Global Journal of Engineering Science and Research Management

REVIEW OF SQUARE ROOTING AND TONE INJECTION METHOD FOR PAPR REDUCTION IN OFDM SYSTEM

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DOI: 10.5281/zenodo.51763

KEYWORDS: Orthogonal frequency division multiplexin (OFDM), Peak to average power ratio (PAPR), Tone Injection (TI)

ABSTRACT
The best multi-carrier system for wireless communication is an OFDM system for which PAPR is one of the major critical problems. Previously, various solutions have been proposed to reduce the PAPR. In this paper, we are reviewing these solutions on basis of PAPR, bit error rate (BER), complimentary cumulative distribution function (CCDF), in band and out of band radiation. Later section investigates the simulation results and conclusion based on the above parameters.

INTRODUCTION
OFDM was first proposed in 1966, patented in 1970 which has many well-known benefits, such as robustness against frequency selective fading or narrowband interference, high bandwidth efficiency, and efficient implementation [1]. OFDM is a special case of multicarrier transmission, where a single data stream is transmitted over a number of lower rate subcarriers [2]. The main objective to use OFDM is to increase the robustness against the selective fading or narrowband interference. In single carrier system if signal gets fade or interfered then entire link gets failed where as in multicarrier system only a small percentage of the subcarriers will be affected. Due to OFDM system's immunity from selective fading it is widely used in high speed communication [1] devices like ADSL Modem, DAB, DVB and WLAN. It is also going to be used in 4G cellular communication networks. Since its discovery lot of research has been done in this area to improve OFDM communication system for future needs.

Despite many advantages, a major drawback of OFDM is its high Peak-to-Average Power Ratio (PAPR) problem, which makes system performance very sensitive to nonlinear distortions. Indeed, when the OFDM signal with high PAPR passes through a nonlinear device, the signal may suffer significant nonlinear distortions and severe power penalty which is unaffordable for battery powered portable wireless terminals. To reduce the PAPR of OFDM signals, several PAPR reduction techniques have been proposed [1] [2] [4]. Clipping is the most straightforward PAPR reduction technique but can lead to significant out-of-band distortion. In order to alleviate such effects filtering can be applied [6]. However this causes significant peak re-growth. Distortion less techniques such as Tone Reservation [5] can also be employed. Tone Reservation reserves a small number of data tones in the frequency domain to generate an effective cancellation signal for high peaks in the time domain. This can be computationally very burdensome and may cause a significant (up to 20%) reduction in data through-put. Selective Mapping (SLM) is implemented by generating a set of sufficiently-different candidate signals from the original data signal. The transmitter selects and submits the candidate signal having the lowest PAPR. Partial Transmit Sequencing (PTS) is a similar technique in which sub-blocks of the original signal are optimally combined at the transmitter to generate a transmitted signal with a low PAPR. Although SLM and PTS are effective at reducing the PAPR, they require the use of side information in order to decode the signal at the receiver [7].

The rest of the paper is organized as follows. Section-II describes the PAPR problem and in Section-III, we present details of the different PAPR reduction techniques. Simulation results are presented in section-IV. The paper is concluded in Section-V.

PAPR BACKGROUND THEORY

Most radio systems employ the high power amplifier (HPA) in the transmitter to obtain sufficient transmission power. For the purpose of achieving the maximum output power efficiency, the HPA is usually operated at or near the saturation region. Moreover, the nonlinear characteristic of the HPA is very sensitive to the variation in signal amplitudes. However, the variation of OFDM signal amplitudes is very wide with high PAPR [7].

Therefore, HPA will introduce inter-modulation between the different subcarriers and introduce additional interference into the systems due to high PAPR of OFDM signals. This additional interference leads to an increase in BER. In order to lessen the signal distortion and keep a low BER, it requires a linear work in its linear amplifier region with a large dynamic range. However, this linear amplifier has poor efficiency and is so expensive. Power efficiency is very necessary in wireless communication as it provides adequate area coverage, saves power consumption and allows small size terminals etc [1][7].

It is therefore important to aim at a power efficient operation of the non-linear HPA with low back-off values and try to provide possible solutions to the interference problem brought about. Hence, a better solution is to try to prevent the occurrence of such interference by reducing the PAPR of the transmitted signal with some manipulations of the OFDM signal itself. Large PAPR also demands the DAC with enough dynamic range to accommodate the large peaks of the OFDM signals. Although, a high precision DAC supports high PAPR with a reasonable amount of quantization noise, but it might be very expensive for a given sampling rate of the system. Whereas, a low-precision DAC would be cheaper, but its quantization noise will be significant, and as a result it reduces the signal Signal-to-Noise Ratio (SNR) when the dynamic range of DAC is increased to support high PAPR. Furthermore, OFDM signals show Gaussian distribution for large number of subcarriers, which means the peak signal quite rarely occur and uniform quantization by the ADCs is not desirable. If clipped, it will introduce in band distortion and out-of-band radiation (adjacent channel interference) into the communication systems. [1][9] Therefore, the best solution is to reduce the PAPR before OFDM signals are transmitted into nonlinear HPA and DAC.

For an OFDM signal with *M* subcarriers and total continuous time signal $x(t)$ consisting of all the OFDM block, the PAPR is defined as,

$$PAPR = \max |x(t)|^2 / E|x(t)|^2 \quad (1)$$

In particular, a baseband OFDM signal with M subchannels has,

$$PAPRmax = 10\log_{10} M \quad (2)$$

From the central limit theorem, it follows that for large values of M (M>64), the real and imaginary values of $x(t)$ become Gaussian distributed. Therefore the amplitude of the OFDM signal has a Rayleigh distribution, with a cumulative distribution given by,

$$F(z) = 1 - e^{-z} \quad (3)$$

The probability that the PAPR is below some threshold level can be written as,

$$P(PAPR \leq z) = (1 - e^{-z})M \quad (4)$$

In fact, the complementary cumulative distribution function (CCDF) of PAPR of an OFDM is usually used, and can be expressed as,

$$P(PAPR > z) = 1 - (1 - e^{-z})M \quad (5)$$

PAPR REDUCTION TECHNIQUES

There has been a lot of work done to reduce PAPR by lot of scholars. In this PAPR we will focus on the conventional PAPR reduction methods such as square rooting technique and tone injection method [5].

THE SQUARE ROOTING METHOD

Square rooting method is one of the distortion based method of PAPR reduction [3]. Some of the statistical properties of signals can be changed by applying special mathematical operations. As an example, the Rayleigh distribution of any signal will change into Gaussian distribution if the square root operation is applied to that signal. Also, the Chi-Square distribution can be transformed into Rayleigh distribution by applying the same process, square rooting. Not only the statistical distribution changes by square rooting, but the mean and variance values of the signal are also varied. This process, square rooting, is exploited in this work to realize reduction of the PAPR value. From the central limit theorem and for large number of input samples, the imaginary and real parts of the IFFT outputs will follow Gaussian distributions. Hence, the amplitude (envelope) of the complex valued OFDM symbols will have Rayleigh distribution computed by,

$$x(n) = (\mathrm{Re}\{x[n]\})^2 + (\mathrm{Im}\{x[n]\})^2 \qquad (6)$$

$x(n)$ **:** Amplitude values of OFDM symbols, random variable (RV) of Rayleigh distribution.
$(\mathrm{Re}\{x[n]\})$**:** Real part of OFDM symbols, RV of Gaussian distribution.
$(\mathrm{Im}\{x[n]\})$**:** Imaginary part of OFDM symbols, RV of Gaussian distribution.

At the same time, the power distribution becomes a central chi-square distribution.

$$X_k = \sqrt{|x_k|}.e^{j\Phi} \qquad (7)$$

where $e^{j\Phi}$ is the phase of x_k

The square rooting technique can be used to improve OFDM transmission performance. This technique is used to compand the OFDM signal before it is converted into analog waveform. The OFDM signal, after taking IFFT, is companded and quantized. After D/A conversion, the signal is transmitted through the channel. At the receiver end then the received signal is first converted into digital form and expanded in order to recover the original signal.[8]

It can increase the average transmit power to reduce the PAPR and make the signal power value easier to be near to power non-linear changes in the amplifier region, so that the signal is likely to be distorted.

TONE INJECTION (TI) METHOD

Tone injection is a efficient techniques to reduce the PAPR of OFDM signals. The key idea in TI is that both transmitter and receiver reserve a subset of tones for generating PAPR reduction signalsς. Note that these tones are not used for data transmission. In TI, the objective is to find the time domain signal ς to be added to the original time domain signal to reduce the PAPR. Let (ς=0,1,…N-1) denote complex symbols for tone injection at reserved tones. Thus, the data vector changes to after tone reservation processing, and this results in a new modulated OFDM signals as,

$$X = \mathrm{IFFT}\ (x+\varsigma) \qquad (8)$$

TI also uses an additive correction to optimize in ς. The basic idea of TI is to extend the constellation and thus the same data point corresponds to multiple possible constellation points. One option is to replicate the original shaded constellation into several alternative ones. Therefore, is a translation vector such that ς = X mod (X). Note that TI needs not require the extra side information and the receiver only needs to know how to map the redundant constellations on the original one. An alternative strategy is to move the constellation points by applying an FFT on the clipped time signals, and the same operations are repeated till the entire constellation points are within specified boundaries and the PAPR specification of the time signal is satisfied [5]. Some modifications of TI have been proposed to obtain good performance including PAPR reduction and low complexity [5]. The TI technique is more problematic than the Tone Rejection technique since the injected signal occupies the frequency band as the information bearing signals. Moreover, the alternative constellation points in TI technique have an increased energy and the implementation complexity increases for the computation the optimal translation vector [5].

SIMULATION RESULTS

*A.*SIMULATION PARAMETERS

Simulation parameters are listed in Table I. The number of subcarriers, *K,* is set to 16. The number of FFT/IFFT points, *F* is set to 64, which corresponds to 4-times oversampling in the time domain. The simulations are performed for an IEEE 802.11a compliant OFDM system employing 16-QAM in which *N* = 64 subcarriers are used. MATLAB simulator is used to carry out these results.

TABLE I SIMULATION PARAMETERS

Number of subcarriers, *K*	16
Number of IFFT points, *F*	64
Data modulation	16-QAM
Channel model	AWGN
Maximum number of iterations in PAPR reduction	10

*B.*SIMULATION RESULTS

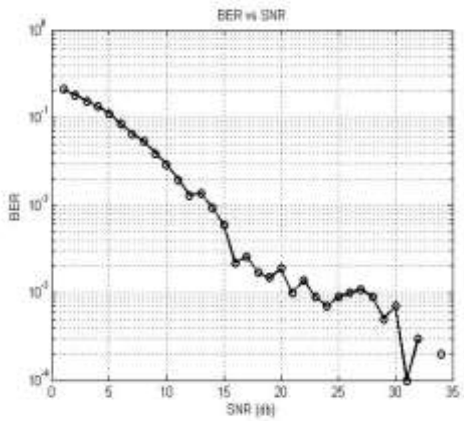

Fig1: BER vs. SNR curve for square rooting

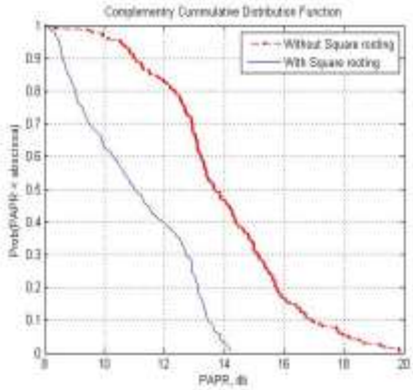

Fig 2: CCDF plot for square rooting

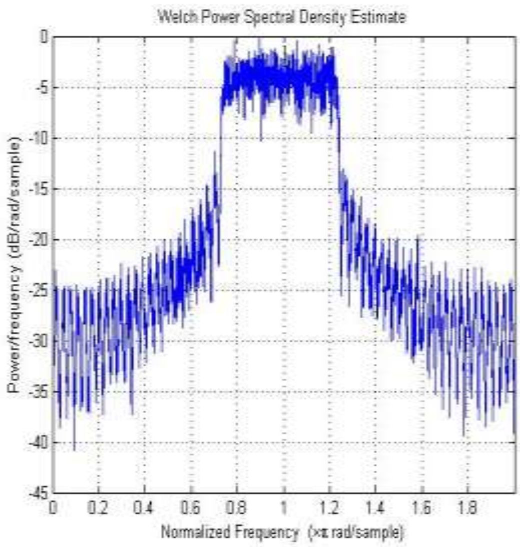

Fig 3: In-band and out of band radiation for Square rooting

Fig-1 signifies the BER vs SNR curve.It is clear that as we go on increasing the SNR,bit error rate reduces. An acceptable amount of BER 10^{-4} was achived at SNR=30db.

In Fig-2 the results are presented in terms of Complementary Cumulative Distribution Function (CCDF) for an OFDM output symbol blocks before and after processing. The difference in PAPR performance between the conventional OFDM system, and that obtained from the square rooting method are observed. The CCDF curve was obtained at SNR=10db. As could be seen, the performance of the system in term of PAPR show that maximum reduction in PAPR value of slightly more than 5dB was achieved by the square rooting method for the OFDM system parameters of 10048 samples and 16-QAM modulation scheme.

As shown in the fig-3 In-band and out of band radiation graph is investigated. the performance of the technique in a communication system also depends on the effect of the resulting in-band distortion and on how much out-of-band power will result after non-ideal amplification. We can clearly observe that due to non-linear effect In-band distortion is high which effects BER of the system. Out-band distortion causes degradation in spectral efficiency. Due to non-linearity effect in-band radiation is more which ultimately results in slight increase in bit error rate of the system.

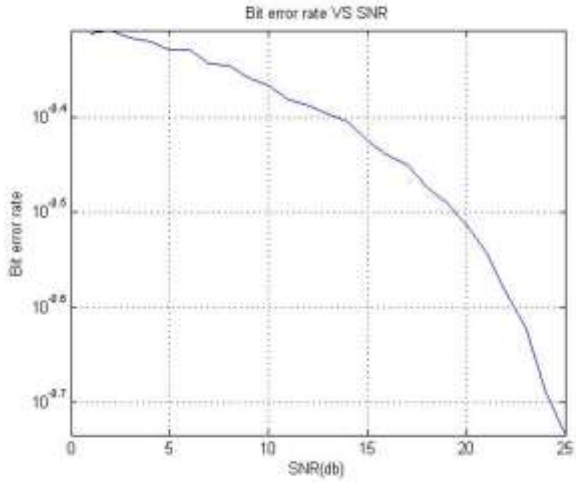

Fig4: BER vs SNR curve for TI method

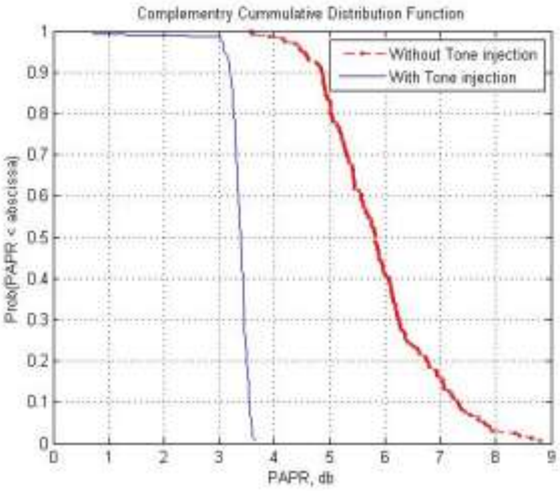

Fig 5: CCDF plot for TI Method

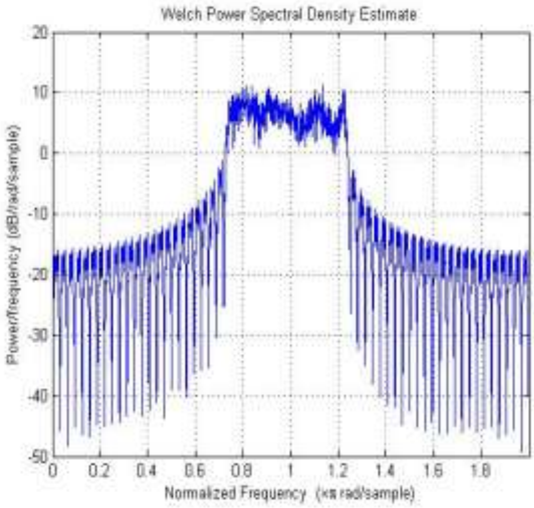

Fig 6: In-band and out of band radiation for TI method

All the simulation parameters were kept same for tone injection method. Fig-4 states that the bit error rate (BER) vs. signal to noise ratio plot. Bit error rate of Tone injection method largely depends upon the side information Fig-5 elaborates Complementary cumulative distribution function curve. CCDF curve was obtained at SNR=10db. It can be seen that an excellent PAPR reduction of 4db was achieved by TI method. This method is highly complex than square rooting technique. Method also achieves excellent PAPR reduction.

In-band and out of band radiation is investigated in Fig-6 we can conclude that out of band radiation is more than the square rooting technique method due to side information in-band radiation is less than which ultimately results in slight increase in bit error rate of the system.

CONCLUSION

This paper mainly focuses on one of the challenging drawback of OFDM that is high PAPR. Square rooting method is simple non-liner distortion based method, while tone injection method is complex distortion less method. The simulation proves that though TI method is affective to reduce the PAPR. It costs significant increase the out of band radiation which increases bit error rate of the system. Square rooting method achieves good PAPR reduction with less bit error rate. 30db SNR was enough to achieve desired SNR CCDF curves investigates that TI method is slightly better than clipping. We get nearly 5db and 4db reduction in TI and square rooting methods. Square rooting method is suitable for OFDM applications that are sensitive to spectral efficiency and noise, since it allows efficient reduction in PAPR value with low out-of band radiation. TI method can be better where we require large reduction in PAPR but price is paid by reducing throughput and data rate of system. High BER is another problem which can be overcome by adding redundancy in data and coding techniques.

ACKNOWLEDGMENT

The authors are grateful to the SRES' College of engineering Kopargaon and Savitribai Phule Pune University (SPPU) for providing necessary motivation, support and facilities to complete the paper.

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