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Comparative analysis of SLM and Iterative Flipping PAPR Reduction Techniques

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Abstract— **OFDM (Orthogonal Frequency Division Multiplexing) technique has been widely adopted in many wireless communication systems due to its high data-rate transmission ability and robustness to the multipath fading channel. Instead of a lot of advantages of OFDM technique, it suffers from the major problem of high Peak-to-Average Power Ratio (PAPR) which results inefficient use of the High Power Amplifier and could limit transmission efficiency. OFDM consist of large number of independent subcarriers, as a result of which the amplitude of such a signal can have high peak values. In this paper we have discussed different PAPR reduction techniques and compared Selective Mapping and Iterative Flipping with each other. No doubt both of techniques can minimize the PAPR value but MATLAB simulation results shows that SLM can do better PAPR reduction in comparison to IF. Moreover we analyzed that even IF does not show good PAPR reduction results but this method has less computation complexity which is also a good factor to consider its effectiveness.**

Index Terms— OFDM, BPSK, PTS, IF& PAPR

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) technology is one of the most attractive techniques for fourth generation (4G) wireless communication. It is a multicarrier modulation technique, whose dynamic range is typically two or four times larger than a single carrier system. MIMO OFDM system has many advantages over single carrier system such as robustness in frequency selective fading channels, High spectral efficiency immunity to inter-symbol interference and capability of handling very strong multipath fading [1]. Therefore this technique has been adopted by many high-speed data transmission standards such as Digital terrestrial mobile communication, Digital Audio Broadcasting (DAB), Digital Video Broadcasting terrestrial (DVB-T), wireless asynchronous transfer mode (WATM), Modem/ADSL [3]. But OFDM is having two major drawback of a high Peak-to-Average Power ratio (PAPR) and spectral efficiency loss due to guard interval. This causes clipping of the OFDM signal by the High power amplifier (HPA) and in the HPA output producing nonlinearity. This non-linearity distortion will result in-band distortion and out-of-band radiation [4]. The in-band distortion causes system performance degradation and the out-of-band radiation causes adjacent channel interference (ACI) that affects systems working in neighbor band. Hence the OFDM signal may have In-band and Out-of-band distortion which degradation of Bit-error-rate (BER) performance. One solution is to use a linear power amplifier with large dynamic range. However, best solution to reduce PAPR by using through PAPR reduction techniques [5].

There are many PAPR reduction methods have been proposed. Some methods are designed based on employing redundancy, such as coding [6], [7], selective mapping with explicit or implicit side information [8], [9], or tone reservation [10], An apparent effect of using redundancy for PAPR reduction is the reduced transmission rate. PAPR reduction may also be achieved by using extended signal constellation, such as tone injection [11], or multi-amplitude CPM. The associated drawback is the increased power and implementation complexity. A simple PAPR reduction method can be achieved by clipping the time-domain OFDM signal.

The paper is organized as follows. In Section II, OFDM model is discussed. Literature survey of existing techniques is presented in Section III. In Section IV Methodology of SLM & IF are given. Section V describes the comparative results of SLM and IF techniques. Finally, conclusions and future works are drawn in VI.

II. BASIC PRINCIPLE OF OFDM

Orthogonal Frequency Division Multiplexing is a frequency division multiplexing (FDM) scheme utilized as a digital multi – carrier modulation method [12]. A large number of closely spaced orthogonal sub – carriers is used to carry data. Figure1 shows a block diagram of an OFDM system.

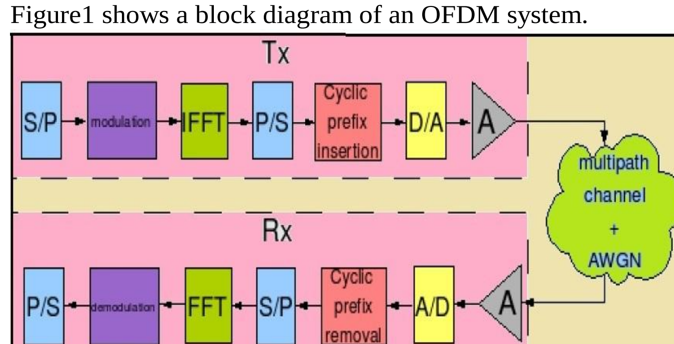

Figure1: Block Diagram of OFDM

Two periodic signals are orthogonal when the integral of their product over one period is equal to zero [5]. For the case of continuous time:

$$\int_0^T \cos(2\pi n f_o t)\cos(2\pi \text{ m } f_o t)\,\text{dt} = 0 \qquad (1)$$

for the case of discrete time:

$$\sum_{k=0}^{n-1} \cos(\frac{2\pi kn}{N}) COS(\frac{2\pi kn}{N})\,\text{dt} = 0 \qquad (2)$$

Where m≠n in both cases.

III. LITERATURE REVIEW

The concept of Orthogonal Frequency Division Multiplexing (OFDM) has been known since 1960, but it only reached sufficient maturity for the deployment in standard system during 1990s. In OFDM modulation scheme, multiple data bits are modulated simultaneously by multiple carriers. This procedure partitions the transmission frequency band into multiple narrower sub bands, where each data symbol's spectrum occupies one of these sub bands [7]. As compared to the conventional frequency division multiplexing (FDM), where such sub bands are non-overlapping, OFDM increases spectral efficiency by utilizing sub bands that overlap .To avoid interference among subbands, the subbands are made orthogonal to each other, which means that subbands are mutually independent [13]. High PAPR is the one of the main drawback of the OFDM system. There are several techniques that are used to reduce PAPR of the OFDM. PAPR reduction techniques vary according to the needs of the system and are dependent on various factors. These techniques are divided into two groups. These are signal scrambling techniques and signal distortion techniques [12].

3.1 Signal Scrambling Techniques

The fundamental principle of this technique is to scramble each OFDM signal with different scrambling sequences and select one which has the smallest PAPR value for transmission [14], [15]. Apparently, this technique does not guarantee reduction of PAPR value below to a certain threshold, but it can reduce the appearance probability of high PAPR to a great extent. Scrambling techniques are also called non- distortion techniques. This type of approach include: Selective Mapping (SLM), Partial Transmit Sequences (PTS), Interleaving schemes, Tone Reservation (TR), Tone Injection (TI), Block Coding etc.

3.1.1 Block Coding Techniques

The fundamental idea is that of all probable message symbols, only those which have law peak power will be chosen by coding as valid code words for transmission [6]. No introduction of distortion to the signals. If there have N subcarriers, they are represented by 3N bits using QPSK modulation and thus 3N messages. Using the whole message space corresponds to zero bits of redundancy. Using only half of the messages corresponds to one bit of redundancy. The remaining message space is then divided in half again and this process continues until N bits of redundancy have been allocated which corresponds to a rate one-half code for N carriers. Large PAPR reduction can be achieved if the long information sequence is separated into different sub blocks, and all sub block encoded with System on a Programmable Chip [10].

3.1.3 Selective Mapping Technique

Selected Mapping (SLM) technique is the most promising reduction technique to reduce Peak to Average Power Ratio (PAPR) of Orthogonal Frequency Division Multiplexing (OFDM) system. It was introduced by Baumel, Fischer and Huber in 1996 [16]. SLM Techniques are very flexible as they do not impose any restriction on modulation applied in the subcarriers or on their number. SLM method effectively reduces PAPR without any signal distortion. But it has higher system complexity and computational burden. This complexity can lower by reducing the number of IFFT block [17]. In particular SLM technique whole set of signal represent the same signal but from it most favorable signal is chosen related to PAPR. The side information must be transmitted with the chosen signal. This technique is probabilistic, will not remove the peaks but prevent it from frequently generation. This scheme is very reliable but main drawback that is side information must be transmitted along with chosen signal. SLM needs to transmit the information to the receiver, about the selected signal, as side information. If there is a error in the received side information, then the receiver cannot recover the information from the transmitted selected signal. That's why a strong protection against transmission errors is needed regarding side information, once the receiver has this side information then the decoding process is very simple [12].

3.1.3 Partial Transmit Sequence

Muller and Hubber recommended an effective and flexible peal power reduction scheme for OFDM system by Partial Transmit Sequences in 1997 [18]. In 3000 Jayalath and Tellambura project the PTS technique in another way. In this, the OFDM data blocks of N symbols are partitioned into M sub blocks. Each of the sub blocks is then multiplied by one of the P rotational factors, which is generated randomly. The rotational factors are chosen such that they have unit magnitude. If the PAPR of the resulting OFDM symbol is less than the threshold, the signal is transmitted. If not, another set of rotational factors is generated and the PAPR of the OFDM symbol is compared with the threshold. This process is repeated till the PAPR of the OFDM symbol becomes less than the threshold or the maximum number of iterations is reached. log3 (M) bits are transmitted as 'side information', in order to decode the transmitted sequence at the receiver. These rotational factors are embedded along with the data sequence and accounts for the redundancy. Higher PAPR reduction can be achieved with the increase in the number of sub blocks M but this requires the use of M separate IDFTs. Seung and Jae (3004), Lim et al (3005), Yang et al (3006), and Trung and Lampe (3008) also used the Partial Transmit Sequence technique to achieve the low PAPR with low computational complexity. A nonlinear iterative PTS method is proposed to search the optimal combination of phase factors with low complexity (Gao etal, 3009) [10]. In this technique Metroplis criterion is adopted to avoid the search of optimum phase factor being trapped in local optimum phase factor, thus the PAPR performance can be further improved.

3.1.4 Interleaving Technique

The notion that highly correlated data structures have large PAPR can be reduced, if long correlation pattern is broken down. The basic idea in adaptive interleaving is to set up an initial terminating threshold [18]. PAPR value goes below the threshold rather than seeking each interleaved sequences. The minimal threshold will compel the adaptive interleaving (AL) to look for all the interleaved sequences. The main important of the scheme is that it is less complex than the PTS technique but obtains comparable result. This method does not give the assurance result for PAPR reduction.

3.1.5 Tone Reservation

Tone reservation (TR) technique is one of the efficient techniques to reduce PAPR. This method is based on adding a data block dependent time domain signal to the original multicarrier signal to reduce its peaks. This time domain signal can be easily computed at the transmitter and stripped off at the receiver. For the TR technique, the transmitter does not send data on a small subset of carries that are optimized for PAPR reduction [19]. The main idea of this method is to keep a small set of tones for PAPR reduction. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones. This method explains an additive scheme for minimizing PAPR in the multicarrier communication system. It shows that reserving a small fraction of tones leads to large minimization in PAPR ever using with simple algorithm at the transmitter of the system without any additional complexity at the receiver end. Here, N is the small number of tones, reserving tones for PAPR reduction may present a non–negligible fraction of the available bandwidth and resulting in a reduction in data rate.

3.1.6 Tone Injection

Tone injection technique is a signal scrambling technique. It was introduced by Muller, S.H, Huber and J.B. The basic idea of this technique is to increase the constellation size so that each of the points in the original basic constellation can be mapped into several equivalent points in the expanded constellation. Since each symbol in a data block can be mapped into one of the several equivalent constellation points, these extra degrees of freedom can be exploited for PAPR reduction. This method is called tone injection because replacing points in the basic constellation for the new points in the larger constellation which corresponds to injecting a tone of the proper phase and frequency in the multi-carrier symbol. This method need to side information for decoding signal at the receiver side that cause extra IFFT operation which is more complex [10].

3.2 Signal Distortion Techniques

Signal distortion techniques are Peak Windowing, Envelope scaling, Peak Reduction Carrier, Clipping and Filtering.

3.2.1 Amplitude Clipping and Filtering

Amplitude clipping is the simplest technique which may be under taken for PAPR reduction in an OFDM system. This technique was introduced by May and Rholing in 1998 [7]. A threshold value of the amplitude is set in this case to limit the peak envelope of the input signal. Signal having values higher than this pre-determined value are clipped and the rest are allowed to pass through un-disturbed. The problem in this case is that due to amplitude clipping distortion is observed in the system which can be viewed as another source of noise. A repeated filtering and clipping operation can be implemented to solve this problem. The desired amplitude level is only achieved after several iteration of this process.

3.2.3 Peak Windowing

The peak windowing method has been suggested by Van Nee and Wild. This method, proposes that it is possible to remove large peaks at the cost of a slight amount of self interference when large peaks arise infrequently. Peak windowing reduces PAPRs at the cost of increasing the BER and out-of-band radiation. The technique of peak windowing offers better PAPR reduction with better spectral properties. In peak windowing method we multiply large signal peak with possible, a specific window, for example; Gaussian shaped window, cosine, Kaiser and Hamming window. In view of the fact that the OFDM signal is multiplied with several of these windows, consequential spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Thus, the window should be as narrow band as possible, conversely the window should not be too long in the time domain because various signal samples are affected, which results an increase in bit error rate (BER) [20].

3.2.3 Envelope Scaling

The Envelope Scaling technique has been proposed by Foomooljareon and Fernando. They anticipated a new algorithm to reduce PAPR by scaling the input envelope for some subcarriers before they are sent to IFFT. They used 356 subcarriers with QPSK modulation technique, so that envelopes of all the subcarriers are equal. The key idea of this scheme is that the input envelope in some sub carrier is scaled to achieve the smallest amount of PAPR at the output of the IFFT [10]. Thus, the receiver of the system doesn't need any side information for decoding the receiver sequence. This scheme is appropriate for QPSK modulation; the envelopes of all subcarriers are equal

3.2.4 Peak Reduction Carrier

Peak Reduction Carrier technique is proposed by Tan and Wassell. The technique is to use the data bearing peak reduction carriers (PRCs) to reduce the effective PAPR in the OFDM system. It includes the use of a higher order modulation scheme to represent a lower order modulation symbol. The amplitude and phase of the PRC is positioned within the constellation region symbolizing the data symbol to be transmitted. This method is suitable for PSK modulation; where the envelopes of all subcarriers are the same. When the QAM modulation scheme will be implemented in the OFDM system, the carrier envelope scaling will result in the serious BER degradation. To limit the BER degradation, amount of the side information would also be excessive when the number of subcarriers is large.

IV. PEAK TO AVERAGE POWER RATIO

The PAPR of the transmitted signal (t) is the ratio of the maximum instantaneous power and the average power [11].

$$\mathrm{PAPR} = \max \frac{[|\mathrm{x}_n|_{0<n<LN-1}{}^{2}]}{E|\mathrm{x}_n|^{2}\}} \quad 0 \leq t \leq T \qquad (3)$$

Where E {.} denotes expectation operator, i.e. average power. For the discrete-time signal x_n the PAPR can be calculated as: PAPR can be calculated as:

$$\mathrm{PAPR} = \max \frac{[|x_n|^2]}{E|x_n|^2\}} \quad 0 \le n \le LN-1 \qquad (4)$$

Basically peak-to-average power ratio (PAPR) is the most popular parameter used to evaluate the dynamic range of the time-domain OFDM signal or signal envelop variation or the crest factor (CF) where PAPR = CF^2. Crest factor is another parameter which is widely used in the literature, and defined as the square root of the PAPR.

The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques [11]. The complementary cumulative distribution function (CCDF) is the probability that the PAPR exceeds a certain threshold $PAPR_0$.

CCDF (PAPR (X_n)) = P_r (PAPR (X_n))> $PAPR_0$

V. ALGORITHMS FOR PAPR REDUCTION TECHNIQUES

In this paper we have presented 2 techniques to reduce the problem of higher PAPR in OFDM systems. The programs implementing the PAPR reduction and comparison were written in MATLAB (Version 7.6.0.424). The different parameters considered for simulation purpose are shown below in Table 1.

S. No	Simulation Parameters	Value
1.	Number of Sub carriers	256
2.	Number of Sub blocks	2,4,8,16
3.	Oversampling Factor	4
4.	Modulation Type	BPSK
5.	Phase Factor	[1,-1]

Table 1: Simulation Parameters

5.1 Selective Mapping Technique

The SLM technique was first described by Bauml et al.In the SLM, the input data sequences are multiplied by each of the phase sequences to generate alternative input symbol sequences. Each of these alternative input data sequences is made the IFFT operation, and then the one with the lowest PAPR is selected for transmission [12].

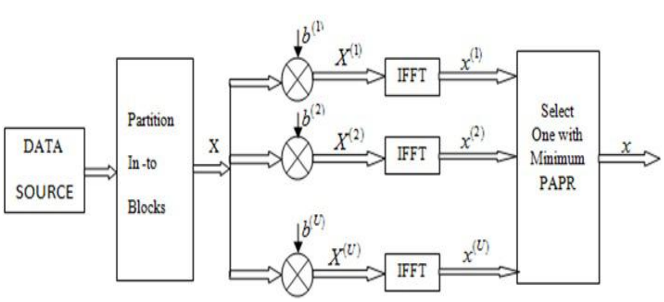

Figure: 2 Block diagram of SLM technique

1) Let the input data be represented as

$X^u = [X_0, X_1, X_2 \ldots\ldots X_{N-1}$

2) Now each data block is multiplied by U different phase sequences, each having length N and resulting in modified data blocks B^U and given by

$B^u = [b_{u,0}, b_{u,1}, b_{u,2}, b_{u,3}, \ldots\ldots b_{u,N-1}]$

where u = 1, 2, 4……………………

3) B [(1)] is used as the all-one vector of length N in order to include unmodified data block in the set of modified data blocks.

4) Now multiply input data stream with U phase sequences, resulting in modified u data blocks.

$X^u = [X_0\, b_{u,0}, X_1 b_{u,1}, X_2 b_{u,2} \ldots\ldots X_{n-1}\, b_{u,N-1}]$

Now taking IFFT, the multicarrier signal becomes

$$x^u = \sum_{u=1}^{U} IFFT(X^{(u)})$$

Where u= 1,2,3………………

Now signal having lowest PAPR is selected for transmission. At the receiver, the reverse operation is performed to recover the original data block. For implementation, the SLM technique needs U, IDFT operations, and the number of required side information bits is [log2 U] for each data block. This approach is applicable for all types of modulation techniques and any number of sub-carriers. In SLM, the amount of PAPR reduction depends on the number of phase sequences U and the design of the phase sequences.

5.1.1 Simulation Results for SLM Technique

The PAPR reduction performance of SLM technique is analyzed and discussed here for 2, 4& 8subblocks. Figures 3,4 & 5 are showing the simulation results of SLM techniques for 2,4 & 8 sub blocks. The graph is plotted for CCDF of PAPR in original signal and SLM techniques. CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given fixed threshold PAPR.

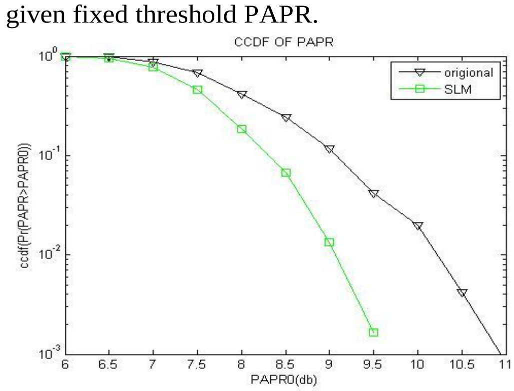

Figure 3: CCDF's of PAPR in SLM and original techniques with M = 2 sub blocks (N = 256; L = 4, BPSK modulation)

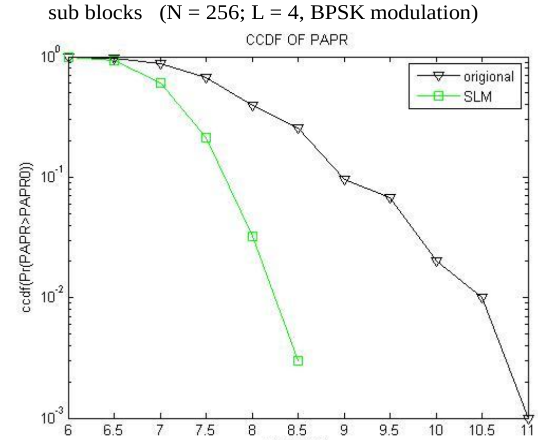

Figure 4: CCDF's of PAPR in SLM and original techniques with M = 4 sub blocks (N = 256; L = 4, BPSK modulation)

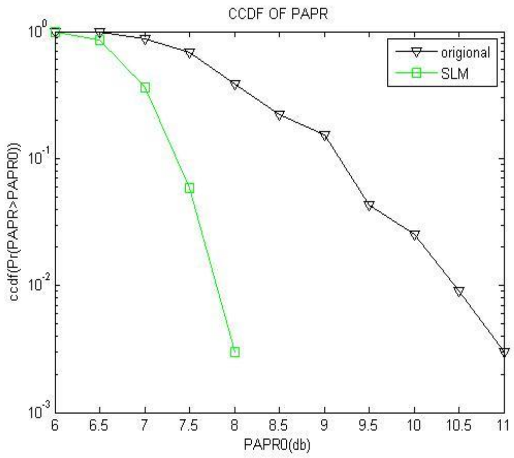

Figure 5: CCDF's of PAPR in SLM and original techniques with M = 8 sub blocks (N = 256; L = 4, BPSK modulation)

6.1 Iterative Flipping Technique

In the iterative flipping algorithm, one keeps only one phase set in each sub-block. Even though the phase set chosen in the first sub block shows minimum PAPR in the first sub block that is not necessarily minimum if we allow it to change until we continue the procedure up to the end sub block. For simplicity, the phase factor here is chosen as [1,-1]. These can be expanded to more phase factors. The algorithm is as follows.

1) After dividing the data block into M disjoint sub blocks, one assumes that $b^m = 1$; (m = 1, 2,………………..M) for all of sub-blocks and calculates PAPR of the OFDM signal.

2) Then one changes the sign of the first sub-block phase factor from 1 to -1 ($b^1 = -1$), and calculates the PAPR of the signal again.

3) If the PAPR of the previously calculated signal is larger than that of the current signal, keep $b^m = -1$. Otherwise revert to the previous phase factor, $b^m = 1$.

4) Suppose one chooses $b^m = -1$. Then the first phase factor is decided, and thus kept fixed for the remaining part of the algorithm.

5) Next, we follow the same procedure for the second sub-block. Since one assumed all of the phase factors were 1, in the second sub-block, one also changes $b^2 = 1$ to $b^2 = -1$, and calculates the PAPR of the OFDM signal.

6) If the PAPR of the previously calculated signal is larger than that of the current signal, keep $b^2 = -1$. Otherwise, revert to the previous phase factor $b^2 = 1$.

This means the procedure with the second sub-block is the same as that with the first sub-block. One continues performing this procedure iteratively until one reaches the end of sub-blocks.

6.1.1 Simulation Results for SLM Technique

Figure 6 to Figure 8 shows the analysis and simulation of iterative flipping technique for M=2 to M=8. It is observe that the Iterative flipping technique can reduce the PAPR of OFDM signals, and show less computational complexity.

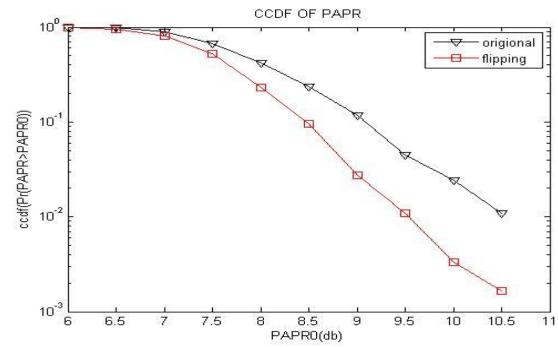

Figure 6: CCDF's of PAPR in IF and original techniques with M = 2 sub blocks (N = 256; L = 4, BPSK modulation)

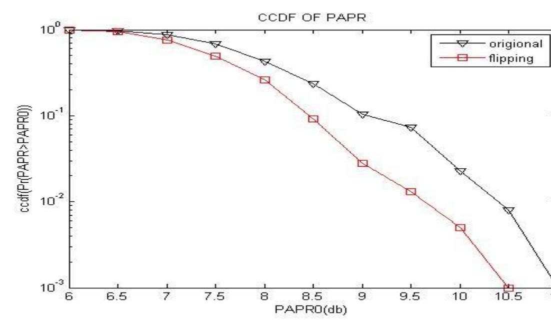

Figure 7: CCDF's of PAPR in IF and original techniques with M = 4 sub blocks (N = 256; L = 4, BPSK modulation)

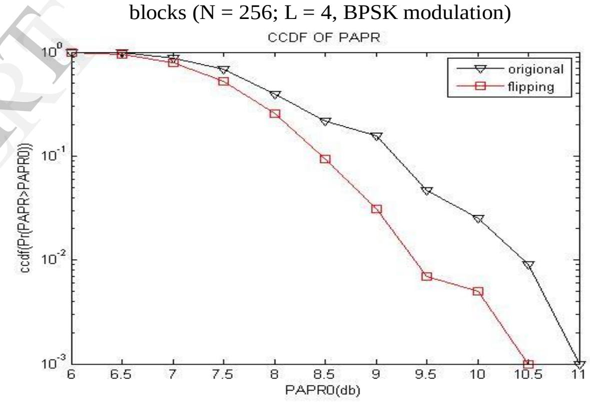

Figure 8: CCDF's of PAPR in IF and original techniques with M = 8 sub blocks (N = 256; L = 4, BPSK modulation)

VI Results of Comparative Analysis of SLM & IF Techniques

Finally we have presented comparison of SLM & IF techniques. In simulations, an OFDM system is considered with number of sub-carriers (N=256), over-sampling factor (*L*=4) and BPSK Modulation. The phase factor is chosen as {1,-1}. Figure 9 to Figure 12 show the graphs for the complement cumulative distribution function (CCDF) of PAPR in original(without reduction technique), Iterative flipping technique and SLM technique for the different values of M = 2; 4; 8 sub-blocks respectively. Here CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given fixed threshold PAPR.

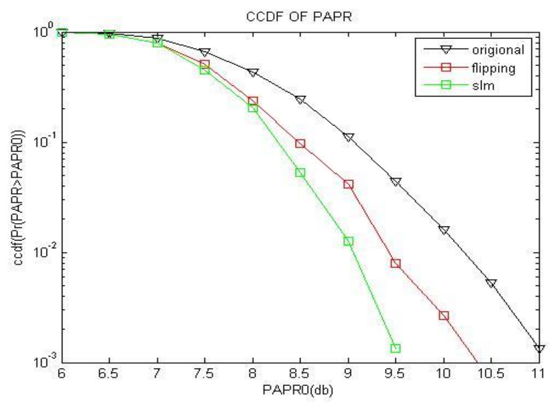

Figure 9: CCDF's of PAPR in SLM, IF and original techniques with M = 2 sub blocks (N = 256; L = 4, BPSK modulation)

In this case, SLM technique is compared with Iterative flipping and PAPR of original signal, and simulation results show that all these three PAPR reduction techniques reduce the PAPR of the OFDM signal. It is also seen that when the value of threshold PAPR is low, the performance of Iterative flipping technique and SLM technique is almost same, but for higher value of threshold PAPR, SLM technique gives better performance than the Iterative flipping technique.

Figure 10 shows the CCDF's of PAPR in SLM & IF techniques for M = 4 sub-blocks. As expected, the performance of SLM and Iterative techniques has improved when compared to case with M = 2. The graph also shows that for higher value of threshold PAPR, SLM technique yields the best performance amongst IF technique.

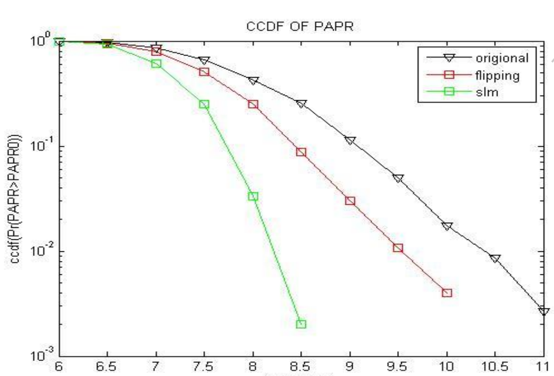

Figure 10: CCDF's of PAPR in SLM, IF and original techniques with M = 4 sub blocks (N = 256; L = 4, BPSK modulation)

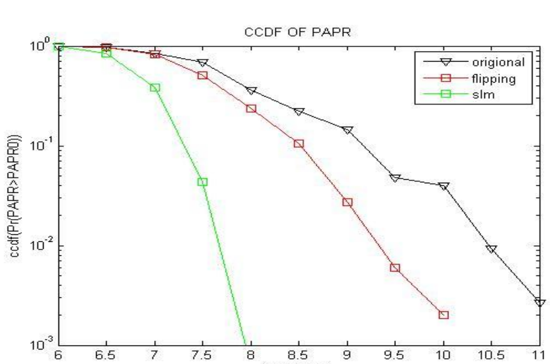

Figure 11: CCDF's of PAPR in SLM, IF and original techniques with M = 8 sub blocks (N = 256; L = 4, BPSK modulation)

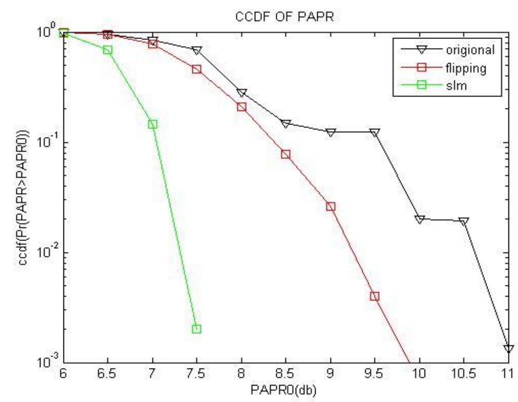

Figure 12: CCDF's of PAPR in SLM, IF and original techniques with M = 16 sub blocks (N = 256; L = 4, BPSK modulation)

Figure 11& Figure 12 illustrates the case of M = 8 & 16 sub-blocks. It can be seen that SLM technique for 16 sub blocks shows a significant improvement in PAPR reduction performance when compared with the cases for M = 2, 4 & 8. Though Iterative techniques also show improvement in their PAPR reduction as M increases, but the amount of performance increase is comparatively lesser. Thus performance of SLM technique continuously increases as the number of sub blocks increases.

VII Conclusion & Future Scope

In this paper we have discussed 2 PAPR reduction techniques. The simulation results show that all the 2 methods can lower the PAPR but it can be seen that as the number of sub blocks increase the performance of SLM technique is continuously improved and the SLM technique exhibits better PAPR reduction performance than the Iterative flipping techniques. The Iterative flipping technique offer less PAPR reduction performance than the SLM technique, but it is less computationally complex than the SLM technique. No specific PAPR reduction technique is the best solution for all multicarrier transmission systems. Rather, the PAPR reduction technique should be carefully chosen according to various system requirements. Our future work will be extended by developing New PAPR reduction technique for further optimization of the PAPR.

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