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A Comparative analysis of various schemes for PAPR reduction of OFDM Signals

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Abstract: For wireless application, an OFDM (Orthogonal Frequency Division Multiplexing) technique is widely adopted and promising technique, due to high data rate transmission, great immunity to impulse noise, robustness to multipath fading channel. But there is one of the major problem of this technology is the high PAPR (Peak to Average Power Raito) of transmission signal due to superposition of many subcarriers. In an OFDM signal, the large fluctuation in amplitude produce a major problem during amplification, High PAPR is main problem in OFDM modulation. There are many types of technique presents for reduction of PAPR. The selection criteria for one of the methods is depend on PAPR reduction, Power increase, increased BER at receiver and computational complexity. In this paper present a comparative analysis of various schemes for PAPR reduction on review basis.

Index Terms— **Clipping & filtering, OFDM, PAPR.**

I. INTRODUCTION

As in the development of communication technology, in both links of communication i.e. wire and wireless link demand of high and speedy data rate also increases. In this case, new modulation techniques are required which is able to transfer the large amount of the data on higher data rate. Allowable Bit Error Rate (BER) and Maximum delay. Orthogonal Frequency Division Multiplexing (OFDM) is one of them. OFDM is a digital transmission method developed to meet the increasing demand for higher data rate in communication which can be used in both wire & wireless environment.[1]

Orthogonal Frequency Division Multiplexing (OFDM) is a widely used modulation and multiplexing technology which gives the basic supports of many telecommunication standards. OFDM concept is based on spreading the data to be transmitted over a large numbers of carriers, each being modulated on low rate. In fact, OFDM is a specialized FDM, the additional constraint being; all the carrier signals are orthogonal to each other by appropriately choosing the frequency spacing between them, In OFDM the subcarrier frequencies are preferred so that the subcarrier are orthogonal to each other, meaning that crosstalk between the sub channel is eliminated and inter carrier guard band are not required. Orthogonality gives the carrier a valid reason to be closely spaced with overlapping without inter carrier interface [3]. However, any multicarrier signal with a large crest factor (CF=peak voltage/rms voltage). When passed through a non linear device the signal may suffer significant spectral spreading; these problems overcome by using a linear device or to back off the operating point of nonlinear device; both approaches resulting in a significant power efficiency penalty.

In term of fading phenomena of multipath OFDM gives better performance over the signal carrier system along with this OFDM has a big disadvantage in term of Peak-To-Average-Power ratio (PAPR) [4][5]. The technique and method of modulation cause these high peaks.

These signal peaks cause distortion and saturation in nonlinear device (like power amplifier), leading to inter-modulation of sub carrier and out of band radiation. Also implementation of circuit is too difficult and designing become to more complexes likely to say it gives high cost amplification which leads to inefficient transmission [6].

A rich variety of signal used in modern communications system characterized by large envelope fluctuation. This fact creates problems for distortion free and effective amplification [7]. A solution of problem consists in decreasing envelope fluctuation of the signal before amplification, variation of envelope. The signals are characterized by its peak to average power ratio (PAPR). PAPR reduction is especially important for multicarrier transmission, for instance in orthogonal frequency division multiplexing (OFDM) system [7][8]. Thus it is quite necessary for reduce the PAPR.

Among a wide number of various methods to be developed for PAPR reduction such as, Clipping & Filtering, Block Coding Techniques, Sub-block Coding Techniques, Tone Reservation, Interleaving, Additive Corrective Function, PAR Reduction Codes, Active Constellation, Peak Windowing, Hadamard Transform, Artificial Signals and Convex Optimization, Selected Mapping, Partial Transmit Sequence (PTS), Random Phase Updating.

II. OFDM SYSTEM MODEL

A Basic OFDM system is shown in figure I. Here an input data symbols are supplied into a channel that data are mapped onto BPSK/QPSK/QAM constellation.
The data symbols are converted from serial to parallel and using Inverse Fast Fourier Transform (IFFT) to achieve the time domain OFDM symbols. Time domain symbols can be represented as:

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

Where, X_K is the transmitted symbol on k^{th} subcarriers
N is the number of subcarriers
Time domain signal is cyclically extended to prevent Inter Symbol Interface (ISI) from the former OFDM symbol using cyclic prefix (CP)

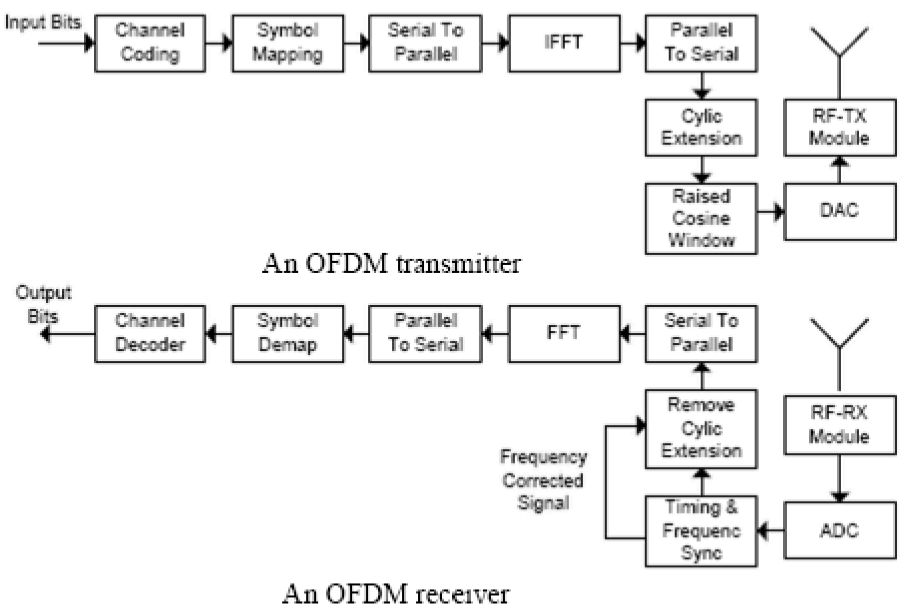

Fig:-1 A basic Diagram of OFDM Transceiver

The Digital to Analog Converter (DAC) is performed to convert the baseband digital signal into analog signal. This operation is executed in DAC block of diagram. Then, the analog signal is preceded to the Radio Frequency (RF) frontend. The RF frontend performs operations after receiving the analog signal. The signal is up converted to RF frequencies using mixer and amplified by using Power Amplifier (PAs) and then transmitted through antennas. At the receiver side, the received signal is down converted to base band signal by RF frontend.
The analog signal is digitized and re-sampled by the Analog to Digital Converter (ADC). The ADC is used to digitize the analog signal and re-samples it. In the figure, frequency and time synchronization block are not shown because of simplicity. Cyclic prefix is removed from the signal in frequency domain. This step is done by the Fast Fourier Transform (FFT) block. The received symbols in the frequency domain can be represented as:-

$$Y(k) = H(k)X_m(k) + W(k) \quad \text{………………..} \text{(II)}$$

where, Y (k) is the received symbol on the subcarrier, H (k) is the frequency response of the channel on the same subcarrier and W (k) is the additive noise added to, subcarrier which is generally assumed to be Gaussian random variable with zero mean and variance of . Thus, simple one tap frequency domain equalizers can be employed to get the transmitted symbols. After FFT signals are de-interleaved and decoded to recover the original signal.

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III. MATHEMATICAL DEFINITION OF OFDM SIGNAL

OFDM consists of multiple carriers. Each carrier can be presented as a complex waveform like:

$$s_c(t) = A_c(t)e^{j[\omega_c(t)+\emptyset_c(t)]} \quad \text{.............................. ..(III)}$$

Where, $A_c(t)$ is the amplitude of the signal $s_c(t)$; $\emptyset_c(t)$ is the phase of the signal $s_c(t)$

The complex signal can be described by

$$S_i(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_n(t)e^{j[\omega_n(t)+\emptyset_n(t)]} \quad \text{...................... (IV)}$$

This is a continuous signal. Each component of the signal over one symbol period can take fixed values of the variables like

$\emptyset_n(t) \rightarrow \emptyset_n$ $\quad A_n(t) \rightarrow A_n$

Where, n is the number of OFDM block.

T is a time interval and the signal is sampled by 1/T then it can be represented by:

$$Si(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j[(\omega_0+\omega\Delta n)kT+\emptyset_n]} \quad \text{.................... (V)}$$

Let ω_0=0 then the signal becomes

$$Si(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j[(\omega\Delta n)kT+\emptyset_n]} \quad \text{..................... (VI)}$$

The signal is compared with general Inverse Fourier Transform (IFT)

$$g(kT) = \frac{1}{N}\sum_{n=0}^{N-1} G\left(\frac{n}{NT}\right) e^{j[2\pi nk/N]} \quad \text{.................... (VII)}$$

Here, s(kT) is time frequency domain.

The OFDM signal can be defined by Fourier Transform. The Fast Fourier Transform (FFT) can obtained frequency domain OFDM symbols and Inverse Fast Fourier Transform (IFFT) can obtain time domain symbols.

IV. PEAK-TO-AVERAGE POWER RATIO (PAPR)

What is PAPR?

The peak to average power ratio for a signal x(t) is defined as

$$PAPR = \frac{\max[x(t)x^*(t)]}{E[x(t)x^*(t)]}$$

where, ()* corresponds to the conjugate operator.

Expressing in deciBels,

$$PAPR(in\ dB) = 10\log_{10} PAPR$$

PAPR OF A SINGLE SINE TONE

Consider a sinusoidal signal having the period T

$$x(t) = \sin(2\pi f t)$$

The peak value of the signal is

$$\max[x(t)x^*(t)] = +1$$

The mean square value of the signal is,

$$E[x(t)x^*(t)] = \frac{1}{T}\int_0^T \sin^2(2\pi ft) = \frac{1}{2}$$

Given so, the PAPR of a single sine tone is,

$$PAPR = \frac{1}{(1/2)} = 2$$

```
%  Matlab script
clear all
close all
xt = sin(2*pi*1*[0:1/64:0.999]);
plot(xt,'b.-','LineWidth',4)

grid on
xlabel('sample number')
ylabel('amplitude')
title('sine wave')
```

ISSN: 2319-5967
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Volume 3, Issue 2, March 2014

```
meanSquareValue = xt*xt'/length(xt)
peakValue = max(xt.*conj(xt))
```

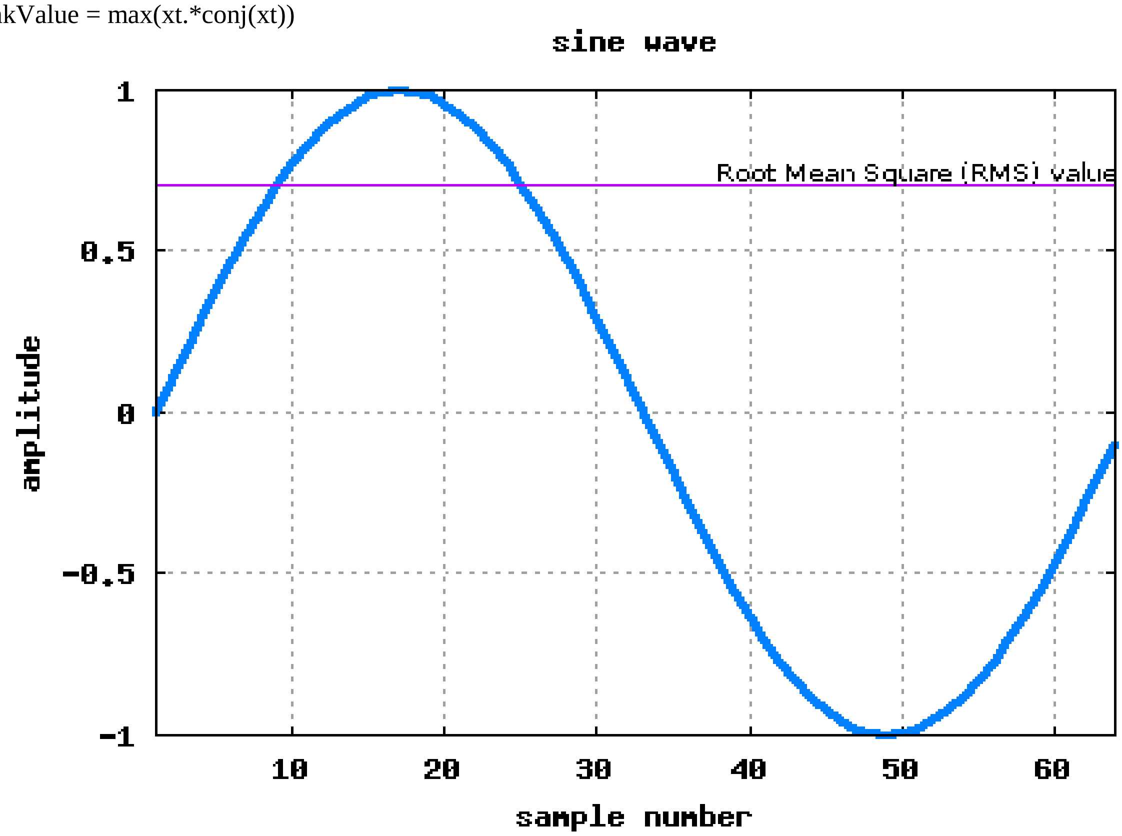

Fig:-2 Wave form of single sine tone

PAPR OF A COMPLEX SINUSOIDAL

Consider a sinusoidal signal having the period T.

$$x(t) = e^{2\pi ft}$$

The peak value of the signal is

$$\max[x(t)x^*(t)] = +1$$

The mean square value of the signal is,

$$E[x(t)x^*(t)] = \frac{1}{T}\int_0^T e^{4\pi ft} = 1$$

Given so, the PAPR of a single complex sinusoidal tone is, PAPR = 1

% **Matlab script**

```
close all
clear all
% defining a signal in frequency domain
% subcarrier +1 alone
xF = [zeros(1,6) zeros(1,26) 0 1 zeros(1,25) zeros(1,5) ];
xt = 64*ifft(fftshift(xF));
meanSquareValue = xt*xt'/length(xt)
peakValue = max(xt.*conj(xt))

plot(real(xt),'b','LineWidth',2)
hold on
plot(imag(xt),'g','LineWidth',2)
xlabel('sample number')
ylabel('amplitude')
```

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ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 3, Issue 2, March 2014

```
title('complex sinusoidal')
legend('real', 'imag')
grid on
```

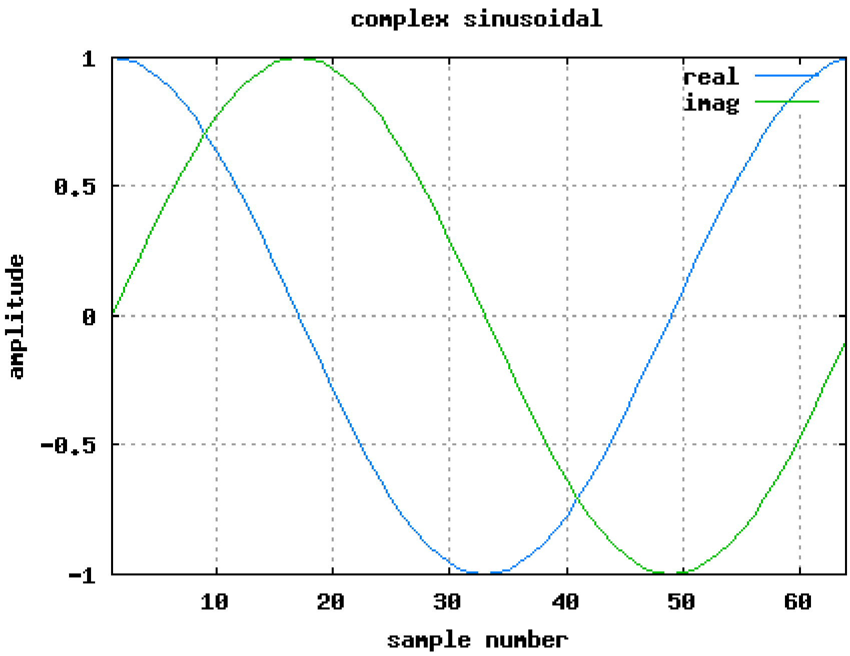

Fig:-3 Waveform a single complex sinusoidal

Maximum expected PAPR from an OFDM waveform

From the previous post (here), we have learned that an OFDM signal is the sum of multiple sinusoidal having frequency separation $\frac{1}{T}$ where each sinusoidal gets modulated by independent information a_k. Mathematically, the transmit signal is,

$$x(t) = \sum_{0}^{K-1} a_k e^{\frac{j2\pi kt}{T}}$$

For simplicity, let us assume that $a_{k=1}$ for all the subcarriers. In that scenario, the peak value of the signal is, Given so, the peak to average power ratio for an OFDM system with K subcarriers and all subcarriers are given the same modulation is,

$$PAPR = \frac{K^2}{K} = K$$

It is reasonably intuitive that the above value corresponds to the maximum value of PAPR (when all the subcarriers are equally modulated, all the subcarriers align in phase and the peak value hits the maximum).

V. PAPR REDUCTION TECHNIQUES

There have been many new approaches developed during the last few years. Several PAPR reduction techniques have been proposed in the literature. These techniques are divided into two groups. These are signal scrambling techniques and signal distortion techniques. The signal scrambling techniques are:

(I) Block coding (II) Selective Level Mapping (SLM) (III) Partial Transmit Sequences (PTS)

Signal scrambling techniques work with side information which minimized the effective throughput since they commence redundancy. Signal distortion techniques introduce band interference and system complexity also. Signal distortion techniques minimize high peak dramatically by distorting signal before amplification.

The signal distortion techniques are:

(I) Clipping (II) Peak windowing (III) Peak cancellation (IV) Peak power suppression

(V) Weighted multicarrier transmission

A. *Signal Scrambling Techniques*

1. Block Coding Techniques

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Volume 3, Issue 2, March 2014

Coding techniques can be applied for signal scrambling, M sequences, Golay complementary sequences, Shapiro-Rudin sequences codes can be used to reduce the PAPR efficiently.

This Block coding technique has been used for the minimization of the peak to mean envelope power ratio of multicarrier communication system [9]. The block coding techniques have three stages for the development. The first stage works with the collection of appropriate sets of code words for any number of carriers, any M-ary phase modulation method, and any coding rate. The second stage works with the collection of the sets of code words which enable proficient implementation of the encoding/decoding. The third stage offers error deduction and correction potential.

There different methods for the collection of the sets of code words. The mainly insignificant method is peak envelope power (PEP) for all possible code words for a certain length of given number of carriers. This technique is simple and accurate for short codes because it needs extreme computation. Natural algorithms are mainly sophisticated searching techniques and used for the collection of longer code words. A selection of code words select from searches for encoding and decoding can be performed with a look up table or using combinatorial logic exploiting the mathematical structure of the codes minimization when the frame size is bigger. 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 (SOPC).

2. Block Coding Scheme with Error Correction

This Block coding scheme with Error Correction has been proposed by to introduce a new block coding proposal for minimization of peak to average power ratio (PAPR) of an OFDM system [9]. Block coding has error correction capability. In block coding method, the OFDM symbol can be reduced by selecting only those code words with lower PAPR. This method is proposed that properly designed block codes can not only minimize the PAPR, but also give error correction capability. Contrasting the method in [10], which only presents error detection; this method can improve the overall system performance and provides error correction capability.

3. Selected Mapping (SLM)

Selective Mapping (SLM) is used for minimization of peak to average transmit power of multicarrier transmission system with selected mapping [11]. A complete set of signal is generated signifying the same information in selected mapping, and then concerning the most favorable signal is selected as consider to PAPR and transmitted. The input data structure is multiplied by random series and resultant series with the lowest PAPR is chosen for transmission. To allow the receiver to recover the original data to the multiplying sequence can be sent as 'side information'.

One of the preliminary probabilistic methods is SLM method for reducing the PAPR problem. The good side of selected mapping method is that it doesn't eliminate the peaks, and can handle any number of subcarriers. The drawback of this method is the overhead of side information that requires to be transmitted to the receiver of the system in order to recover information.

4. Partial Transmit Sequence (PTS)

This proposed method is based on the phase shifting of sub-blocks of data and multiplication of data structure by random vectors. This method is flexible and effective for OFDM system[12]. The main purpose behind this method is that the input data frame is divided into non-overlapping sub blocks and each sub block is phase shifted by a constant factor to reduce PAPR.

PTS is probabilistic method for reducing the PAPR problem. It can be said that PTS method is a modified method of SLM. PTS method works better than SLM method. The main advantage of this scheme is that there is no need to send any side information to the receiver of the system, when differential modulation is applied in all sub blocks.

5. Interleaving Technique

Interleaving technique is another proposed Scheme for reduction peak to average power ratio of an OFDM transmission. The basic idea in interleaving is to set up an initial terminating threshold. 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. In this circumstance, higher order error correction method could be used in addition to this method.

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Volume 3, Issue 2, March 2014

6. Tone Reservation (TR)

The main idea of this method is to keep a small set of tones for PAPR reduction. This can be originated as a convex problem and this problem can be solved accurately [13]. 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. The advantage of TR method is that it is less complex, no side information and also no additional operation is required at the receiver of the system. Tone reservation method is based on adding a data block and time domain signal. A data block is dependent time domain signal to the original multicarrier signal to minimize the high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at the receiver.

7 .Tone Injection (TI)

Tone Injection (TI) method is based on general additive method for PAR reduction. Using an additive method achieves PAPR reduction of multicarrier signal without any data rate loss. Tone injection (TI) uses a set of equivalent constellation points for an original constellation points to reduce PAPR. The main idea behind this method is to increase the constellation size. Then, each point in the original basic constellation can be mapped into several equivalent points in the extended constellation, since all information elements can be mapped into several equivalent constellation points. These additional amounts of freedom can be utilized for PAPR reduction. This method is called Tone Injection method because of replacing the 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. The drawbacks of this method are; need to side information for decoding signal at the receiver side, and cause extra IFFT operation which is more complex.

B. Signal Distortion Techniques

1. Peak Windowing

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 [14]. Peak windowing reduces PAPRs at the cost of increasing the BER and out-of-band radiation. Clipping is a one kind of simple introduces PAPR reduction technique which is self interference. The technique of peak windowing offers better PAPR reduction with better spectral properties.

In peak windowing method we multiply large signal peak with 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).

2. Envelope Scaling

The Envelope Scaling technique has been proposed a new algorithm to reduce PAPR by scaling the input envelope for some subcarriers before they are sent to IFFT [15]. 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. 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. Results show that PAPR can be reduced significantly at around 4 dB. Finally the system of single scaling factor and number of clusters equal to number of sub carriers is recommended.

3. Peak Reduction Carrier

Peak Reduction Carrier has been proposed to use of the data bearing peak reduction carriers (PRCs) to reduce the effective PAPR in the OFDM system [16]. This scheme includes the use of a higher order modulation scheme to represent a lower order modulation symbol. This permits the amplitude and phase of the PRC to be positioned within the constellation region symbolizing the data symbol to be transmitted. This scheme is appropriate for PSK modulation; where the envelopes of all subcarriers are equal. 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

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the bit error rate (BER) degradation, amount of the side information would also be excessive when the number of subcarriers is large.

4. Clipping and Filtering
High PAPR is one of the most common problems in OFDM. A high PAPR brings disadvantages like increased complexity of the ADC and DAC and also reduced efficiency of radio frequency (RF) power amplifier.
One of the simple and effective PAPR reduction techniques is clipping, which cancels the signal components that exceed some unchanging amplitude called clip level. However, clipping yields distortion power, which called clipping noise, and expands the transmitted signal spectrum, which causes interfering [17]. Clipping is nonlinear process and causes in-band noise distortion, which causes degradation in the performance of bit error rate (BER) and out-of-band noise, which decreases the spectral efficiency [18].
Clipping and filtering technique is effective in removing components of the expanded spectrum. Although filtering can decrease the spectrum growth, filtering after clipping can reduce the out-of-band radiation, but may also cause some peak re-growth, which the peak signal exceeds in the clip level [19]. The technique of iterative clipping and filtering reduces the PAPR without spectrum expansion. However, the iterative signal takes long time and it will increase the computational complexity of an OFDM transmitter [17]. But without performing interpolation before clipping causes it out-of-band. To avoid out-of-band, signal should be clipped after interpolation. However, this causes significant peak re-growth. So, it can use iterative clipping and frequency domain filtering to avoid peak re-growth.
In the system used, serial to parallel converter converts serial input data having different frequency component which are base band modulated symbols and apply interpolation to these symbols by zero padding in the middle of input data. Then clipping operation is performed to cut high peak amplitudes and frequency domain filtering is used to reduce the out of band signal, but caused peak re-growth [19]. This consists of two FFT operations. Forward FFT transforms the clipped signal back to discrete frequency domain. The in-band discrete components are passed unchanged to inputs of second IFFT while out of band components are null. The clipping and filtering process is performed iteratively until the amplitude is set to the threshold value level to avoid the peak out-of band and peak re-growth.

VI. OVERALL ANALYSIS OF DIFFERENT TECHNIQUES
There are several techniques has been proposed in literature. Thus, it is possible to reduce the large PAPR by using the different techniques. Note that the PAPR reduction technique should be chosen with awareness according to various system requirements.
There are many issues to be considered before using the PAPR reduction techniques in a digital communication system. These issues include PAPR reduction capacity, power increase in transmit signal, BER increase at the receiver, loss in data rate, computational complexity increase and so on. Simultaneously most of the techniques are not proficient to obtain a large reduction in PAPR with low coding overhead, with low complexity, without performance degradation and without transmitter and receiver symbol handshake.

Table 1. Comparison of PAPR Reduction Techniques

Name of Schemes	Name of parameters		
	Distortion less	Power increases	Data rate loss
Clipping and Filtering	No	No	No
Block Coding	Yes	No	Yes
Partial Transmit Sequence(PTS)	Yes	No	Yes
Selective Mapping (SLM)	Yes	No	Yes
Interleaving	Yes	No	Yes
Tone Reservation (TR)	Yes	Yes	Yes
Tone Injection(TI)	Yes	Yes	No

VII. CONCLUSION
OFDM is a promising technique for wireless communication systems although it has some drawbacks which are given below:
1. High PAPR
2. Frequency offset

High PAPR is one of the major problems of OFDM system. There are several techniques to reduce the PAPR in OFDM transmission system. All PAPR reduction techniques have some advantages and disadvantages. These PAPR reduction techniques should be chosen carefully for getting the desirable minimum PAPR. All PAPR reduction techniques are based on particular situation of system. This section describes and summarizes several techniques of PAPR and proposes repeated clipping and frequency domain filtering technique which is the best solution for PAPR.

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