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Impact of Hard Limited Clipping Crest Factor Reduction Technique on Bit Error Rate in OFDM Based 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 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 that CFR has more effects 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 9 dB results in a 2 dB 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

OFDM has a PAPR of approximately 12 dB. For a linear transmitter, the system must treat equally peak signals even though the average is much lower. For a linear transmitter, this "headroom" is required to guarantee that waveform peaks are not distorted. Providing such headroom results in the power amplifiers that are much larger and consume more power than a similar unit that top out at the average power.

One remedy to reducing the required headroom is CFR [1]. With CFR, the composite signal peaks and 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 and increases the Error Vector Magnitude (EVM) and the BER.

The past studies have shown the effect of CFR on EVM and the reader is left to calculate BER [2], [3]. While transmitted EVM is important for standard cellular (3GPP) systems, the other applications like point-to-point or point-to-multipoint systems are being developed where BER and Adjacent Channel Leakage Power Ratio are the primary concerns.

A. Theoretical Background

CFR leads to degradation in EVM and has been a subject of many studies. The relation between EVM and Signal to Noise Ratio (SNR) is given in [4]:

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

This degradation in SNR has a well-known impact on BER [5] and is added to the transmission channel's impairments such as multipath and Additive White Gaussian Noise (AWGN). Maintaining a specified EVM is imperative in many systems such as 3GPP and 3GPP2. There is no need to find SNR and BER. However, it may be useful in some cases to directly observe the impact of CFR on BER without having to know EVM.

B. Experimental Background

Different methods of CFR have been described: hard limiting, repetitive clipping and filtering, etc. [6], [7]. The impact of these on EVM and BER is difficult to find analytically [8]. But, the effect can be simulated and tested.

The work undertaken here was not to compare and contrast the CFR methods, but it is 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. The efficacy of one CFR technique over another is left for the future studies. It is important to note that when this algorithm finds an instantaneous magnitude exceeding a predefined crest reduction, the magnitude is attenuated to the desired clipping level whilst retaining the phase of the waveform.

II. OBJECTIVE

The objective of this study is to develop a method to simulate and visualize the end-to-end impact of CFR directly on BER. The objective was not to perform a study for various implementations of CFR. We present a simulation and a 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 (2) where A_{max} is the maximum value allowed by the waveform. As an extension of this work,

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the other crest reduction techniques are easy to implement and study by editing the clipping algorithm.

$$x'_n = \begin{cases} x_n, & |x_n| \le A_{\max} \\ A_{\max} e^{j\angle x_n}, & |x_n| > A_{\max} \end{cases} \tag{2}$$

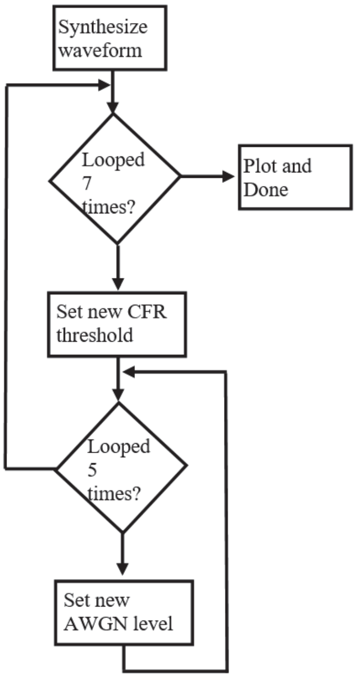

Fig. 1 Flow chart of the simulation algorithm

III. METHODOLOGY

We started with OFDM simulation MATLAB code by Lima et al. [9]. 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), number of frames, chips per frame, turbo or non-turbo encoding, normal, and extended cyclic-prefix. The result is a MATLAB test vector that represents 10 frames of an OFDM signal voltage, and each frame is 10 ms long. The settings in the simulation were:

1. 25 MHz bandwidth
2. 15 kHz channel spacing
3. Extended cyclic prefix
4. No turbo encoding/decoding
5. No transmit or receive diversity
6. Channel type EPA-LTE

This test vector is now ready for CFR by finding the maximum and the RMS levels. The work presented here used a simple hard limiting algorithm, but the other soft limiting methods can be implemented and tested. After this, AWGN is added to the crest-reduced vector and a simulated receiver demodulates the data, and calculates the BER. Plots of BER versus Eb/No as shown here were modified to show multiple lines. In the original code, the user gets only one plot of BER versus Ed/No per setting.

The final algorithm used in this work is presented in flow chart form in Fig. 1. 10 frames of data were synthesized with random data. Then, the BER analyses preceded using increasing levels of CFR clipping.

IV. RESULTS

The results shown here are from the simulations of an OFDM waveform using QPSK, 16-QAM, and 64-QAM modulation. The plots show and BER versus Eb/No 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, 3 dB is a clipping level of 0.708 of the peak, and 6 dB 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. 2 shows that, as expected, the BER increases as clipping level (attenuation) increases. For example, to achieve a 1% BER, approximately 11.6 dB of Eb/No is needed when no CFR is used (0 attenuation). With a clipping level of 15 dB, about 13 dB of Eb/No is needed to achieve the same BER. This shows that QPSK can tolerate severe clipping at this BER.

Fig. 3 shows the same spread of clipping level (attenuation) when 16-QAM is used for the data modulation. Notice that the dramatic effect high levels of clipping have on BER. Assuming the same 1% BER threshold, 15 dB Eb/No is needed under no CFR. As opposed to the QPSK case, the effect of 15 dB CFR is well off the plot. Taking a more reasonable clipping level of 9 dB, Eb/No needs to be approximately 16.5 dB. In this case, a 9 dB reduction in headroom would only require an increase of 1.5 dB in signal level to remain a 1% BER.

Fig. 4 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 on 3dB clipping after averaging over 10 runs. Increasing the clipping level to 6 dB appears to result in 3 dB degradation in Ed/No. Clipping levels of 9dB and greater result in a dramatic increase in SNR needed to maintain a 1% BER or less.

TABLE I
SELECTED RESULTS

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

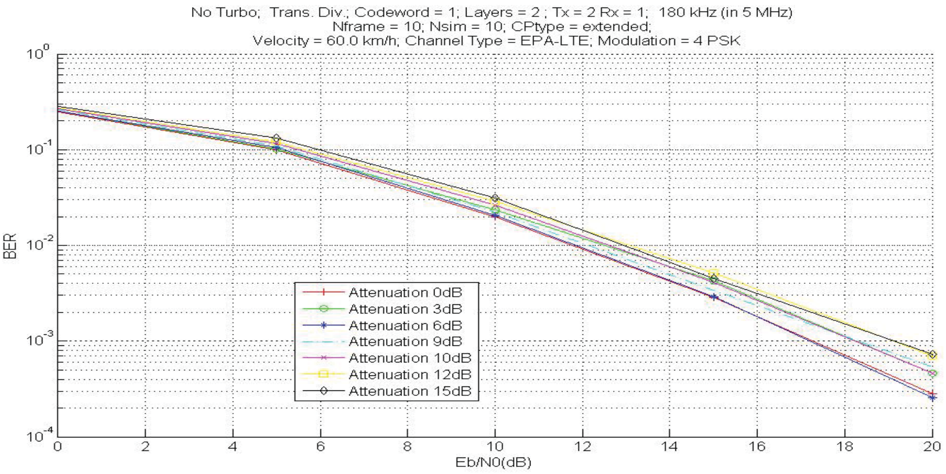

Fig. 2 The simulated effect of hard-clipping CFR on BER at various Eb/No levels for QPSK modulation

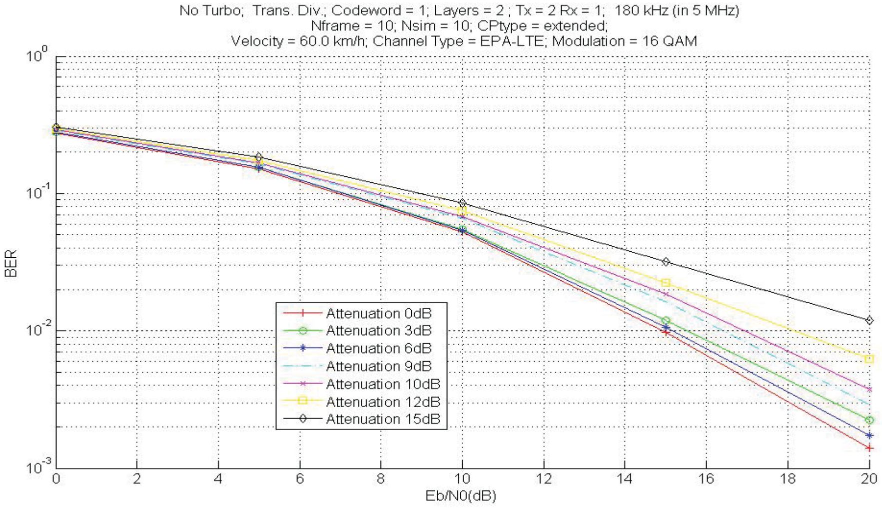

Fig. 3 The simulated effect of hard-clipping CFR on BER at various Eb/No levels for 16-QAM modulation

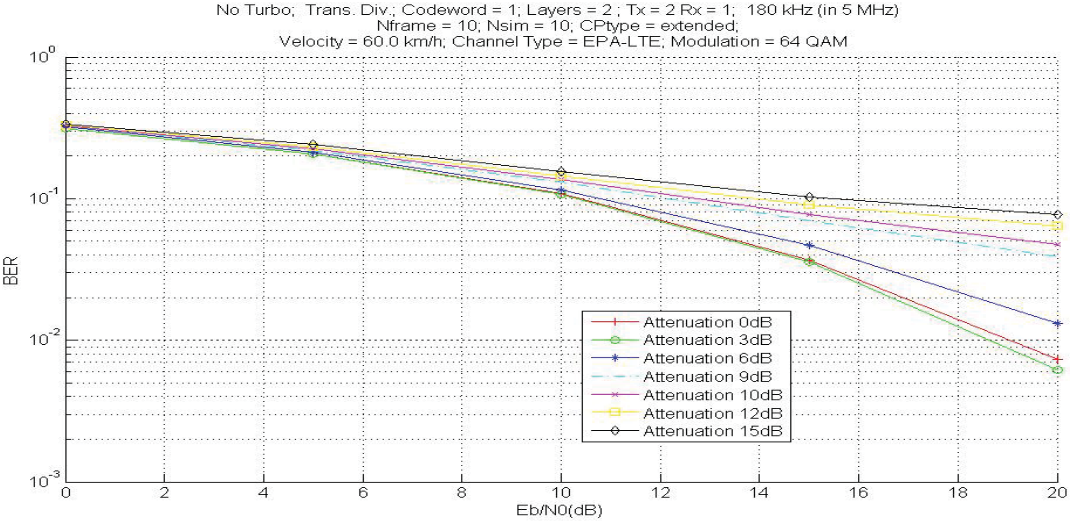

Fig. 4 The simulated effect of hard-clipping CFR on BER at various Eb/No levels for 64-QAM modulation

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 exceeds the decrease in headroom. This breakeven depends on the modulation and target BER where using all the newly available headroom cannot compensate for the increase in SNR at the receiver. We have not considered AACLR in this work and is highly depended on method of CFR. ACLR can be determined by simply adding a spectral tool in MATLAB after CFR is applied. We leave the study of CFR method and ACLR to future studies.

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