ISSN: 2321-7782 (Online)
Volume 3, Issue 2, February 2015
International Journal of Advance Research in Computer Science and Management Studies
Research Article / Survey Paper / Case Study
Available online at: www.ijarcsms.com

A Comparative Study of Different PAPR Reduction Methods in OFDM System

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Abstract: Orthogonal frequency division multiplexing (OFDM) signal is a multicarrier modulation technique, one of the attractive techniques for 4th Generation Wireless communication System. But the major disadvantage of OFDM is that in time domain, it leads to high peak to average power ratio (PAPR). However, PAPR exhibited by OFDM signals require linear operation of analog devices, with the associated trade-off of poor power efficiency. Several methods to reduce this PAPR problem have been effectively researched while revealing the short comings. In this study we recognize the needto present the effect of OFDM system parameters on the behaviour of the PAPR. Also here we will compare different PAPR reduction techniques such as clipping, Selective Level Mapping (SLM) and Modified Selective Level Mapping (MSLM).

Keywords: Orthogonal frequency division multiplexing (OFDM), peak to average power ratio (PAPR), Selective Level Mapping (SLM), Modified Selective Level Mapping (MSLM) and Quadrature Amplitude Modulation(QAM)..

I. INTRODUCTION

The orthogonal frequency division multiplexing (OFDM) technique has become very popular in the last two decades. The current and next generations of communications systems depend mainly on such technique because of its ability to combat multipath fading channels using the corresponding concept of cyclic prefix (Guard Interval). In addition, it provides a high data rate and high spectrum efficiency compared with single carrier systems. However, its major drawback is represented by high output peak-to-average power ratio (PAPR) events. These events cause inter modulation distortion that result in nonlinearity, which affect the overall system performance.

As the result of large peak power, the D/A converter may become highly complex and the power amplifiers may have a non-linear range, which leads to an inefficiency of the amplifier. Therefore, it's useful to reduce the PAPR of OFDM system. There are number of techniques to deal with the problem of PAPR. Some of them are amplitude clipping, filtering, coding, partial transmit sequence and selected mapping (SLM) [1]. Here, we are going to compare clipping, Selective Level Mapping (SLM) and Modified Selective Level Mapping (MSLM) [3] to reduce PAPR ratio. Clipping method is distorted technique while SLM and MSLM are distortion less techniques. We simulate all results in MATLAB environment and then we will compare results based on reduction in PAPR ratio.

II. RELATED WORKS

Chang [5] and Saltzberg [6] developed FDM in the mid 60's by introducingmultiple carriers which overlap in the frequency domain without interfering with each other, utilizing the frequency spectrum more efficiently, hence OFDM. However the complexity issue still remained.

In the 1970's Weinstein and Ebert [7] used an Inverse Discrete Fourier Transform (IDFT) and Discrete Fourier Transform (DFT) to perform the modulation and demodulation respectively, exploiting the sinusoidal nature of the Fourier Transform and significantly reducing the complexity of an OFDM system.

In the last 10 years more advances in practical OFDM systems have been made, particularly in Europe where various projects and prototypes were initiated such as DIgital VIdeo Narrowband Emission (HD-DIVINE), System de Television En Radiodiffusion NumeriquE (STERNE), and digital Terrestrial Television broadcasting (dTTb). This has led to the adoption of OFDM in many European standards. OFDM has progressed to the point where it has now been used for various communication applications such as Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) in Europe. It has also been adopted as the physical layer modulation scheme for wireless networking standards such as Hiperlan2 in Europe and the Institute of Electrical and Electronic Engineers (IEEE) 802.11a, g standards in the United States.

However while OFDM successfully alleviates the problem of dispersive channels there are still some problems which need to be addressed such as time and frequency synchronization, frequency selective fading, and the Peak to Average Power Ratio.

III. Peak to Average Power Ration

OFDM has become a popular technique in various high-speed wireless data transmission systems. Due to the nature of the IFFT it sums N sinusoids through superposition; some combinations of the sinusoids create large peaks [1]. The drawback of a large dynamic range is that it places pressure on the design of components such as the word length of the IFFT/FFT pair, DAC and ADC, mixer stages, and most importantly the HPA which must be designed to handle irregularly occurring large peaks. Failure to design components with a sufficiently large linear range results in saturation of the HPA. Saturation creates both in band distortion, increasing the BER and out of band distortion, or spectral splatter, which causes ACI.

OFDM signals therefore cause serious problems such as a severe power penalty at the transmitter, which is prohibitive for use in portable wireless systems where the terminals are powered by Battery. Recently, a number of PAPR reduction schemes have been proposed to alleviate this undesirable property of OFDM signals. To evaluate the capability of PAPR reduction schemes or design systems involving nonlinear devices, it is necessary to understand the properties of the PAPR in OFDM signals.

In the discrete time domain, an OFDM $x_n$signal of Nsubcarriers can be expressed as:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi k \frac{n}{N}} \quad 0 \le n \le N-1 \qquad (1)$$

Where $X_k, k = 0,1,2 \dots \dots, N-1$ input symbols are modulated by BPSK, QPSK or QAM and n is the discrete time index.

The PAPR of an OFDM signal is defined as the ratio of the maximum to the average power of the signal, as follows

$$PAPR(x) = 10 \log_{10} \frac{max\{|x_n|^2\}}{E\{|x|^2\}} \quad 0 \le n \le N-1 \qquad (2)$$

Where $E\{.\}$denotes expected value operation and $x = [x_1, x_2, \dots\dots x_{N-1}]^T$

IV. PAPR Reduction Techniques

Several techniques have been proposed to reduce the PAPR. These techniques can mainly be categorized in to two types that are

- Signal scrambling techniques
- Signal distortion techniques

Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR. Coding techniques can be used for signal scrambling. Golay complementary sequences, Shapiro-Rudin sequences, M sequences, Barker codes can be used efficiently to reduce the PAPR [2]. However with the increase in the number of carriers the overhead associated with exhaustive search of the best code would increase exponentially. More practical solutions of the signal scrambling techniques are block coding, Selective Level Mapping (SLM) and Partial Transmit Sequences (PTS).

The signal distortion techniques introduce both In band and Out-of-band interference and complexity to the system. The signal distortion techniques reduce high peaks directly by distorting the signal prior to amplification. Clipping the OFDM signal before amplification is a simple method to limit PAPR.

A. Clipping Method

We have implemented the clipping method here. The simulations were performed using MATLAB. MATLAB m -files were selected because it provides convenience and flexibility required to vary system parameter.

The algorithm is based on clipping the amplitude of OFDM signal that exceeds threshold value say (γ). The amplitude of signals exceeding clipping threshold value (say γ) is clipped and the signals having amplitudes less than amplification threshold value say (say γ) is kept as it is.

$$R(n) = \begin{cases} R(n), & \text{for} R(n) \le \gamma \\ \gamma \;, & \text{for } R(n) > \gamma \end{cases}$$

PAPR is calculated for clipped signal and compared with that of the original PAPR of OFDM signal. Clipping can be performed by clipping the complex envelope of OFDM signal.

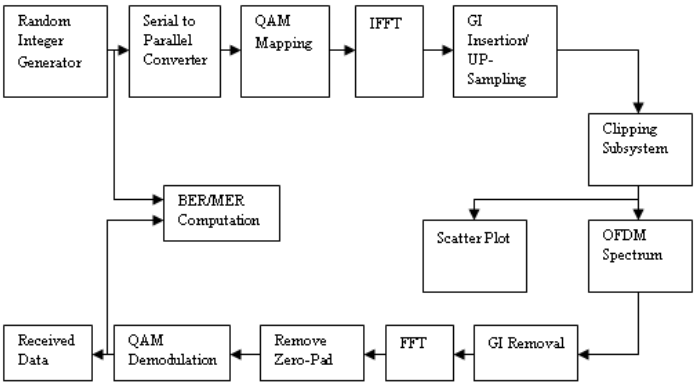

Fig.1 OFDM transceiver model for clipping

Fig. 1 shows block diagram of clipping method, here random integer generator generates random data then it will get converted into parallel streams. After applying qam modulation and IFFT we clip OFDM signal at different clipping levels. Also we apply QAM and PSK modulation technique and will see the changes occurred in PAPR ratio. Also we notice the effect of modulation order and different no. of subcarriers on PAPR ratio.

B. Selective Level Mapping

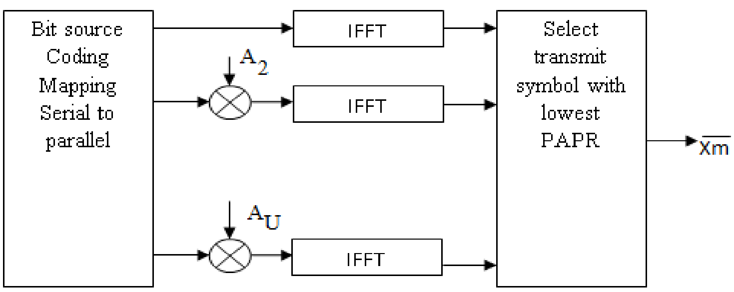

Fig. 2 Block diagram of SLM reduction technique.

SLM scheme is one of the initial probabilistic approaches for reducing the PAPR problem, with a goal of making occurrence of the peaks less frequent, not to eliminate the peaks [1]. In selected mapping (SLM) method a whole set of candidate signals is generated representing the same information, and then the most favorable signal as regards to PAPR is chosen and transmitted. This method is distortion less method as it does not clip original signal [8]. The side information about this choice needs to be explicitly transmitted along with the chosen candidate signal. This can be done by using following equations [1]. The OFDM data block is multiplied element by element with phase sequences

$$A_U(t) = [a_u, 0, a_u, 1, \dots\dots\dots a_u, N-1]^T \quad u = 1,2,\dots\dots\dots U \quad (3)$$

To make the U phase rotated OFDM data blocks.

$$X_u(t) = [X_{u,0}, X_{u,1} \dots\dots\dots X_{u,N-1}]^T \quad (4)$$

Where $X_{u,m} = X_m a_{u,m}$, $m = 0,1,\dots\dots\dots\dots N-1$, $a_{u,m} \in \{\pm 1, \pm j\}$

All U phase rotated OFDM data blocks represent the same information as the unmodified OFDM data block provided that the phase sequence is known. To include the unmodified OFDM data block in the set of the phase rotated OFDM data blocks, we set each element of the first phase sequence A1 as "1." After applying the SLM technique to X, equation (5) becomes

$$x_u(t) = \frac{1}{N}\sum_{m=0}^{N-1} X_m\, a_{u,m} e^{j2\pi f_m t}, \quad 0 \le t \le NT \quad (5)$$

The PAPR is calculated for U phase rotated OFDM data blocks by

$$x_u(t) = \frac{\max_{0\le t\le NT}|x_u(t)|^2}{\frac{1}{NT}\int_0^{NT}|x_u(t)|^2 dt} \quad (6)$$

Among the phase rotated OFDM data blocks, the one with the lowest PAPR is selected and transmitted. The scheme can handle any number of subcarriers and drawback associated with the scheme is the overhead of side information that needs to be transmitted to the receiver. The scheme can handle any number of subcarriers and drawback associated with the scheme is the overhead of side information that needs to be transmitted to the receiver.

C. Modified Selective Level Mapping

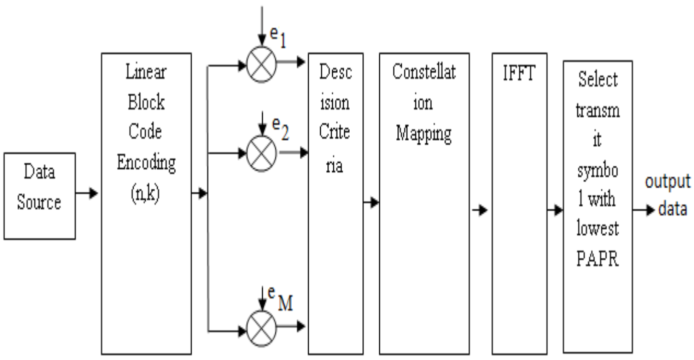

Fig 3. Block diagram of MSLM reduction technique.

The main purpose of the modified SLM technique is to re-duce PAPR and IFFT block [5]. There is only one IFFT block at transmitter if the sequence which is the lowest PAPR can be found out by a decision algorithm before IFFT [3]. Therefore it reduces required hardware and hence reduces complexity in design of hardware. The block diagram for modified SLM is given in Fig. 3

The decision algorithm for modified SLM is given as follows.

Step 1: A binary information source is divided into blocks of 4 bits.

Step 2: Each information block is encoded into a codeword c by a [7, 4] hamming encoder.

Step 3: A control bit added to codeword c to create an extended hamming code of 8 bits.

Step 4: Calculate the error table and coset leader, 16 in number

Step 5: Sixteen vectors are constructed as c+e1, c+e2, c+ e3...........etc.

Step 6: For each scrambled codeword calculate the value of $Z = U^2 + V^2 + W^2$

Step 7: Scrambled codeword with the minimum Z is selected and then Transformed to OFDM signal by constellation mapping and IFFT.

V. Simulation and Result Conclusion

A. *Simulation and Result of Clipping Method*

- Simulation Parameter

No. of Subcarriers (N) = 128, 256, 512, 1024

Clipping Level (γ) = 0.2, 0.4, 0.6

Modulation Order (M) = 16

TABLE I
PAPR Ratio at Different Clip Levels and at M=16

No. of Subcarriers	Different Clip Levels		
	γ = 0.2	**γ = 0.4**	**γ = 0.6**
N=128	10.7239	13.5655	12.3572
N=256	11.6342	11.0473	14.8257
N=512	12.3607	13.6856	13.7918
N=1024	12.1346	16.1492	16.6289

Above result shows that increase in clipping level PAPR ratio also increases.

Now apply PSK and QAM as modulation technique we get variation in reduction of PAPR ratio for same modulation order and for same no. of subcarriers the results are as shown in table 2.

- Simulation Parameter

No. of Subcarriers (N) = 128, 256, 512, 1024

Modulation Technique = PSK / QAM

Modulation Order (M) = 4, 8, 16, 32

TABLE III
Comparison of PSK and QAM Modulation

No. of Subcarriers	Different Modulation Order for PSK				Different Modulation Order for QAM			
	M= 4	**M= 8**	**M= 16**	**M=32**	**M= 4**	**M= 8**	**M= 16**	**M=32**
N=128	8.8173	12.5822	10.1101	13.3953	8.7199	9.8707	9.61472	9.71487
N=256	9.1885	13.1532	11.6614	14.0878	10.9841	10.4325	13.046	10.778
N=512	12.8379	12.0674	11.7361	12.7646	13.0205	10.2017	11.1966	11.8732
N=1024	11.4666	13.2082	12.1766	14.9807	12.9593	12.7205	12.7571	12.2235

Above result shows that QAM modulation technique is better than PSK as it gives us less PAPR ratio as compared to PSK.

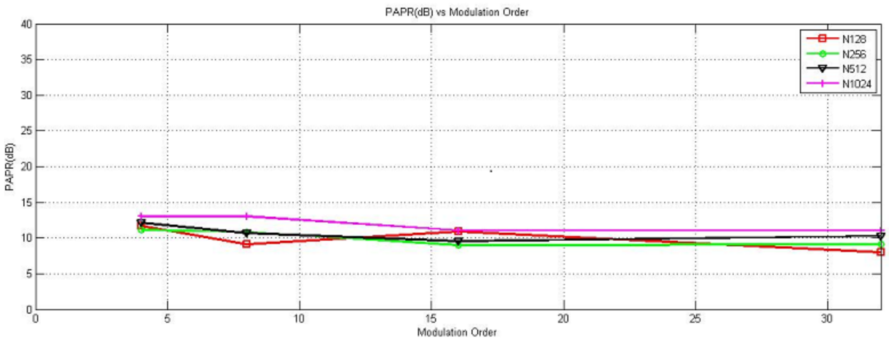

Fig. 4 PAPR Vs modulation order for different no. of subcarriers

Fig. 4 shows that with increase in modulation order and with increase in no. of subcarriers PAPR ratio also increases.

B. *Simulation and Result of SLM*

- Simulation Parameter

No. of subcarriers (N) = 128

Modulation Technique = QAM

Modulation Order (M) = 64

No. of phase sequence (U) = 2,4,8,16

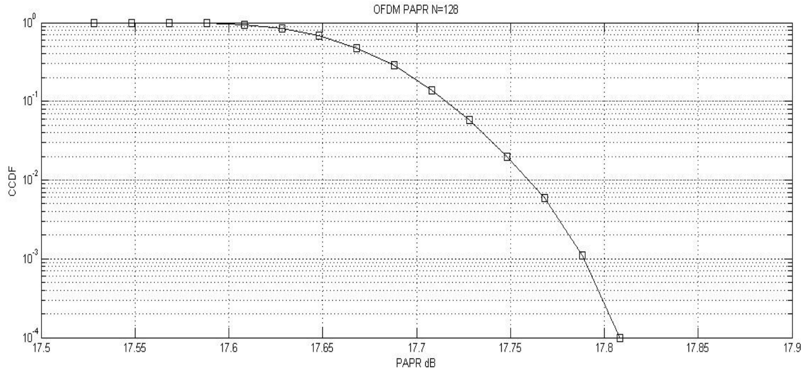

Fig.5 PAPR without SLM where N = 128

Above Fig. 5 shows original PAPR ratio in dB without applying any PAPR reduction technique.

Now apply SLM as PAPR reduction technique and vary no. of phase rotations (U), after simulation we get following results,

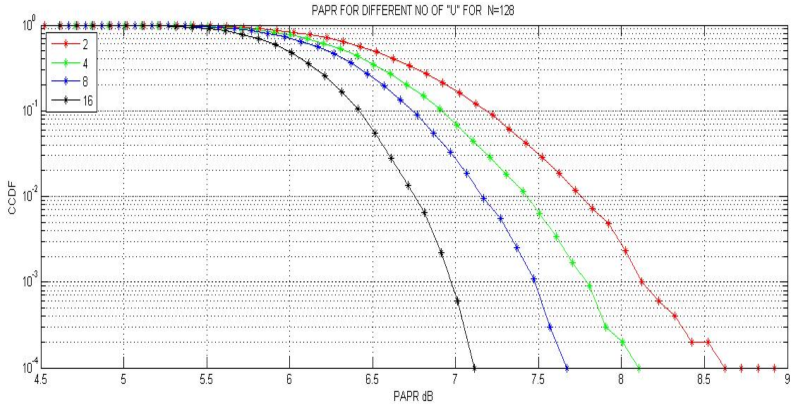

Fig. 6 PAPR with variation of no. of U for SLM where N = 128

Above Fig. 6 shows that SLM method reduces PAPR up to 7.12dB which is 10.7dB less than original signal and as no. of phase sequences increases PAPR decreases.

C. Simulation and Result of MSLM

- Simulation Parameter

No. of subcarriers (N) = 128

Modulation Technique = QAM

Modulation Order (M) = 64

Decision Criteria- $Z=U^2+V^2+W^2$

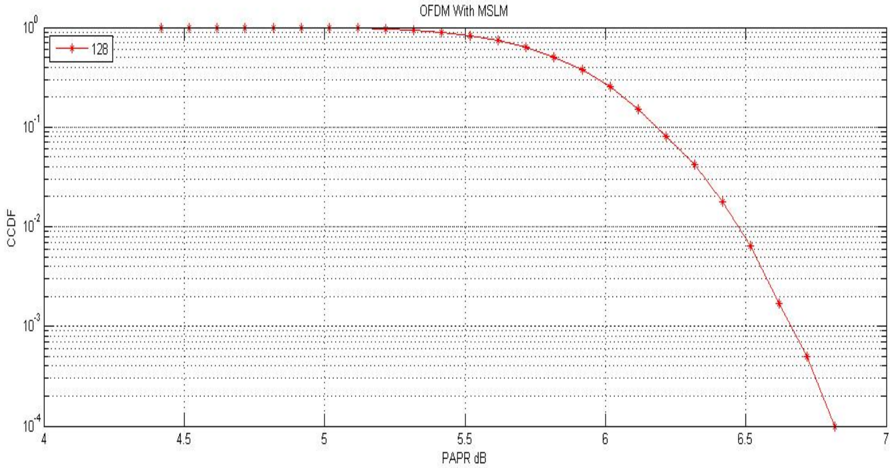

Fig. 7 PAPR Reduction for MSLM where N = 128.

Above Fig. 7 shows that MSLM reduces PAPR up to 6.8dB which is 0.32dB less than SLM also.

Finally, Table 2 shows comparison between clipping, SLM and MSLM methods as follows

TABLE IIII
Comparison of Different PAPR Reduction Methods for N=128

Parameter	Different PAPR Reduction Methods		
	Clipping	**SLM**	**MSLM**
N=128	9.31 dB	7.12 dB	6.8 dB

Here we can conclude that MSLM performs better as compared to other two.

VI. Conclusions

A modified selective level mapping reduces more PAPR ratio and performs better than conventional selective level mapping method and clipping method. Also it uses a single IFFT block and takes decision before performing IFFT operation and makes OFDM system more applicable for wireless type of communication.

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