Impact of Threshold Clipping on Bit Error Rate in OFDM-Like Systems

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ABSTRACT

In wireless communications, 3GPP LTE is one of the solutions to meet the greater transmission data rate demand. One issue inherent to this technology is the PAPR (Peak-to-Average Power Ratio) of OFDM (Orthogonal Frequency Division Multiplexing) modulation. This high PAPR affects of the efficiency of power amplifiers. One approach to mitigate this effect is the Crest Factor Reduction (CFR) technique. In this work we simulate the impact of Hard Limited Clipping Crest Factor Reduction technique on BER (Bit Error Rate) in OFDM based Systems. In general, the results showed CFR has more effect on higher digital modulation schemes, as expected. More importantly, we show the worst-case degradation due to CFR on QPSK, 16QAM, and 64QAM signals in a linear system. For example, hard clipping of 9dB results in a 2dB increase in signal to noise energy at a 1% BER for 64-QAM modulation.

Keywords: Bit Error Rate; Crest Factor Reduction; OFDM; Physical Layer Simulation

I. INTRODUCTION

Orthogonal Frequency Division Modulation (OFDM) has a high Peak-to-Average Power Ratio (PAPR), meaning the modulated signal peaks at a much higher power than the average. This high peak-to-average ratio is expected because the waveform is a sum of many carriers. For an OFDM signal, the PAPR is approximately 12dB. This causes a problem when providing a radio transmitter with this kind of headroom.

One remedy is Crest Factor Reduction (CFR) [1]. With CFR, the signal peaks, crests, are purposely attenuated in a controlled process. CFR lowers the peak-to-average ratio and reduces the headroom needed in the power amplifier, but introduces distortion. This distortion increases the Error Vector Magnitude (EVM) and the Bit Error Rate (BER).

The work undertaken here was not to compare and contrast CFR methods or modulation and data encoding schemes but to develop a simulation and visualization method where CFR is directly related to BER by simulation. The results shown here used a hard clipping algorithm to reduce the crests in a simulated OFDM waveform.

Fig. 1 shows a histogram of sample voltages from an OFDM signal. The mean is approximately 0.25. For a linear transmitter, the system must treat all signal levels equally. For example, a linear OFDM 10 watt transmitter needs to operate at peak power of 160 watts. That is 150 watts difference between the peak and average signal levels. This 'headroom' is required in to guarantee the peaks are not distorted or clipped. Providing such headroom results in power amplifiers that are much larger and consume more power than similar units that top out at the average power.
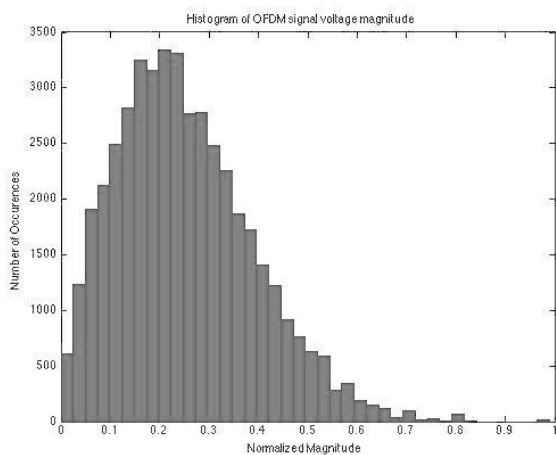

Fig. 1. The simulated effect of hard-clipping CFR on BER at various Eb/No levels for 64-QAM modulation

Past studies have shown the effect of CFR on EVM and the reader is left to calculate BER. While transmit EVM is important for standard cellular (3GPP) systems, other applications like point-to-point or point-to-multipoint systems are being developed where BER and ACLR (Adjacent Channel Leakage power Ratio) is the primary concern.

A. *Theoretical background*

Crest Factor Reduction is the process of reducing the peak to average ratio (reducing signal crests) by a nonlinear process. This leads to degradation in Error Vector Magnitude and has been a subject of prior studies [2,3]. The relation between EVM and Signal-to-Noise Ratio (SNR) is also known [4]

$$EVM_{rma} \approx \sqrt{\frac{1}{SNR}} \qquad (1)$$

This degradation in SNR has a well-known impact on BER [5,6] and is added to the transmission channel's impairments such as multipath and Additive White Gaussian Noise (AWGN). Meeting a specified EVM is imperative in many systems such as 3GPP and 3GPP2. There should be no need to find SNR and relate that to BER because the standards body has set limits on EVM taking SNR, data rate and modulation type into account. However, it may be useful in some cases to directly observe the impact of CFR on BER without having to know the intermediary EVM and SNR.

B. *Experimental Background*

Different methods of CFR have been described in the literature: Hard limiting, repetitive clipping and filtering, soft saturation, etc. [7,8,9]. The goal of all these methods is to reduce the instantaneous dynamic range and as a result the instantaneous headroom needed from the transmitter. In most cases, the impact of CFR on EVM and BER are difficult or impossible to find analytically. But the effect can be simulated and tested.

II. Ojective

The objective of this study is to develop a method to simulate the end-to-end impact of CFR directly on BER of an OFDM waveform. To limit the scope of the study, the type of CFR, transmission channel, encoding is limited to one case of hard limiting CFR in an Additive White Gaussian Noise (AWGN) channel. Shown here are the technique, results, and interpretation. The simulation and analysis can be repeated using other variations of CFR, channel impairments, and waveform encoding.

The objective was not to perform a study of various implementations of CFR. We present a simulation and predictive method that is efficient and flexible. The work presented here implemented hard limiting, i.e. any absolute value above a desired level has made equal to that level, retaining the phase as given in Equation (2) where A_{max} is the maximum value allowed by the waveform.

$$x'_n = \begin{cases} x_n, & |x_n| \leq A_{max} \\ A_{max}e^{j\angle x_n}, & |x_n| > A_{max} \end{cases} \qquad (2)$$

It is important to note that when this algorithm tests if an instantaneous magnitude exceeds a predefined threshold, in which case the magnitude is attenuated to the threshold, clipped, whilst retaining the phase of the waveform.

A secondary objective was to use the method developed as a predictive tool. This was not a primary objective because the results could not be compared to measurements, and laboratory experiments could not be performed with the facilities available. However, as an end goal, the prediction of how much headroom can be reduced is most useful. For example, when simulation shows that the peak-to-average ratio of a particular OFDM waveform can be reduced from 12dB to 6dB, the

transmitter for a 10W average power level need only handle 40W peak, a considerable reduction from 160W.

III. METHODOLOGY

We started with OFDM Matlab simulation code by Lima et al [10]. In general, the algorithm simulates an OFDM waveform that has a data and pilot part. The code has a rich variety of settings where the user has control over modulation (BPSK, QPSK, 8-QAM, 16-QAM, and 64-QAM), bandwidth, number of frames, chips per frame, turbo encoding, normal and extended cyclic-prefix. The waveform is filled by random data or from a data file.

The result is a Matlab test vector that represents an OFDM signal voltage. Then, channel impairments are imposed on this test vector: noise and multipath delay being to two most often used. Finally, the simulated signal is demodulated, the data extracted, and compared to the transmitted data to find the bit error rate.

The Matlab test vectors used in this study consisted of 10 OFDM frames. Each frame held 10ms of data at a chip rate 3.84 MHz. The other settings used are:

1. Hard-limiting CFR

2. AWGN channel, no multipath

3. 25 MHz bandwidth

4. 15 kHz channel spacing

5. Channel QPSK, 16-QAM, 64-QAM

6. Extended cyclic prefix

7. No turbo encoding/decoding

8. No transmit or receive diversity

9. Channel type EPA-LTE

Once created, the test vector is ready for crest factor reduction by finding the maximum and the RMS levels. The work presented here used a simple hard limiting algorithm, but other soft limiting methods can be implemented and tested by changing the CFR function.

After this, AWGN is added to the crest-reduced vector and a simulated receiver demodulates the data, and calculates the BER. Plots of BER verses Eb/No as shown here were modified to show multiple lines.

In the original code, the user gets only one plot of BER verses Ed/No per setting.

The final algorithm used in this work is presented in flow chart form in Fig. 2. Ten frames of data were synthesized with random data. Then the BER analyses preceded using increasing levels of CFR clipping. Not shown in Fig. 2 is the option to perform a Monte Carlo analysis of the end-to-end simulation with different test vectors containing random data generated by a new seed.

IV. RESULTS

The results shown here are from simulations of an OFDM waveform using QPSK, 16-QAM, and 64-QAM modulation. The plots show BER verses Eb/No (bit-energy to noise ratio) for 7 clipping levels. Each line on the plot represents a different clipping level reduction (attenuation) in dB from the peak value in the waveform, i.e. 0 dB is no clipping, 3dB is a clipping level of 0.708 of the peak, 6dB is a clipping threshold of 0.501 the peak. All plots show the average results of a Monte Carlo analysis by repeating the algorithm in Fig. 2 a total of 10 times.

Fig. 3 shows that, as expected, the bit error rate increases as clipping level (attenuation) increases. For example, to achieve a 1% BER, approximately 11.6dB of Eb/No is needed when no CFR is used (0 attenuation). With a clipping level of 15dB, approximately 13dB of Eb/No is needed to achieve the same BER. This illustrates that QPSK can tolerate severe clipping at this bit error rate.
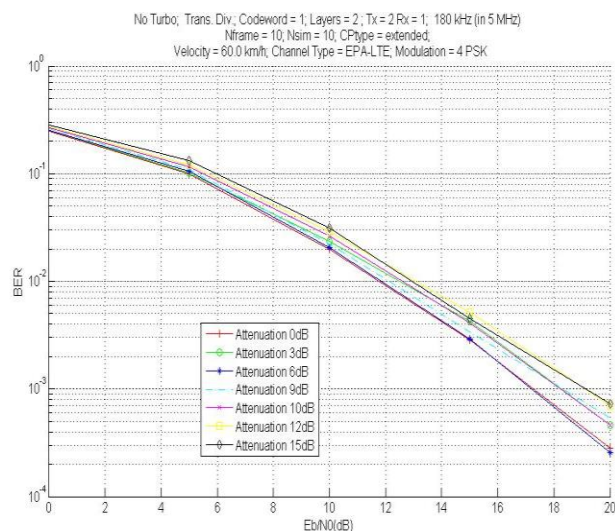
Fig. 3. The simulated effect of hard-clipping CFR on BER at various Eb/No levels for QPSK modulation

Fig. 4 shows the same spread of clipping level (attenuation) when 16-QAM is used for the data modulation. Notice the dramatic effect high levels of clipping have on BER. Assuming the same 1% BER threshold, 15 dB Eb/No is needed under no crest factor reduction as expected. As opposed to the QPSK case, the effect of 15dB CFR is well off the plot. Taking a more reasonable clipping level of 9dB, Eb/No needs to be approximate 16.5dB to achieve 1% BER. In this case, a 9 dB reduction in
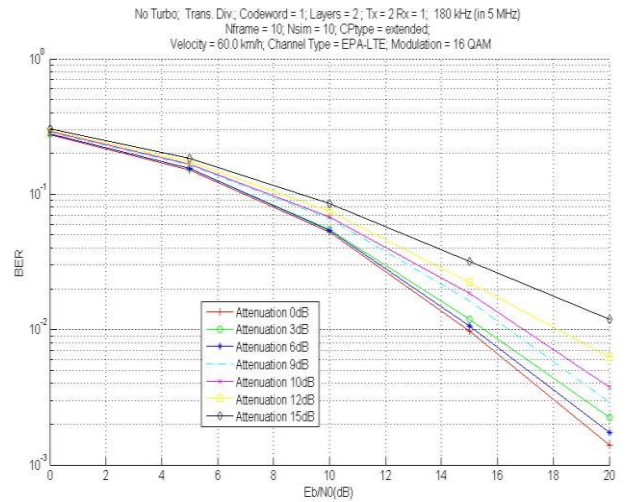

Fig. 4. The simulated effect of hard-clipping CFR on BER at various Eb/No levels for 16-QAM modulation

Increasing the clipping level to 6dB appears to result in 3dB degradation in Ed/No. One can conclude that increasing clipping beyond this point result in ever higher signal to noise degradation that what might be gained by the increased transmit power available by lowering the headroom needed in the transmitter.

Fig. 2. Flow chart of the simulation algorithm

instantaneous dynamic range would only require an increase of 1.5 dB in signal level.

Fig. 5 shows the effect of hard clipping on BER for 64-QAM modulation. As expected, a more dramatic effect is seen at high clipping levels. Note that at 1% BER benchmark, there is no statistical impact at 3dB clipping after averaging over 10 runs.
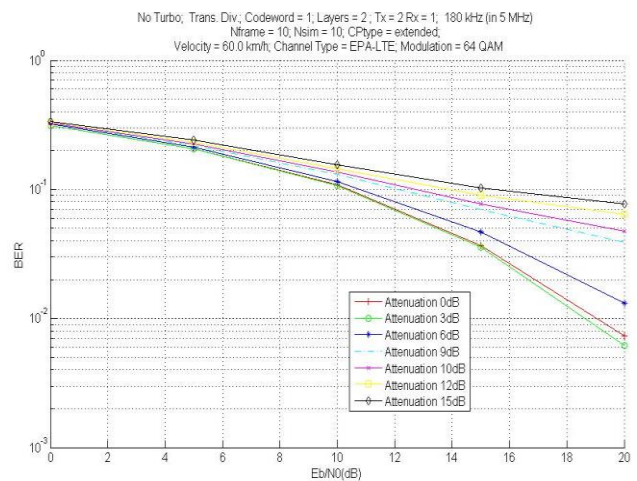

Fig. 5. The simulated effect of hard-clipping CFR on BER at various Eb/No levels for 64-QAM modulation

Table 1 shows a summary of selected data for the three data modulation types. The BER benchmark is 1% for all cases summarized. The SNR increase columns represent how much the signal-to-noise ration should be increased to maintain a 1% BER. The predictive value possibly lies in relating the SNR increase to either transmit power or transmitter headroom.
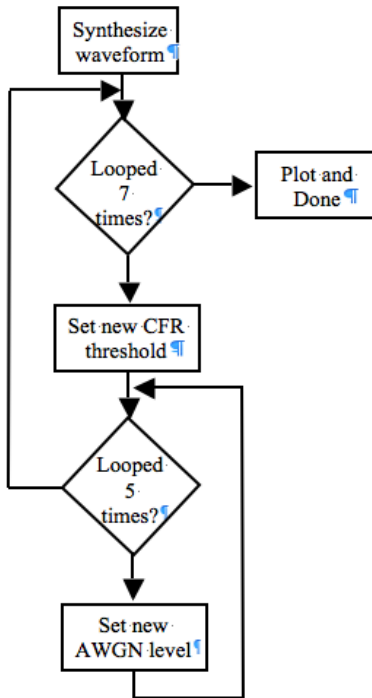
In cases where the radiated power can be increased, requiring less headroom allows more average transmit power. For example, if 6dB CFR, the data indicates transmit power can be increased by 6dB, this more than compensates for the 2dB degradation incurred in SNR for 64-QAM modulation.

TABLE I.   TABLE OF SELECTED RESULTS

Type	Simulation Results			
	BER	*3dB CFR SNR Increase*	*6dB CFR SNR Increase*	*9dB CFR SNR Increase*
QPSK	0.01	≈ 0	≈ 0	0.2dB
16-QAM	0.01	≈ 0	0.2 dB	1.4 dB
64-QAM	0.01	≈ 0	2 dB	≈ 12 dB

In the cases where the average transmit power is the maximum allowed, a reduction in headroom due to reducing the instantaneous signal peaks can result in a significant reduction in transmitter size, power, and cost.

V. CONCLUSION

The purpose of this study was to simulate the effect of one CFR technique (hard limiting) on BER. Assuming that a one-to-one reduction in crest factor can result in a corresponding increase in power output, there is a point where the degradation in SNR needed exceeds the decrease in headroom. This breakeven depends on the modulation and target BER when using all the newly available headroom cannot compensate for the increase in SNR at the receiver. We have not considered ACLR in this work.

REFERENCES

[1] T. May and H. Rohling, "Reducing the Peak-to-Average Power Ratio in OFDM Radio Transmission Systems," 84th Vehicular Technology Confrence, 1998, VTC 98, 18-21 May, 1998, pp 2474-2478.

[2] C. Zhao, R. Baxley, G. Zhou, D. Boppana, and J. Kenney, "Constrained clipping for crest factor reduction in multiple-user ofdm," in Radio and Wireless Symposium, 2007 IEEE, Jan 2007, pp. 341–344.

[3] R.J. Baxley, C. Ahao, and G. Tong, "Constrained Clipping of Crest Factor Reduction in OFDM," IEEE Transactions on Bradcasting, Dec. 2006, pp 570-575.

[4] H. Mahmond and H. Arslan, "Error Vector Magnitude to SNR Conversion for Nondata-Aided Receivers," in IEEE Transactions on Wrieless Communications, May 2009, pp 2694-2704.

[5] R.A. Sahfik, S. Rahmen and R Islam, "On the Extended Relationships Amung EVM, BER and SNR as Performance Matrics," 4th International Confrence on Electrical and Computer Engineering, ICECE 2006, 19-21 Dec. 2006. Pp 408-411

[6] R.J. Baxley, C. Ahao, and G. Tong, "Magnitude-Scaled Selected Mappng: A Crest Factor Reduction Scheme for OFDM Without Side-Information Transmission," 2007 IEEE International Conference on Acoustics, Speech and Signal Processing - ICASSP '07, April 15-20, 2007, pp III-373 – III-376.

[7] A. Molina, K. Azadet, and C. Li, "Crest factor reduction (cfr) using asymmetrical pulses," Nov. 25 2014, uS Patent 8,897,388. [Online]. Available: http://www.google.com/patents/US8897388

[8] L. Freiberg, A, Annamalai, and V.K. Bhargava, "Crest Factor Reduction Using Orthogonal Spreading Codes in Multi-Carrier CDMA System," Waves of the Year 2000, The 8th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 1-4 Sept, 1997, vol.1 pp 120-124.

[9] X. li and l. Cimini, "The Effects of Clipping and Filtering on the Performance of OFDM," IEEE communications letters, May 1998, vol. 2, pp 131-133.

[10] M. Lima, C. Gussen, B. Espindola, T. Ferreira, W. Martins, and P. Diniz, "Open-source physical-layer simulator for lte systems," in Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on, March 2012, pp. 2781–2784.

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