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Correlative Coding with Clipping and Filtering Technique in OFDM Systems

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Abstract

The major setbacks of Orthogonal Frequency Multiplexing (OFDM) is its peak-to-average power ratio (PAPR) and intercarrier interference (ICI). The occurrence of these factors restricts its application. Here, the clipping and filtering PAPR reduction technique is being investigated to reduce the PAPR and out-of-band radiation simultaneously by implementing correlative coding. This paper focuses on the preliminary measurement studies that was carried out. It is shown through simulation that the collaboration of these techniques gives a reasonable PAPR reduction and improves the out-of-band radiation.

1. Introduction

The Orthogonal Frequency Division Multiplexing (OFDM) technique is an appealing technique for achieving high-bit-rate data transmission, due to its robustness against the multipath fading and intersymbol interference (ISI) [1]. However, high peak-to-average-power ratio (PAPR) resulted in significant signal distortion in the presence of a nonlinear amplifier. Furthermore, the frequency offset in OFDM system leads to loss of orthogonality among subcarriers, hence producing intercarrier interference (ICI).

Among the methods to reduce PAPR are those including block coding, partial transmit sequence (PTS) and selected mapping. However, the simplest approach is by the clipping technique. This technique allows the high amplitude peaks to be clipped before being sent to the power amplifier. Clipping is often favoured since large peaks occur very rarely [2, 3]. Besides that, this technique is also applicable for large numbers of subcarriers and does not need any complicated computation like other methods.

Clipping is a nonlinear process. Thus, it must be performed in a controlled manner to prevent any signal distortion. The effects of clipping are in-band distortion and out-of-band distortion. In-band distortion or the degradation in the wanted signal strength occurs since clipping modifies the signal artificially. Clipping an oversampled signal causes lesser effect of distortion to the signal within the original band. This is because oversampling reduces the effect of clipping noise in the wanted signal by spreading them in a wider bandwidth. By performing clipping on an oversampled signals also resulted in a lesser peak regrowth [2].

The out-of-band radiation can be reduced by performing frequency domain filtering. This filtering results in a lesser peak regrowth and also completely eliminates the out of band radiation thus allowing the original unclipped signal to be retrieved [4].

As mentioned earlier, ICI caused by channel frequency offsets in one of the major problems of OFDM systems. The performance degradation of the OFDM may be severe due to the loss of orthogonality factor. ICI self-cancellation scheme has been proposed to solve this problem. A simple solution is to perform correlative coding on the frequency domain data [5, 6].

In literature, ICI self-cancellation scheme and PAPR reduction techniques have been considered separately for the reduction of PAPR and ICI. The intent of this paper is to investigate and explore the potential of correlative coding in a clipping filtering. Preliminary measurement results of PAPR and out-of-band radiation are presented in this paper.

2. Clipping and Filtering OFDM System

The output of the IFFT of OFDM system is the summation of all the subcarriers. Since the subcarriers are independent of each other, they tend to add up constructively and destructively. This forms a high PAPR. In the clipping technique, the high peak of the signal is clipped by the amplitude clipper. The transfer function of the clipping nonlinearity under consideration can be expressed as:

$$y(t) = \begin{cases} -A, & \text{if } s(t) \le -A \\ s(t), & \text{if } |s(t)| < A \\ A, & \text{if } s(t) \ge A \end{cases} \tag{1}$$

where y(t) is the clipped OFDM signal and A is the clipping level [4].

Oversampling by a factor of K can be performed by inserting N(K-1) zeroes in the middle of the mapped complex vector. An oversized IFFT is selected to convert the discrete frequency domain signal to a discrete time domain signal. Out-of-band radiation which occurs due to clipping an oversampled signal can be filtered by frequency domain filtering. This filter consists of a forward FFT and an Inverse FFT. The clipped signal will be passed to the forward FFT that will convert the discrete time domain signal to discrete frequency domain signal. The zeroes that are added when performing the oversampling are the out-of-band components. Thus these out-of-band components must be removed and finally the filtered signal is passed back to the Inverse FFT for transmission [4].

3. Correlative Coding With Clipping Filtering OFDM System

In this section, the effect of frequency-domain correlative coding on clipping and filtering OFDM system is investigated. This coding which is also known as partial response signaling was used in the single carrier system to eliminate intersymbol interference (ISI) due to timing errors. Studies have shown that frequency domain correlative coding provides simple solution to intercarrier interference (ICI) problem in OFDM system [5, 6]. This method introduced a controlled ICI onto the OFDM signal.

In this paper, the equation for the correlative coding used in this simulation is shown in equation (2)

$$b_k = a_k - a_{k-2} \quad (2)$$

The coded symbol which has three possible values (2, 0, -2) are modulated on N subcarriers. This coding is conducted before performing the clipping filtering. Precoding is also performed before modulation in order to avoid error propogation during decoding process.

The received signal on subcarrier k is written as:

$$r_k = \sum_{l=0}^{N-1} b_l S(l-k) \quad (3)$$

for k=0,1, ..., N-1 where

$$S(l-k) = \frac{\sin(\pi\varepsilon)}{N\sin\left(\frac{\pi}{N}(\varepsilon+l-k)\right)}.\exp\left(j\frac{\pi}{N}(N-1)(\varepsilon+(l-k))\right) \quad (4)$$

is the ICI effect of the lth subcarrier to the kth subcarrier with the occurrence of normalized frequency offset, ε.

This paper however will not include the ICI investigation. In this technique, due to the introduction of controlled ICI when correlative coding is performed, a lower out-of-band radiation is expected from the clipping process of an oversampled signal.

4. Results

Some results of clipped filtered OFDM have been demonstrated through computer simulations for N=128 subcarriers. Figure 1 shows the resultant PAPR due to clipping for various clipping levels with different oversampling factors.

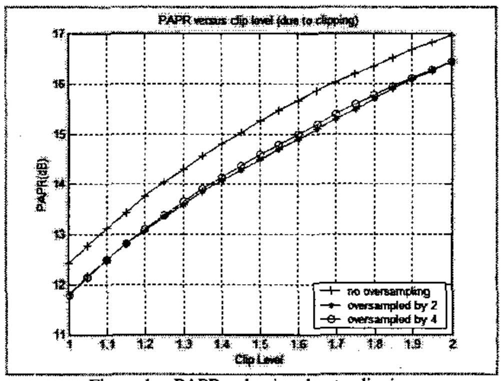

Figure 1. PAPR reduction due to clipping

It can be seen that a better PAPR reduction can be achieved by clipping the oversampled signal. Figure 2 shows the BER versus clip level for different oversampling factors. However, it is learnt that clipping an oversampled signal causes out-of-band radiation [2].

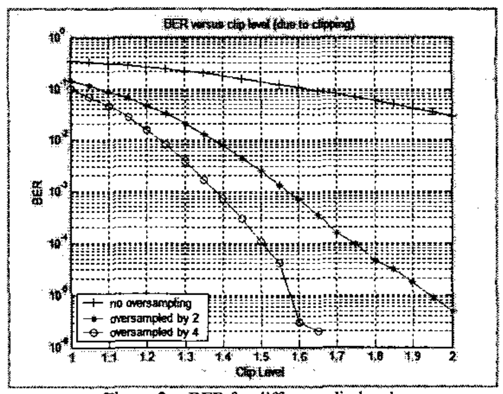

Figure 2. BER for different clip levels

From Figure 2, the BER improves with the oversampling factor. However, more distortion occurs if clipping is performed without oversampling compared to clipping at an oversampled rate. The graph also shows that oversampling allows the OFDM signal to be clipped more severely with lesser BER degradation. Figure 3 illustrates the PAPR for clipped and filtered signal. It can be seen that the PAPR increases at about 1.77-3.5 dB compared to when only clipping method is performed. However, this technique gives a lesser peak increment. The out-of-band radiation is eliminated when frequency domain filtering is performed.

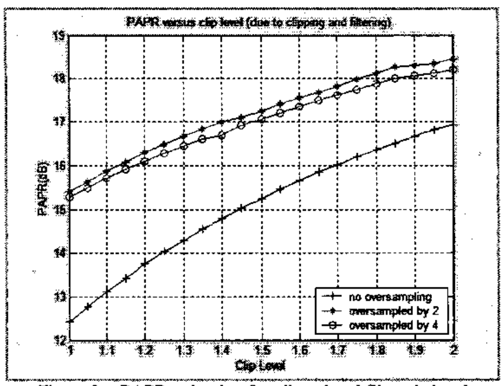

Figure 3. PAPR reduction for clipped and filtered signal

Figure 4 shows the PAPR reduction when correlative coding is applied to the clipping filtering PAPR reduction technique. At clip level of 1.5, the PAPR increased 4.8% for oversampling by a factor of 2 and decreased 0.5% when oversampled by 4.

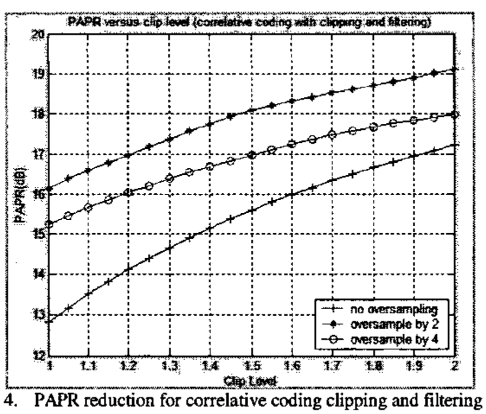

Figure 4. PAPR reduction for correlative coding clipping and filtering technique

Figures 5, 6, 7 and 8 shows the vector scope display when correlative coding is applied to the clipping and filtering technique for N=64. The clipping ratio is the same for all cases. The vector frequency of the correlated coded OFDM signal is shown in Figure 5. Performing clipping on the signal increases the out-of-band radiation slightly as shown in Figure 6. However, these out-of-band radiation is suppressed by the frequency domain filtering. The output of this filter is shown in Figure 7. With correlative coding, the out-of-band radiation due to clipping an oversampled OFDM signal is reduced significantly compared to the technique without correlative coding as shown in Figure 8. Nevertheless, this out-of-band power is completely eliminated after performing the frequency domain filtering.

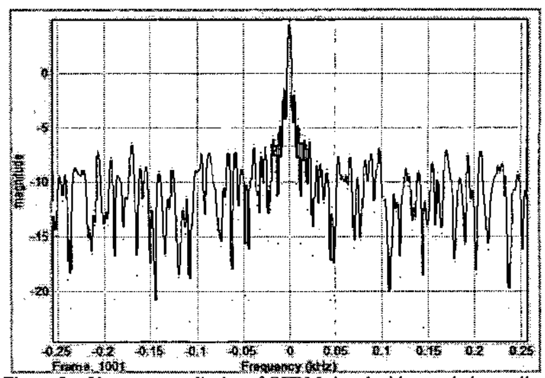

Figure 5. Vector scope display of OFDM signal with correlative coding

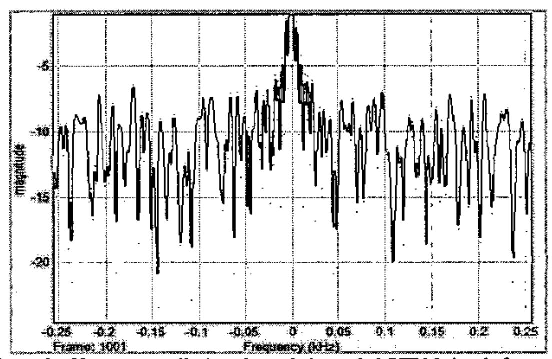

Figure 6. Vector scope display of correlative coded OFDM signal after clipping

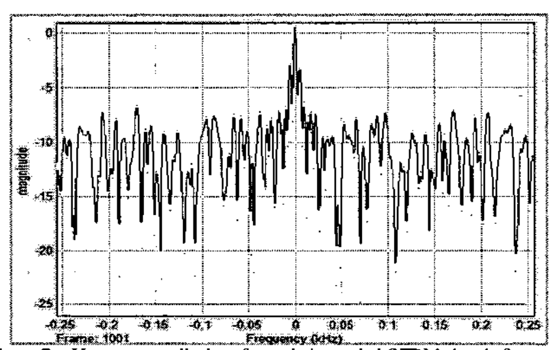

Figure 7. Vector scope display of correlative coded OFDM signal after frequency domain filtering

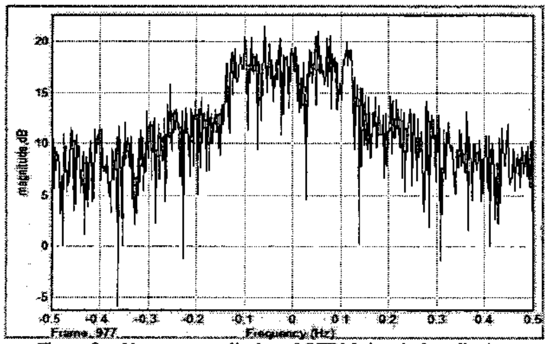

Figure 8. Vector scope display of OFDM signal after clipping

5. Conclusion

In this paper, the clipping and filtering PAPR reduction technique is being investigated to reduce the PAPR and out-of-band radiation simultaneously by implementing correlative coding. Preliminary measurements of PAPR and the out-of-band are being studied. It showed that by employing correlative coding, the PAPR performance is reasonable comparing to clipping and filtering technique. In addition, with the use of partial response signaling in frequency domain, the out-of-band radiation of the clipped oversampled OFDM signal is reduced significantly. Using this technique, the frequency domain filtering can be omitted, hence reducing the implementation complexity. However, the effectiveness of this technique in reducing ICI should be investigated. Currently, this investigation work is being conducted in order to know the usefulness of this technique in OFDM system.

References

[1] J. A. C. Bingham, "Multicarrier modulation for data transmission: An idea whose time has come", *IEEE Communications Magazine*, pp. 5-14, May 1990.

[2] X.Li and L.J. Cimini, "Effects of clipping and filtering on the performance of OFDM", *IEEE Communications Letters*, Vol. 2, no 5, pp. 131-133, May 1998.

[3] H. Ochiai and H. Imai, "On clipping for peak power reduction OFDM signals", in Proc. *IEEE Vehicular Technology Conf*erence, vol. 2, pp. 731-735, 2000.

[4] J. Armstrong, "New OFDM peak-to-average power reduction scheme", *IEEE Vehicular Technology Conference*, pp. 756-760, May 2001.

[5] Y. Zhao, J-D. Leclercq and S-G. Haggman, "Intercarrier interference compression in OFDM communication systems by using correlative coding", *IEEE Communications Letters,* vol. 2, no. .8, pp 214-216, August 1998.

[6] Y. Zhao and S-G Haggman, "Intercarrier interference self-cancellation scheme for OFDM mobile communication systems", *IEEE Transactions on Communications,* vol. 49, no. 7, pp 1185-1191, July 2001.