Use of Peak-to-Average Power Reduction Technique in HIPERLAN2 and its Performance in a Fading Channel

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Abstract: A technique that uses clipping has been recently proposed to reduce the peak-to-average-power ratio (PAPR) in orthogonal frequency divisional multiplexing (OFDM) signals. The technique uses a discrete Fourier transform (DFT) based filter to reduce out-of-band (OOB) power after the interpolated baseband OFDM signal is clipped. In this paper, the technique is applied to HIPERLAN2 to reduce the PAPR of the transmitted signals. Like many other OFDM systems, HIPERLAN2 has a number of unused subcarriers. The DFT based filter is used to null the unused subcarriers at the band edge. The effect of in-band distortion on the system's bit error rate (BER) is studied. Results show that effect of clipping noise on the system's BER is minimal in the fading environment.

1. Introduction

A major disadvantage of OFDM is that it has a high peak-to-average power ratio (PAPR) which means that a very linear output amplifier with large dynamic range is needed. Such amplifiers are inefficient and expensive to operate. Any amplifier non-linearity causes unwanted out-of-band power. However, the high magnitude peaks in the OFDM signals occur rarely.

One of the simplest ways to reduce the PAPR is to clip the high amplitude peaks. Several clipping techniques have been described in the literature [1-2]. Some clip the signal at the output of the inverse discrete Fourier transform (IDFT). But subsequent interpolation causes regrowth of the signal peaks [3]. Other clipping techniques clip the signal after interpolation and use a filter to reduce the resulting out-of-band power. However the filters, which have been proposed, are complicated and computationally expensive. In addition they cause peak regrowth and result in significant distortion of the wanted signal [1]. The technique presented in [4] clips the signal after interpolation and uses a new form of frequency domain digital filtering to filter the out-of-band power. This form of filtering results in less peak regrowth and causes no distortion to the wanted signal components, while reducing the out-of-band power to the same level as the original unclipped signal. In [4] the new technique was described for the case where all the subcarriers are used to carry data. In many OFDM applications, such as HIPERLAN2 [5], digital audio broadcasting (DAB) and digital video broadcasting (DVB), a number of band-edge subcarriers are unused. The filter can be designed to remove components at the frequencies of the band-edge subcarriers to improve the performance of the new technique.

In this paper, the new form of clipping and filtering technique is presented to reduce PAPR in OFDM systems. The filter is used to null the unused subcarriers. The effect of in-band distortion that results from clipping in the system's BER is discussed. The study is extended to fading channels. Simulation results are presented for HIPERLAN2.

2. New PAPR reduction scheme

Figure 1 shows the block diagram of the PAPR reduction scheme [4]. The data vector $a_0, a_1, \cdots, a_{N-1}$ is input to an oversize IDFT. For HIPERLAN2, $N = 64$ and there are 12 unused subcarriers which include the dc term and the Nyquist term. In the input vector, the dc term a_0 and a_k's for $k \in (N/2-5, \cdots, N/2+5)$ on the band-edge subcarriers including Nyquist term are initialized to zero. The interpolation of the baseband signal is performed by inserting $N(I_1-1)$ zeros in the middle of the input vector, where I_1 is the required interpolation factor. This results in trigonometric interpolation of the time domain signal at the output of IDFT [6]. The interpolated signal is then clipped with a clipping ratio, *CR*. *CR* is defined as the ratio of the clipping level to the root-mean-square power of the unclipped baseband signal. The non-linear processing of the clipping is given by

$$b'_{k,i} = \begin{cases} b_{k,i} & if \quad |b_{k,i}| \le A, \\ A\exp\{j\arg(b_{k,i})\} & if \quad |b_{k,i}| \ge A. \end{cases} \qquad (1)$$

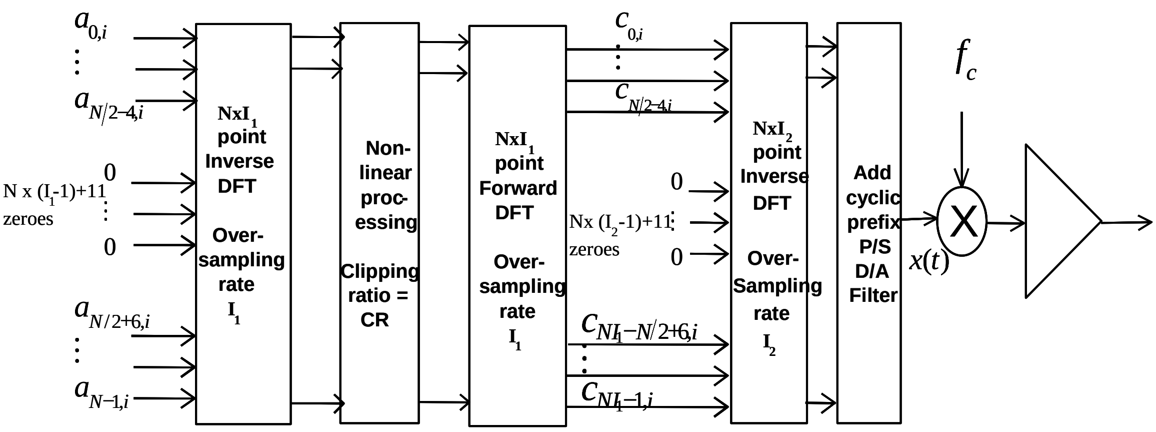

Figure 1. Block diagram of new peak reduction technique

where A is the clipping level decided by the CR. After clipping, the signal is filtered. The filter consists of a forward and an inverse DFT. The forward DFT converts the clipped signal back to the discrete frequency domain. The outputs corresponding to wanted signal $c_{0,i},\cdots,c_{N/2-1,i},c_{NI_1-N/2+1,i},\cdots,c_{NI_i-1}$ are passed unchanged to the corresponding inputs of the IDFT. The remaining inverse DFT inputs, $c_{N/2,i},\cdots,c_{NI_1-N/2,i}$ which correspond to out-of-band components, are set to zero. For the case where there are unused band-edge subcarriers the corresponding inputs are also set to zero.

The DFT filter is a time dependent filter that passes only in-band components of the signal while the out-of-band components are attenuated as much as possible. Therefore the filter will not affect the in-band discrete frequency components. Moreover, this time dependent filter does not introduce any intersymbol interference (ISI) as it operates on symbol-by-symbol basis and there is no filtering across the symbol boundaries.

3. PAPR reduction

The new technique is effective in reducing the PAPR of the OFDM signal. Figure 2 shows the complementary cumulative distribution of the instantaneous amplitude of the signal. Note the logarithmic scales. Three cases are shown: the original unclipped signal, clipping before interpolation and clipping after interpolation with an oversampling factor of $I_1 = 2$. For both of the clipping cases, the unused band-edge subcarriers are nulled by the filter. The filtering causes some peak regrowth so the signal amplitude sometimes exceeds the clipping level. PAPR reduction is more effective with clipping after interpolation as there is less peak regrowth. The signal can be repeatedly clipped and filtered to further reduce the PAPR [8].

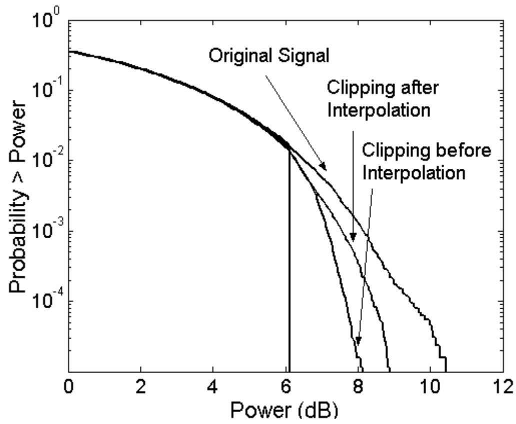

Figure 2. Complementary cumulative distribution of signal amplitude for HIPERLAN2

4. Spectrum of clipped and filtered signal

Figure 3 shows the spectrum of the original signal and of the difference between the original signal and the clipped and filtered signal. The parameters used for the number of subcarriers and nulled subcarriers are those for HIPERLAN2. A clipping ratio, $CR = 6$ dB was used. The simulations were performed for 4-QAM modulation, but other constellations would also give similar results. The baseband signal has been used to modulate a carrier at frequency f_c where f_c is four times the nominal bandwidth. The nominal bandwidth is the bandwidth the signal would have if no subcarriers were nulled. This low carrier frequency was used to reduce the simulation time but more realistic carrier frequencies would give very similar results. In OFDM sharp transitions at symbol boundaries can result in a slow spectral roll-off. To make the spectral roll-off more rapid and make the out-of-band spectrum due to clipping clearer the signal was windowed. The windowing technique used is described in [10]. Figure 3 shows clipping causes no increase in out-of-band power but there is some in-band distortion.

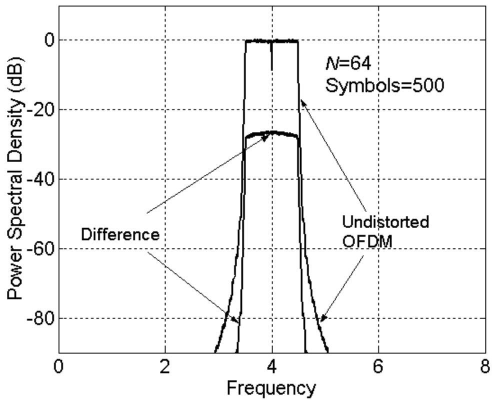

Figure 3. Spectra of original OFDM signal and difference signal

However the level of OOB will increase if the power amplifier is not perfectly linear and/or does not have sufficiently large dynamic range to accommodate all the peaks that regrow as a result of filtering. Practical amplifiers are never perfectly linear and the effectiveness of the peak reduction technique depends strongly on the precise characteristics of the amplifier [10]. Result in [4] show that the OOB power resultant at the output of nonlinear amplifier with limited dynamic range is considerably less when the interpolated baseband OFDM signal is clipped and filtered with the DFT based filter.

5. In-band distortion

The DFT filter based clipping technique causes no increase in out-of-band power so the only limit on its performance is the effect of in-band distortion. It has been shown that in-band distortion at the transmitter due to clipping has two effects on the transmitted signal [7]. There is an overall shrinking of the constellation and an added noise-like component, termed *clipping noise*. The impact of clipping noise on the OFDM transmission is studied in [9]. However, it does not consider the fact that the shrinking of the constellation size can be corrected automatically by the AGC in the receiver. Earlier studies do not consider the effect of fading on clipping noise. The clipping noise causes less degradation than might be expected as the clipping noise is added to the signal at the transmitter. In a fading channel, this noise component also fades along with the signal.

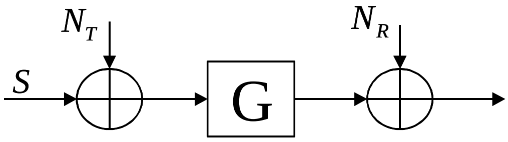

Figure 4. Conceptual model of a subcarrier with noise added at the transmitter

5.1 Effect of transmitter added noise on SNR of the received signal

The effect of fading on the noise added at the transmitter can be understood by considering figure 4 that shows the model of an OFDM subcarrier with clipping noise. Clipping noise N_T is added to the signal power S at the transmitter and the fading in the channel is characterized by G. The value of G on each subcarrier will be different depending on the level of fading experienced by the particular subcarrier. Noise added in the channel or the receiver is represented by N_R. The transmitter noise also experiences fading along with the signal. At the receiver,

$$SNR = \frac{GS}{GN_T + N_R} = \frac{S}{N_T + N_R/G} \qquad (2)$$

For OFDM system subject to frequency selective fading, the BER before error correction depends mainly on the performance of the bad subcarriers that lie in the deep fades [10]. So we only need to consider the effect of N_T at those subcarriers that experience the fading most. For these subcarriers, G is small. After equalization, N_R/G becomes considerably larger than N_T. Therefore, the moderate levels of clipping noise will have a small overall effect on the performance of the system. The effect will be reduced when the fading is severe.

Figure 5 shows the effect of clipping noise on the signal-to-noise ratio (SNR) of the received signal in a fading channel. Two-path channel is considered and the amplitude level in the second path equals $\sqrt{3/4}$ to that of direct path signal. For this 2-path fading channel, the value of G varies from 0.10 on bad subcarriers to 1.4 on good subcarriers. The plots of total signal-to-noise ratio at the receiver for all values of G are drawn for the case when only channel noise and no transmitter noise is added on the subcarrier.

These plots are compared with the plots obtained when both the channel noise as well as transmitter noise is added. Channel noise is added to give S/N_R of 0 dB, 15 dB and 30 dB, and the transmitter noise added to give S/N_T a value of 30 dB. This value is chosen as the results in [4] show that clipping of about $6-7$ dB caused signal-to-clipping noise ratio (SCNR) of 30 dB at the transmitter. Figure 5 shows that when the channel noise is considerably higher than the transmitter noise as in the case of $S/N_R = 0$ dB and $S/N_R = 15$ dB, the transmitter added noise is comparatively very small and it does not degrade the total SNR of the received signal. The effect of transmitter added noise is only noticeable when the channel noise is comparable to it. For lower values of G, the degradation of SNR is very small. On bad subcarriers, fading causes the degradation of SNR at receiver to be very small.

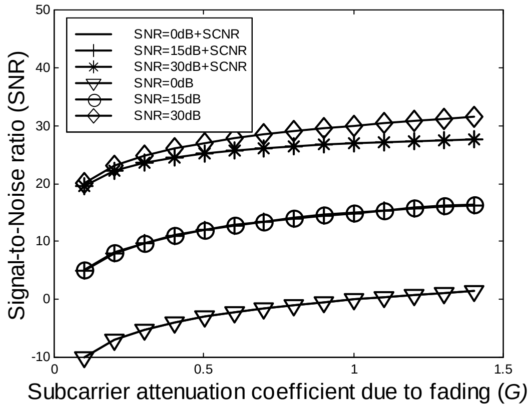

Figure 5: Signal-to-Noise ratio of the received signal in 2-path fading channel

5.2 Effect of clipping noise in the BER of the OFDM system

We know that BER of an OFDM system in fading is dominated by the BERs at the bad subcarriers. In the previous section, we have shown that SNR degradation of the received signal on bad subcarriers is very small. Therefore the clipping noise should have minimal effect in the BER of the system in fading channel.

Figure 6 shows the BER for the new PAPR reduction technique in additive white Gaussian noise (AWGN) using the HIPERLAN2 parameters and $4-$QAM modulation scheme. Results are shown for varying levels of clipping. To make the simulations more realistic the clipping was followed by an ideal limiting amplifier with an input backoff 1 dB greater than the clipping ratio. The input backoff was calculated relative to the unclipped signal level. For 4-QAM even extreme clipping results in comparatively small BERs. Larger constellations would be more sensitive to clipping noise. The BER without clipping is larger than the theoretical graph shown for OFDM because of the energy used in the cyclic prefix.

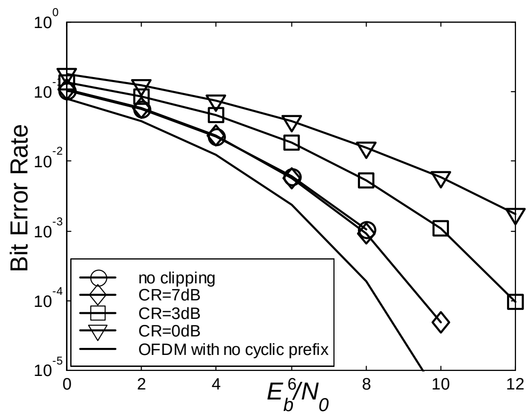

Figure 6: BER versus E_b/N_0 in AWGN for varying clipping ratios

Figure 7 shows the results for a multipath channel when the amplitude of the signal in the delayed path is half that of the main signal. In this simulation a cyclic prefix length of 16 and second path delay of 13 was used, but any delay spread less than the cyclic prefix would have given similar results. For 4-QAM even extreme clipping has little effect on the BER.

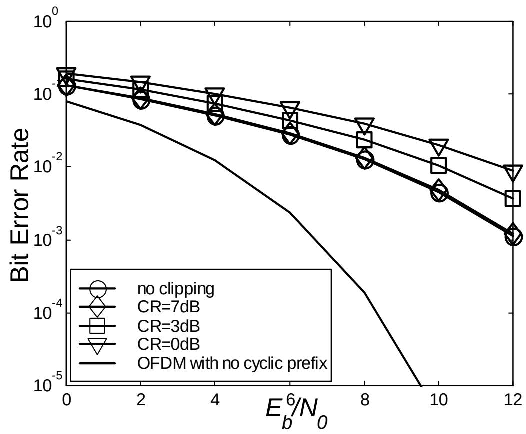

Figure 7: BER versus E_b/N_0 in a two-path channel for varying clipping ratios

6. Conclusions

The application of a new PAPR reduction scheme to HIPERLAN2 with unused band edge subcarriers has been described. The technique can be used in any OFDM systems. The DFT based digital filter is very simple and does not add any in-band distortion. It is shown that the PAPR can be significantly reduced with no increase in out-of-band power and little degradation in BER. The clipping noise that is added at the transmitter is not as bad as the noise added in the channel or receiver because the transmitter added noise also fades in fading channels. The effect of clipping noise on the system BER is also studied. Results show that due to fading the clipping noise will have very little impact on system's BER. As a result of new technique, amplifiers with smaller dynamic range can be used. The new technique is applicable without any changes to the telecommunications standards.

7. References

[1] 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.

[2] R. O'Neill and L. N. Lopes, "Envelope Variations and Spectral Splatter in Clipped Multicarrier Signals," in *Proc. PMRC'95*, Sept 1995, pp. 71-75.

[3] C. Tellambura, "Phase Optimisation Criterion for Reducing Peak-Average Power Ratio for OFDM," *Electronics Letters*, 22 January 1998, Vol. 34, no 2, pp. 169-170.

[4] J. Armstrong, " New OFDM Peak-to-Average Power Reduction Scheme," *IEEE Vehicular Technology Conference*, May 2001, Rhodes, Greece.

[5] ETSI TS 101 475: "Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Physical (PHY) layer".

[6] D. Fraser, "Interpolation by the FFT revisited – an experimental investigation", *IEEE Transactions on Acoustics, Speech and Signal Processing*, Vol. 37, no. 5, pp. 665-675, May 1989.

[7] D. Dardari, V. Tralli, and A. Vaccari, "A theoretical characterization of nonlinear distortion effects in OFDM systems", *IEEE Transactions on Communications*, Vol. 48, no. 10, October 2000, pp. 1755-1764.

[8] Jean Armstrong, "Peak-to-Average Power Reduction for OFDM by Repeated Clipping and Frequency Domain Filtering", submitted to *Communication Letters*.

[9] Mathias Friese, "On the degradation of OFDM-signal due to peak clipping in optimally predistorted power amplifiers," *IEEE Commun. Soc. ICC, GLOBECOM 1998*. Part vol.2, pp.939-44, 1998, Sydney, NSW, Australia.

[10] R. Van Nee and R. Prasad, *OFDM for Multimedia Communications,* Artech House, 2000.