset{[b^1,\ldots b^V]}{\arg\min}\left(\max_{n=0,1,\ldots,N-1}\left|\sum_{v=1}^{V} b^v X^v[n]\right|\right) \tag{6}$$

The objective is to combine all the sub blocks (v) optimally to obtain minimum PAPR without any loss in performance. This can be achieved by employing sub optimal combination algorithms.

Low Complexity search Algorithm

In Conventional PTS, the set of allowable phase factor is b=$\left\{e^{j2\pi i/w} \middle| i=0,1,2,3,\ldots,W-1\right\}$,$W^{V-1}$ phase vectors should be searched to find the optimum phase vector. However many schemes are proposed to reduce search complexity in PTS. One simplest method is sub optimal combination algorithm. In which allowable binary phase factor is {1,-1}.This algorithm partition the input data block in to 'V' number of sub blocks. (i)Then set the phase vectors b^v=1, for v=1…V, calculate the PAPR of eqn.(5) and set this value as the minimum PAPR.
(ii)Set v=2, find PAPR of eqn. (5) with 'b^v'=-1, if PAPR>minimum PAPR, then switch 'b^v'=1, otherwise update the Minimum PAPR=PAPR.
(iii)If v<V, increment 'v' by one and calculate the PAPR. if PAPR>minimum PAPR then switch'b^v'=-1, and repeat this until v=V. Otherwise exit this with optimal phase factors '$\tilde{b}$ '.
The number of computation required for this algorithm is 'V' which is much fewer than the conventional PTS.

A.3. Selective Mapping Algorithm (SLM)

Figure 5 illustrates the block diagram of OFDM with SLM. Here, the input data block X=[X(0),X(1),X(2),...,X(N-1)] is multiplied with 'U' different random phase sequences P^u =

$[P^u_o, P^u_1, P^u_2, ..., P^u_{N-1}]^T$, which produce modified data block $X^u = [X^u(1), X^u(2), ..., X^u(N-1)]$ to construct the symbol with the minimum PAPR to transmit. To implement this 'U' IFFT operations are required.In order to recover the original data block at the receiver ,the selected phase sequence should be transmitted as a side information [4]. In SLM computational complexity is less than PTS algorithm.

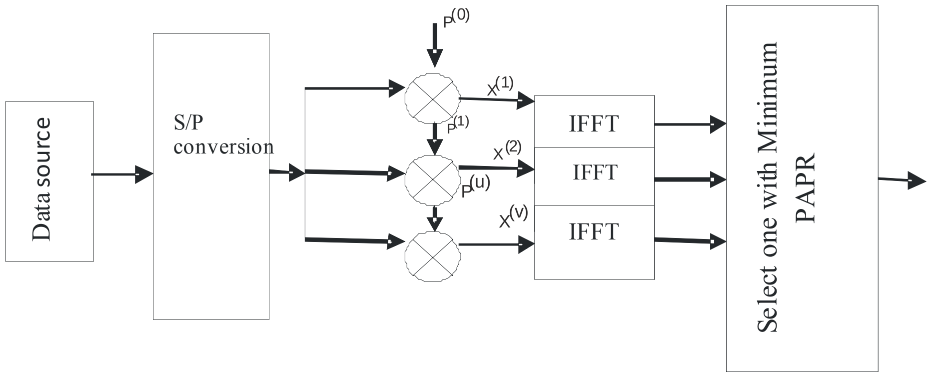

Figure 5. Selective Mapping

A.4 SLM with Clipping algorithm(hybrid technique)

The paper [14] proposed new PAPR reduction method called hybrid technique. It employs selective mapping and clipping. Clipping is a non linear operation and SLM is linear operation.Here, by applying two different types of signal processing technique, we can improve the overall PAPR reduction performance.So,this technique combines the advantage of both clipping and SLM.In this paper first SLM technique is applied to the OFDM signal then clipping is performed on selected signal for transmission. The simulation results shows that this method provides low PAPR than the conventional Clipping,SLM and PTS.

4. Numerical Results and Discussions

A. Clipping method

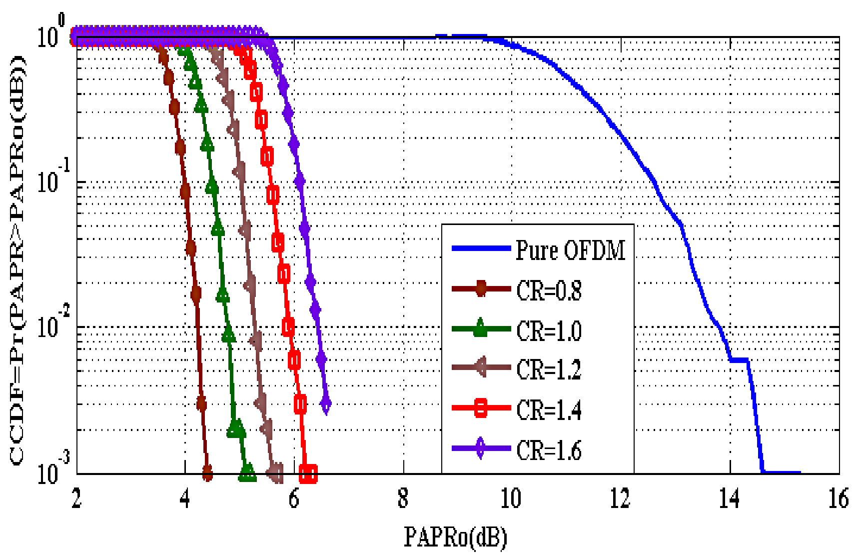

Figure 6. CCDF of OFDM with Clipping when N =64

For the purpose of performance evaluation, the following parameters were considered, number of OFDM symbols=10000, total number of subcarriers N=64, cyclic prefix (CP) length L=16, modulation type=QPSK.Figure6 shows the CCDF of OFDM with clipping method with different clipping Ratio i.e.CR=0.8, 1.0, 1.2, 1.4, 1.6 respectively. It is observed that when clipping ratio is small greater the PAPR reduction .PAPR of pure OFDM signal is 15 dB. After clipping PAPR is decreased to 4.2 dB(for CR=0.8). Hence PAPR is reduced to11dB.

B. PTS Algorithm

Figure 7, 8 shows the CCDF of PTS with different number of sub blocks i.e. v=1, 2, 4, 8, 16.The simulation has been performed with N=64 &128 subcarriers with QPSK modulation. The result presented in this paper are obtained with optimum phase sequence W= {1,-1}.From Figure 7, 8 we can observe that, if the number of sub block increases PAPR decreases. In Figure 7 the PAPR of OFDM signal is 11dB, by applying PTS algorithm PAPR value is reduced to 6 dB when V=16.Now, if we are increasing number of subcarriers N=128, then PAPR is 6.5dB as shown in Figure 8.

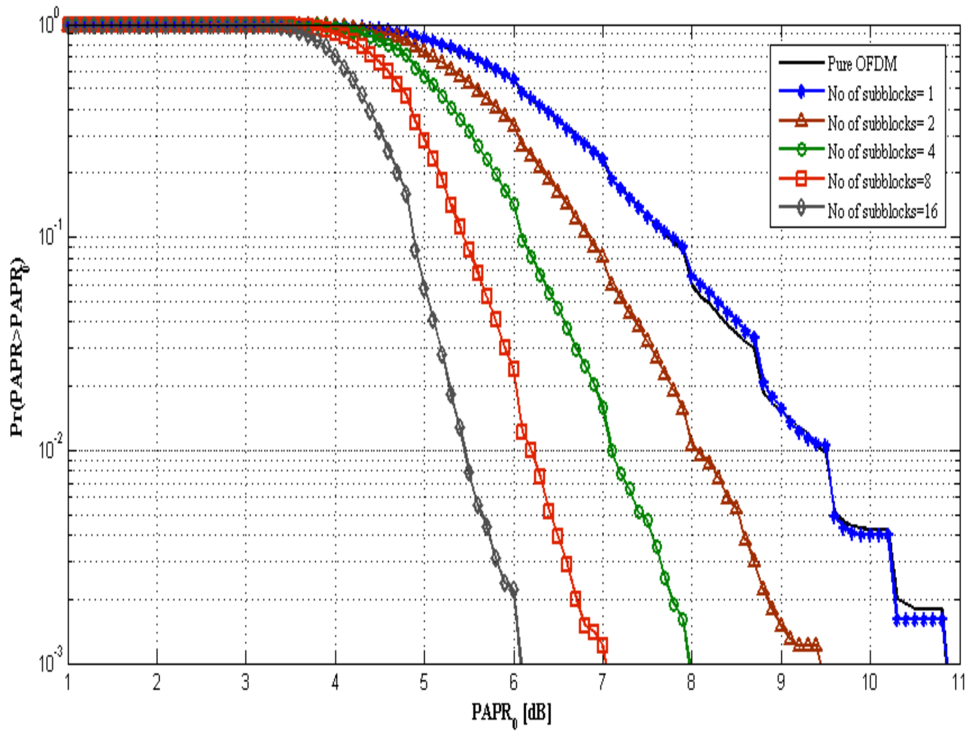

Figure 7. CCDF o f OFDM with PTS when N =64

C. SLM Algorithm

The simulation has been performed for QPSK signal with N=64 sub carriers. Each sub carrier is multiplied with randomly generated phase vector .The result presented in this paper are obtained from the phase vector containing 4 phases i.e. P = {1,-1, j,-j}.PAPR is calculated for OFDM signal with each phase .For particular phase factor OFDM signal having minimum PAPR ,that is selected and transmitted.Figure.9 shows the PAPR performance of SLM. Here PAPR of OFDM is 11.2dB by applying SLM algorithm it is reduced to 7.2dB.So this Method reduces PAPR of OFDM signal by 4 dB from its original value.

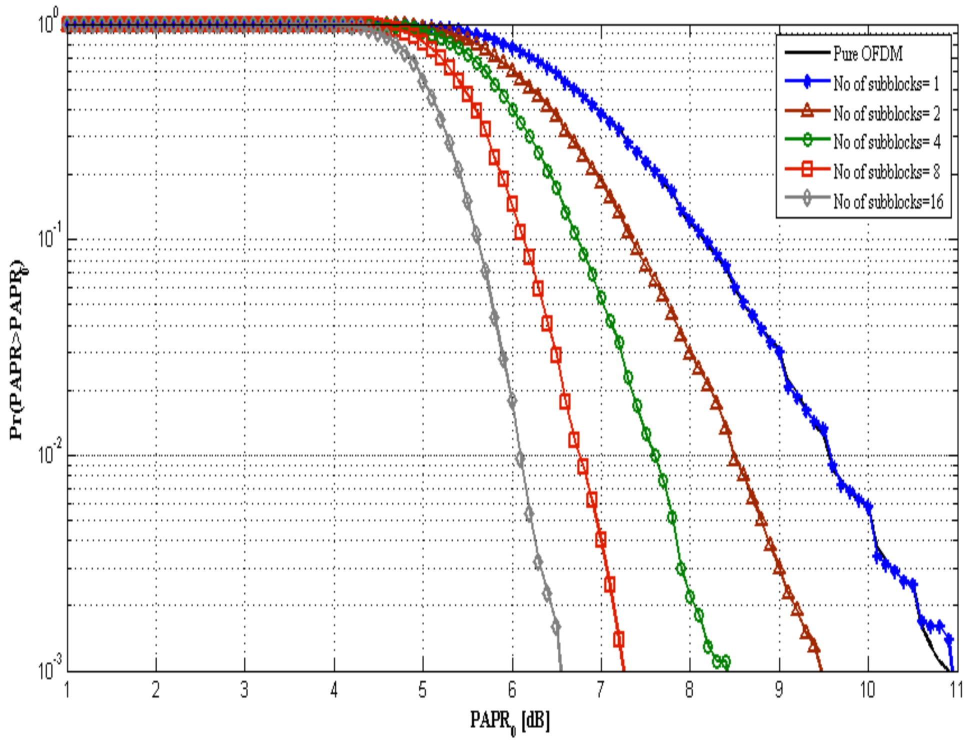

Figure 8. CCDF of OFDM with PTS when N=128

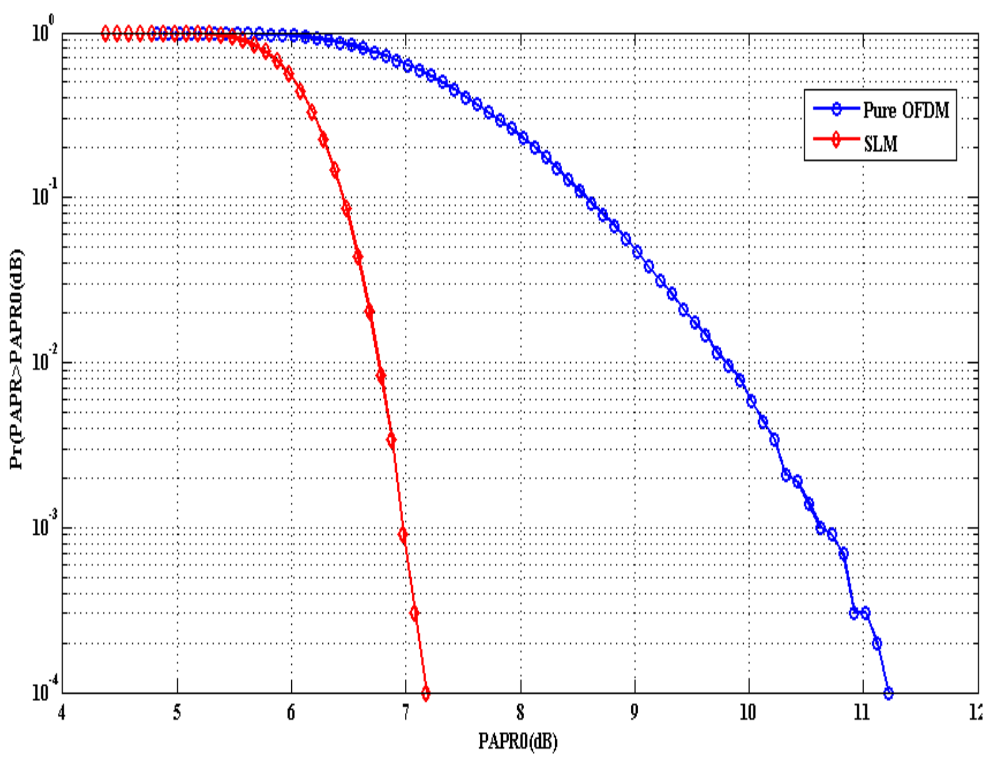

Figure 9. CCDF of OFDM with SLM when N=128

D. SLM with Clipping Algorithm (Hybrid Method)

In Figure 10, we compared the PAPR performance of SLM, Clipping, and SLM with Clipping (Hybrid method) with Pure OFDM. The simulation has been performed for QPSK signal with N=64 sub carriers. Here SLM and clipping methods were applied separately and jointly to the OFDM signal. The simulation result shows that good amount of PAPR reduction is achieved with this hybrid method. Here PAPR of SLM with Clipping is reduced to 3dB. So, hybrid method reduces PAPR of OFDM signal by 9.2 dB from its original value.

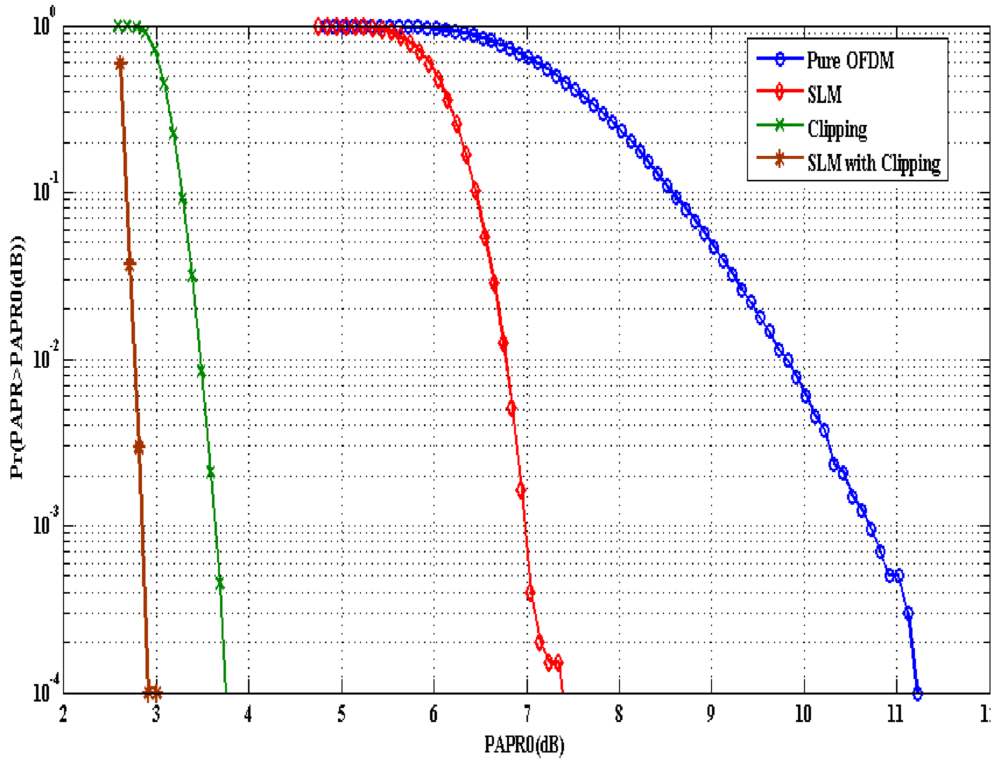

Figure 10. CCDF of OFDM with Hybrid method when N=128

5. Conclusion

In this paper we have discussed about PAPR reduction techniques for OFDM system. Clipping technique is effective and simple. However, clipping will introduce out of band interference. Hence, this method degrades the Bit Error Rate (BER) performance of the system. In PTS and SLM algorithm, main objective is to reduce PAPR .These techniques does not introduce noise as it is introduced in clipping method. Thus, the BER performance of the system is not affected much. In PTS, computational complexity depends on the number of sub blocks used and in SLM, computational complexity is less than PTS. Hence, computational complexity is less in Clipping and SLM algorithms.

For these reasons, this paper applies both the Clipping and SLM (hybrid scheme) in to transmitted OFDM signal. The simulation results shows that the hybrid method has much better PAPR reduction than the other existing methods.

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