

A Comparative Approach between Clipping and Probabilistic Technique for Reducing PAPR of OFDM System

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Abstract

Recent trends and cutting edge technological evolution uses popular Orthogonal Frequency Division Multiplexing (OFDM) technique for transmitting high data rate over radio waves in modern wireless communication systems. Despite of the added advantage of OFDM like immune to frequency selective fading, multipath delay tolerance, and spectral bandwidth it suffers from major drawback of its high Peak to Average Power Ratio (PAPR) of the transmitted signal in time domain which results from sum of several sinusoids. The signal with great peaks can be obtained by constructive addition of subcarriers. Nonlinearities may get overloaded by high signal peaks, causing inter modulation among subcarriers and more critical undesired out-of-band radiation. If RF power amplifiers are operated without large power back-offs, it is impossible to keep the out-of-band power below specified limits. This leads to very inefficient amplification and expensive transmitters so that it is highly desirable to reduce the PAPR and the PAPR problem is more important in the uplink since the efficiency of power amplifier is critical due to the limited battery power in a mobile terminal.

In this paper, a comparatively and simulated approach has been carried out using matlab tool for Clipping and clipping & filtering with a modified clipping & filtering technique for reducing the PAPR based on their CCDF (Complementary cumulative distribution factor and BER (Bit error rate)). The clipping approach is given by clipping and

filtering technique which limits the maximum of transmit signal to a pre-specified level. Simulation results achieve a sharp drop of CCDF curve and reduce PAPR to an acceptable level.

Keywords: *PAPR, CCDF, OFDM, PTS, HPA, CR.*

1. Introduction

As an attractive technology for wireless communication, OFDM is a multicarrier modulation technique for high speed wireless access in multipath fading environment [1], [2], [3] which offers a significant immunity to frequency selective fading, multipath delay spread tolerance, spectral bandwidth efficiency [from amin ppt 2012]. As a result, OFDM has been elected [4],[5] for high data rate communication such as broadband wireless communication systems like WiMAX, DVB-T and future 4G/LTE systems [6]. The transmit signal in an OFDM system can have high peak values in the time domain since many subcarriers components are added via an IFFT operation. Therefore, OFDM systems are known to have a high PAPR, compared with single carrier systems. The PAPR problem is more important in the uplink since the efficiency of power amplifier is critical due to limited battery power in mobile terminals.

Despite of several advantages a challenging issue remains unsolved in the design of the OFDM systems. One of the major exertions is high Peak-to-Average Power Ratio (PAPR) of transmitted OFDM signals. Therefore, the OFDM receiver's detection efficiency is very sensitive to the nonlinear devices used in its signal processing loop. In general, even linear amplifiers impose a nonlinear distortion on their outputs due to their saturation characteristics caused by an input much larger than its nominal value. power P_{in} and the output power P_{out} . Due to the aforementioned saturation characteristic of the amplifier, the [7] possible output is limited by P_{out}^{max} when the corresponding input power is given by P_{in}^{max} . It means that the input power must be backed off so as to operate in the linear region. Therefore, the nonlinear region can be described by IBO (Input Back-Off) or OBO (Output Back-Off). In fact, the high PAPR is one of the most detrimental aspects in the OFDM system, as it decreases the SQNR (Signal-to-Quantization Noise Ratio) of ADC (Analog-to Digital Converter) and DAC (Digital-to-Analog Converter) while degrading the performance of power amplifier in the transmitter [from e book]. If the HPA is not operated in linear region with large power back-off, it is impossible to keep the out-of-band power below the specified limits. This situation leads to very inefficient amplification and expensive transmitters. Therefore, it is important and necessary to research on the characteristics of the PAPR including its distribution and reduction in OFDM systems, in order to utilize the technical features of the OFDM.

One of characteristics of the PAPR, the distribution of PAPR, which bears stochastic characteristics in OFDM systems, often can be expressed in terms of Complementary Cumulative (CCDF). Recently, some researchers have reported on

determination of the PAPR distribution based on different theoretic and hypotheses [8]–[12]. Moreover, various approaches also have been proposed to reduce the PAPR including clipping [12]–[13], coding schemes [13], nonlinear companding transforms [14]–[15], Tone Reservation (TR) and Tone Injection (TI) [16], [17], constellation shaping [17], Partial Transmission Sequence (PTS) and Selective Mapping (SLM) [18]–[19] and other techniques such as pre-scrambles proposed in [20]. These schemes can mainly be categorized into signal scrambling techniques, such as block codes and PTS etc., and signal distortion techniques such as clipping. Although some techniques of PAPR reduction have been summarized in [21], it is still indeed needed to give a comprehensive review including some motivations of PAPR reductions, such as power saving, and to compare some typical methods of PAPR reduction through theoretical analysis and simulation results directly. An effective PAPR reduction technique should be given the best tradeoffs between the capacity of PAPR reduction and transmission power, data rate loss, implementation complexity and Bit-Error-Ratio (BER) performance etc.

In this paper, firstly we investigate the distribution of PAPR based on the characteristics of the OFDM signals. Then, we analyze clipping and probabilistic techniques of PAPR reduction where the result shows the significant reduction in PAPR and then propose the criteria of PAPR reduction in OFDM systems.

2. Definition of PAPR

2.1 Baseband PAPR

2.1.1 Continuous time PAPR

In general, the PAPR of OFDM signals $S(t)$ defined as the ratio between the maximum instantaneous power and its average power

$$PAPR[x(t)] = \frac{\max[x(t)^2]}{P_{av}} \quad (1)$$

Where P_{av} is the average power of $x(t)$ and it can be computed in the frequency domain because IFFT is a (scaled) unitary transformation.

2.1.2 Discrete-time PAPR

The PAPR of the discrete time sequences typically determines the complexity of the digital circuitry in terms of the number of bits necessary to achieve a desired signal to quantization noise for both the digital operation and the DAC. However, we are often more concerned with reducing the PAPR of the continuous-time signals in practice, since the cost and power dissipation of the analog [16] components often dominate. To better approximate the PAPR of continuous-time OFDM signals, the OFDM signals samples are obtained by L times oversampling. L -times oversampled time-domain samples are LN -point IFFT of the data block with $(L - 1)N$ zero-padding. Therefore, the oversampled IFFT output can be expressed as

$$x(n) \triangleq \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j \frac{2\pi n k}{LN}}, 0 \leq n \leq LN - 1 \quad (2)$$

2.2 Passband PAPR

Note that, if N is large, an OFDM system usually does not employ pulse shaping, since the power spectral density of the band-limited OFDM signal is approximately rectangular. Thus, the amplitude of OFDM RF signals can be expressed as

$$\begin{aligned} x_{PB}(t) &= R\{x(t)e^{j2\pi f_c t}\} \\ &= R\{x(t) \cos 2\pi f_c t\} - J\{x(t) \sin 2\pi f_c t\} \end{aligned} \quad (3)$$

Where f_c is the carrier frequency therefore the peak of RF signals is equivalent to that of the complex baseband signals and the average power of the passband signal is

$$\begin{aligned} E[x_{PB}(t)]^2 &= E[R\{x(t)e^{j2\pi f_c t}\}]^2 \\ &= E[(\{x_I(t)\} \cos(2\pi f_c t) - \{x_Q(t)\} \sin 2\pi f_c t)^2] \\ &= \frac{1}{2} E[s(t)^2] \end{aligned} \quad (4)$$

Therefore the PAPR of the passband is twice the baseband PAPR. In this PAPR, we only consider the PAPR of the baseband OFDM signals.

3. Distribution of PAPR in OFDM Systems

Distribution Function (CCDF) used to estimate, bounds for the minimum number of redundancy bits required to identify the PAPR sequences, evaluate the performance of any PAPR reduction scheme, to calculate BER, estimate achievable information rates, determine a proper output back-off of HPA to minimize the total degradation. Moreover, we can directly apply distribution of PAPR to calculate the BER and estimate achievable information rates. In practice, we usually adjust these design parameters jointly according to simulation results. Therefore, if we can use an analytical expression to accurately calculate the PAPR distribution for OFDM systems, it can greatly simplify the system design process. Therefore, it is of great importance to accurately identify PAPR distribution in OFDM systems. Fig. 1 shows the distribution of the PAPR of the OFDM signals with $N = 64, 128, 256, 512$. It is between theoretical and practical PAPR for different FFT size. Largest reduction in PAPR for given FFT size is 64 and it reduces as FFT size increases. For increase of $N=64$ The PAPR reduction is 0.37 dB compared to 128.B.

4. PAPR Reduction Technique

The clipping is the easiest technique to reduce the power by setting a maximum level for the transmitted signal. Though, this technique has several disadvantages:

- The performance of BER could be affected negatively due to the in-band distortion caused by the clipping.
- Also out-of-band radiation usually appears with clipping technique that could disturb the adjacent channels.

However, we can use filtering operation to decrease the appearance of the out-of-band radiation but the signal may exceed the maximum level of the clipping operation. The block diagram of clipping and filtering technique for PAPR reduction is exposed in Fig4. In this figure, N denotes the number of subcarrier and L represents the oversampling factor. In the diagram, The IFFT generate $x'[m]$ which is the L-times oversampled signal. As shown in fig 2, the FFT-IFFT filter is applied to allow the signal passing through a band-pass filter (BPF) then through a low-pass filter (LPF). The outcome of the filtering stage is a less degraded BER performance and a reduced out-of-band radiation. Though, the PAPR reductions improvements are gained at the cost of re-growth the peak where the signal could go beyond the clipping level after applying the filtering operation.

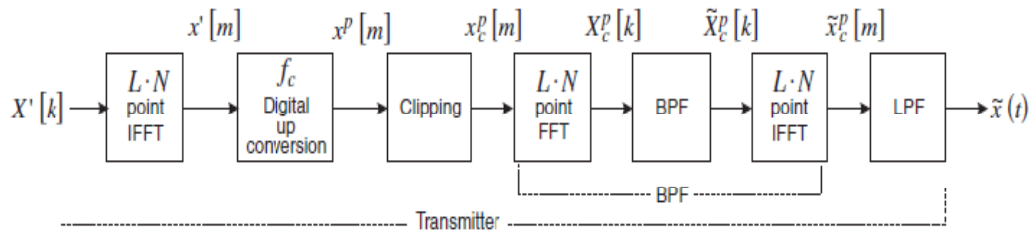


Fig.1: Clipping and filtering scheme for PAPR.

The signal $x^p(m)$ is the passband modulator one with carrier frequency f_c . We symbolize the clipped form of the passband modulated signal as $x_c^p(m)$. The expression of this signal is shown in following equation,

$$x_c^p(m) = \begin{cases} -A & x^p(m) \leq -A \\ x^p(m) & |x^p(m)| < A \\ A & x^p(m) \geq A \end{cases} \quad (5)$$

Where the clipping level is denoted by A and (CR) is the clipping ratio that can be represented as,

$$CR = \frac{A}{\sigma} \quad (6)$$

Where RMS value of OFDM signal is denoted by σ and it is well known that $\sigma = \sqrt{N}$ for baseband and $\sigma = \sqrt{\frac{N}{2}}$ for passband OFDM signal.

Here fig.1 is the output of a OFDM system with different CCDF value, PAPR value for different IFFT size which shows as the number of subblock increases the PAPR value get increased inspite of decreasing which is the object.

Fig. 2 gives the optimum values of CCDF versus PAPR for clipping and filtering technique in which the clipping has been done 1, 2,3 and 4 times and then the signal has been filtered. Fig. 3 shows the graph of CCDF versus PAPR value for different clipping ratio (CR). Fig 4 shows the BER versus PAPR value for clipping and filtering technique for different CR.

5. Simulation Results

Table 1: Parameters used for Clipping & filtering technique

Parameters	Value
Bandwidth BW	1 MHz
Sampling frequency f_s – BW * L	8 MHz
Carrier frequency f_c	2 MHz
FFT size N	128
Number of guard interval (CP)	32
Modulation order	QPSK
Clipping ratio	0.8, 1.0, 1.2, 1.4, 1.6

Table 2: CCDF vs. PAPR for modified method of Clipping & filtering technique.

CCDF value	PAPR value in dB				
	Original PAPR without clipping & filter	One clipping & filter	Two clipping & Filter	Three clipping & Filter	Four clipping & filter
10-1	8.866	7.486	6.841	6.473	6.267
10-2	10	8.1	7.191	6.675	6.381
10-3	10.92	8.523	7.435	6.812	6.455
2×10^{-4}	11.4	8.763	7.628	6.936	6.534

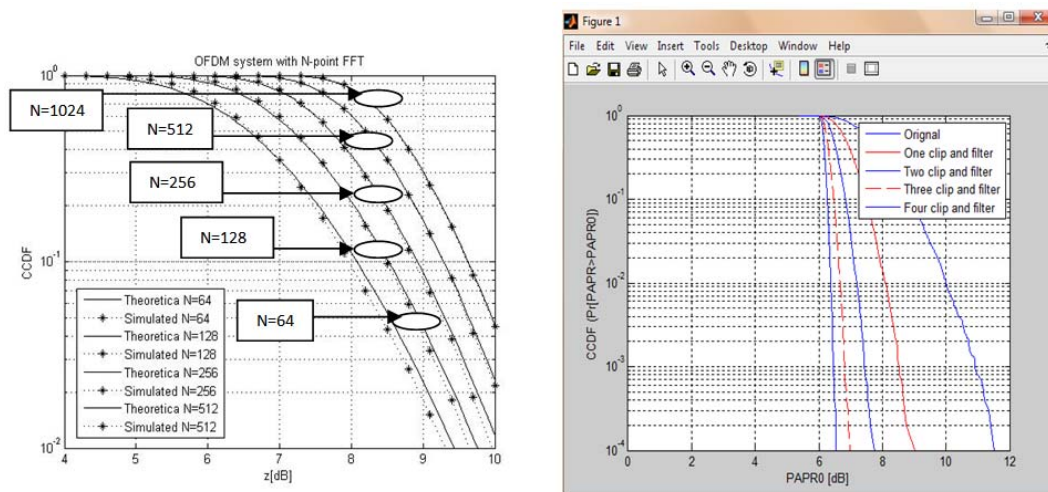
Table 3: BER value for different CR with only clipping technique.

SNR (dB)	BER with Clipping only				
	CR = 0.8	CR = 1.0	CR = 1.2	CR = 1.4	CR = 1.6
0	0.1307	0.09075	0.118	0.08524	0.1084
1	0.1053	0.07567	0.09472	0.06382	0.08787
2	0.09091	0.5945	0.08138	0.05126	0.06866

3	0.07287	0.4594	0.06539	0.03787	0.05472
4	0.06323	0.03339	0.05161	0.02878	0.03917
5	0.04969	0.2429	0.03795	0.02098	0.03028
6	0.04185	0.01984	0.02921	0.01358	0.02185
7	0.03413	0.01382	0.02433	0.01028	0.01626
8	0.02992	0.01	0.01925	0.00724	0.01213
9	0.02335	0.00826	0.01528	0.00480	0.00897
10	0.2063	0.0071	0.01114	0.00389	0.00681

Table 4: BER value for different CR with clipping & filtering technique.

SNR (dB)	BER with Clipping & filtering both				
	CR = 0.8	CR = 1.0	CR = 1.2	CR = 1.4	CR = 1.6
0	0.08185	0.1024	0.07638	0.07531	0.1587
1	0.06406	0.08217	0.0552	0.0576	0.1309
2	0.4524	0.06429	0.04098	0.03717	0.104
3	0.03102	0.04717	0.02972	0.02248	0.0789
4	0.0215	0.03327	0.01791	0.01291	0.0565
5	0.0148	0.02205	0.01142	0.0063	0.03768
6	0.0095	0.01713	0.0059	0.0023	0.02301
7	0.0067	0.01165	0.0046	0.0011	0.01259
8	0.0038	0.0071	0.0024	0.00023	0.0060
9	0.003	0.005	0.0012	7.8×10^{-5}	0.0024
10	0.0016	0.0028	0.0008		0.00078

**Fig.1** CCDF and PAPR distribution of **Fig. 2** CCDF and PAPR for clipping OFDM signal for different IFFT size signal 1,2,3, 4 times and then filtered

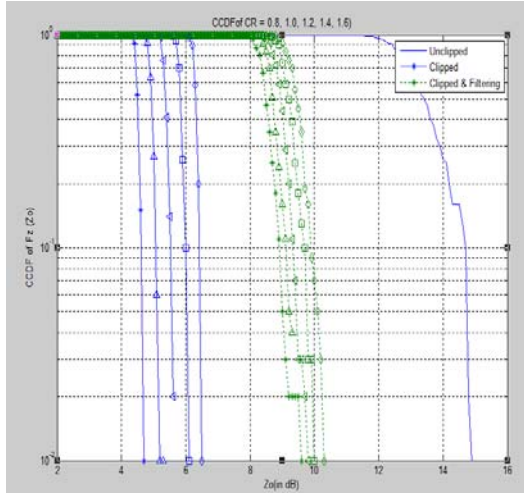


Figure 3: PAPR distribution

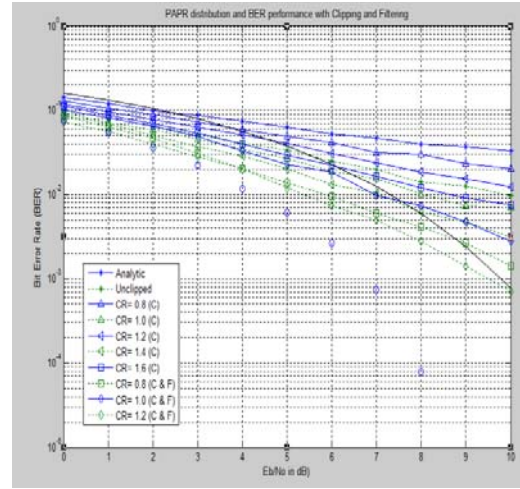


Figure 4: BER performance.

Figure 3 shows the CCDFs of crest factor (CF) for the clipped and filtered OFDM signals but the CCDF of CF can be considered as the distribution of PAPR since CF is the square root of PAPR. Here, “C” and “C&F” denote the case with clipping only and the case with both clipping and filtering, respectively.

6. Conclusion

In this paper we had compared the clipping technique and clipping-filtering technique and kind advance in clipping and filtering technique by doing the clipping some time and then filtering which gives significant improvement in CCDF as we can see in figure 2 and table 1. It can be seen from this figure that the PAPR of the OFDM signal decreases significantly after clipping and increases a little after filtering. It deduces the smaller the clipping ratio (CR) is, the greater the PAPR reduction effect is. Figure 4 shows the BER performance when clipping and filtering technique is used. It can be seen from this figure that the BER performance becomes worse as the CR decreases. Clipping causes in-band signal distortion, resulting in BER performance degradation and out of band distortion can be reduced by filtering but the clipped signal can reduce out-of-band radiation at the cost of peak regrowth. The signal after filtering operation may exceed the clipping level specified for the clipping operation. From simulation result we can see that there is a trade off between the CCDF and BER.

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