Crest Factor Reduction through Scaling and Recovering by Frame in OFDM Communication Systems

Wonhoon Jang[1] and ***Nuno Borges Carvalho***[2]

[1] Institute of Telecommunication, Campus Universitario de Santiago P-3810-193 AVEIRO - PORTUGAL,
wjang@av.it.pt
[2] nbcarvalho@ua.pt

Abstract

A new scheme for reducing crest factor in orthogonal frequency division multiplexing (OFDM) communication systems has been proposed. The reduction is achieved by simply scaling all symbols in a frame that exceeds a desired level on the transmitter side. The scaled symbols are recovered by scaling back on the receiver side. All of those operations can be achieved by adding simple functions such as level detection and summation of symbol amplitudes in baseband. The major advantage is that there is no extra information to be sent to the receiver for those operations due to a fixed scaling factor already shared between the transmitter and receiver. Also, the scheme does not degrade adjacent channel power ratio (ACPR) and error vector magnitude (EVM) at all due to the frame-based scaling and recovering so it does not require filtering after crest factor reduction (CFR) as in clipping. One of the limitations is that this scheme achieves only a CFR of about 2.5dB. For validation of the scheme, the processes in baseband and in RF have been conducted with Simulink and measurement with a power amplifier respectively.

1 Introduction

Orthogonal frequency division multiplexing (OFDM) has been a popular scheme for communication systems because of advantages over single-carrier schemes such as abilities to resist to frequency-selective fading, to use guard interval to remove inter-symbol interference, etc. However a major disadvantage is that OFDM communication systems must deal with high peak-to-average power ratio (PAPR), which degrades efficiency of power amplifiers and hence causes complexity of designing, and also requires a high dynamic range from digital-to-analog/analog-to-digital converters.

Various techniques have been proposed to reduce PAPR and reviewed in [1, 2]. Some techniques such as selective mapping (SLM), partial transmission sequence (PTS), interleaving and coding require to send additional bits, which degrades throughput efficiency. Some techniques such as active constellation extension, and clipping and filtering achieve crest factor reduction (CFR) at the expenses of adjacent channel power ratio (ACPR) and/or error vector magnitude (EVM) degradation. Also complex implementation is required in some techniques such as tone injection, tone reservation, SLM and PTS.

In this paper a new CFR scheme is proposed. The scheme does not require any extra information, and does not degrade EVM and ACPR. Also it is simple to implement.

2 Crest Factor Reduction Scheme

A probability density function (PDF) in Figure 1 is generated using a 16 quadrature amplitude modulation (QAM) signal. Theoretical PDF of amplitude sum of 48 symbols per frame is compared with that of the signal used in baseband simulation. It is observed that amplitude sums are bounded in a certain range (117 - 169 in Figure 1). This suggests possibility to detect and recover symbols without EVM degradation at the receiver if amplitude sum of a frame is located out of the range after scaling all symbols in the frame by a constant at the transmitter. The receiver does not require any extra information transmitted in order to recover the scaled symbols due to the scaling constant shared with the transmitter. Also, the scaling does not cause ACPR degradation because of altering in-band products only. Symbols in a frame that cause relatively low or high peak envelopes can respectively be scaled up or down on the transmitter side. In this

978-1-4244-6051-9/11/$26.00

paper the case of scaling down is demonstrated.

The proposed CFR scheme is shown in Figure 2, which is just a conceptual diagram. On the transmitter

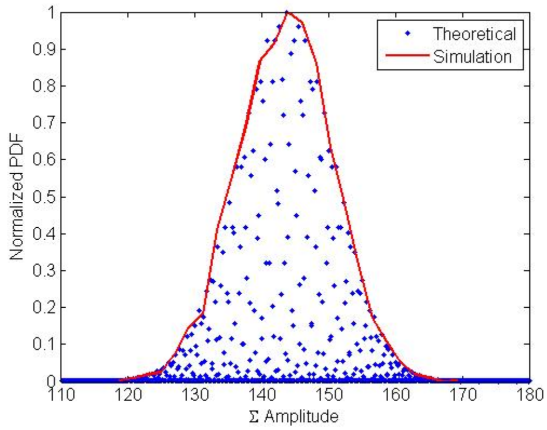

Figure 1: Probability density function of amplitude sum by frame

side, level detector monitors outputs of the inverse Fourier transform (IFFT) block by frame. When any of the outputs in a frame exceeds a target level desired, the level detector generates a control signal for scaling amplitudes of symbols in the frame by a constant already shared with the receiver. The scaled symbols pass through the parallel-to-serial block instead of the original symbols. CFR is achieved by scaling only some frames that contribute to high peak values. The scaling constant is chosen such that an amplitude sum of all symbols in the frame locates below the minimum amplitude sum, which allows the receiver to detect the scaled frames. On the receiver side, amplitude detector in Figure 2 adds amplitudes of symbols in each frame. When an amplitude sum is below the minimum, it generates a control signal to scale back the corresponding symbols by the inverse constant, which completely recovers to the original. To realize the scheme, more necessary control signals between blocks and timing must be considered.

Figure 3 shows amplitudes of complex envelopes of 16 QAM signals before and after CFR. The peak value

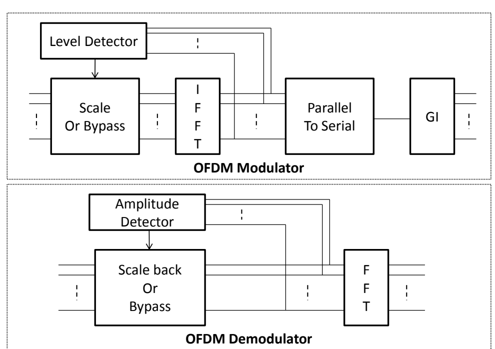

Figure 2: Conceptual diagram of the proposed crest factor reduction scheme

of the unprocessed signal is about 12dB above the average amplitude. It is reduced to 6dB after 50% scaling. Notice that scaling down not only reduces the peak value but also reduces the average power. Hence a limit exists in CFR achievement. Authors have found that the maximum achievable CFR with the scheme is about 2.5dB. Relatively small differences outside the scaled frame in Figure 3 result in keeping the CFR scheme from degrading ACPR.

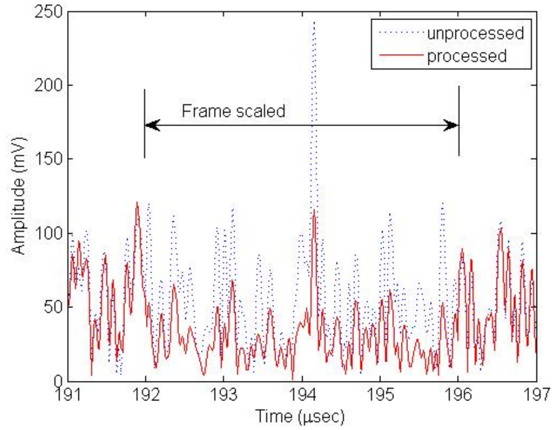

Figure 3: Envelope signals before and after crest factor reduction

3 Measurement and Comparison

To validate the CFR scheme, Simulink and a power amplifier are used for baseband simulation and RF measurement respectively. A complex envelope is taken from an OFDM transmitter in Simulink and uploaded to an arbitrary wave generator. An output complex envelope of the amplifier is captured using a vector signal analyzer and fed to a OFDM receiver in Simulink. These processes are conducted for both cases with and without CFR and compared for effectiveness of the CFR. The output of the class AB amplifier used in measurement starts to compress at -5dBm of an input power. 1dB input compression point is 5dBm. The resulting EVMs and ACPRs as functions of input power are compared in Figure 4 and 5 respectively. There are no degradations caused by the CFR in EVM and ACPR as expected. Some discrepancies especially in EVM from 0 to 5dBm of an input power are observed due to different crest factors. Above 9dBm of input power, both signals seem to be in a deep saturation region where most parts of both signals start to be affected.

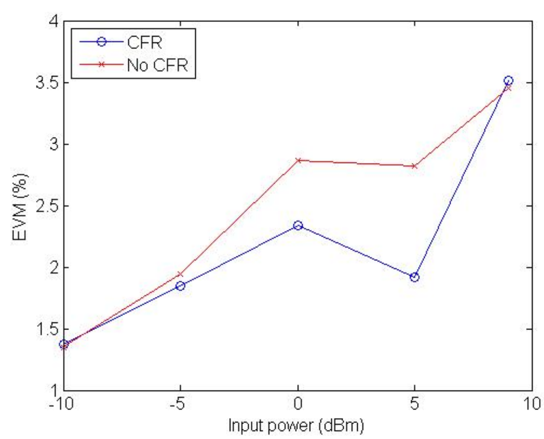

Figure 4: Error vector magnitude depending on input power

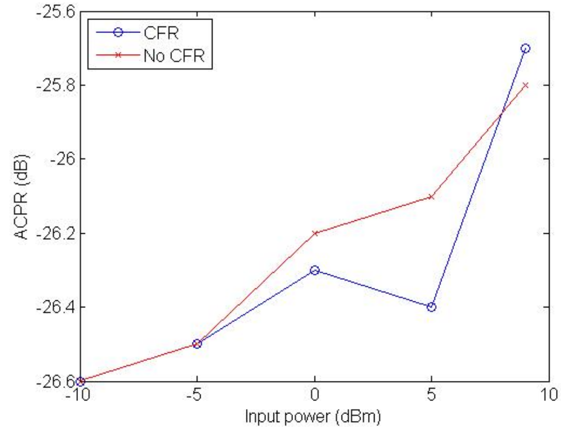

Figure 5: Adjacent channel power ratio depending on input power

4 Conclusion

A new CFR scheme is proposed and validated by an OFDM communication system that combines simulation and measurement. It is easy to implement the scheme due to simple baseband operations required. There is no EVM or ACPR degradation caused by the proposed scheme, and no need to send any extra information to the receiver. The main disadvantage of the scheme is limitation on CFR. A CFR of 2.5dB has been achieved. This technique may be combined with other CFR techniques such as clipping and filtering to achieve more CFR.

5 References

1. T. Jiang, and Y. Wu,"An overview: peak-to-average power ratio reduction techniques for OFDM signals," *IEEE Trans. Broadcasting*, vol. 54, no. 2, June 2008, pp. 257-268.

2. S. H. Han and J. H. Lee, "An Overview of peak-to-average power ratio reduction techniques for multicarrier transmission," *IEEE Wireless Communications*, vol. 12, no. 2, April 2005, pp. 56-65.