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OFDM Wireless Multimedia Communications

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CHAPTER 6

The Peak Power Problem

6.1 INTRODUCTION

An OFDM signal consists of a number of independently modulated subcarriers, which can give a large peak-to-average power (PAP) ratio when added up coherently. When *N* signals are added with the same phase, they produce a peak power that is *N* times the average power. This effect is illustrated in Figure 6.1. For this example, the peak power is 16 times the average value. The peak power is defined as the power of a sine wave with an amplitude equal to the maximum envelope value. Hence, an unmodulated carrier has a PAP ratio of 0 dB. An alternative measure of the envelope variation of a signal is the *Crest factor*, which is defined as the maximum signal value divided by the rms signal value. For an unmodulated carrier, the Crest factor is 3 dB. This 3 dB difference between PAP ratio and Crest factor also holds for other signals, provided that the center frequency is large in comparison with the signal bandwidth.

A large PAP ratio brings disadvantages like an increased complexity of the analog-to-digital and digital-to-analog converters and a reduced efficiency of the RF power amplifier. To reduce the PAP ratio, several techniques have been proposed, which basically can be divided in three categories. First, there are signal distortion techniques, which reduce the peak amplitudes simply by nonlinearly distorting the OFDM signal at or around the peaks. Examples of distortion techniques are clipping, peak windowing and peak cancellation. The second category is coding techniques that use a special forward-error correcting code set that excludes OFDM symbols with a large PAP ratio. The third technique is based on scrambling each OFDM symbol with different scrambling sequences and selecting that sequence that gives the smallest PAP ratio. This chapter discusses all of these techniques, but first makes an analysis of the PAP ratio distribution function. This will give a better insight in the PAP problem and will explain why PAP reduction techniques can be quite effective.

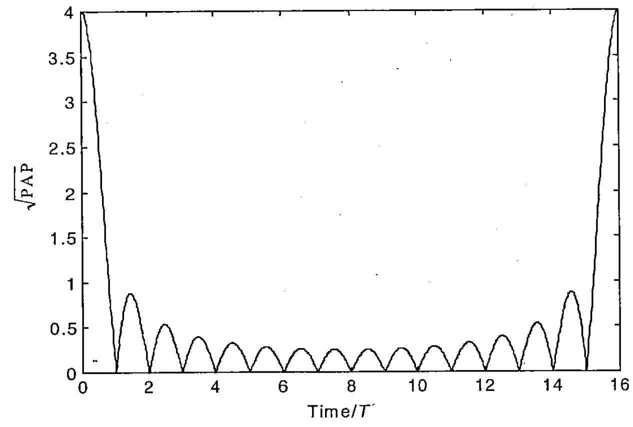

Figure 6.1 Square root of peak-to-average power ratio for a 16-channel OFDM signal, modulated with the same initial phase for all subchannels.

6.2 DISTRIBUTION OF THE PEAK-TO-AVERAGE POWER RATIO

For one OFDM symbol with N subcarriers, the complex baseband signal can be written as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n \exp(j\omega_n t) \tag{6.1}$$

Here, a_n are the modulating symbols. For QPSK, for instance, $a_n \in \{-1,1,j,-j\}$. From the central limit theorem it follows that for large values of N, the real and imaginary values of $x(t)$ become Gaussian distributed, each with a mean of zero and a variance of 1/2. The amplitude of the OFDM signal therefore has a Rayleigh distribution, while the power distribution becomes a central chi-square distribution with two degrees of freedom and zero mean, with a cumulative distribution given by

$$F(z) = 1 - e^{-z} \tag{6.2}$$

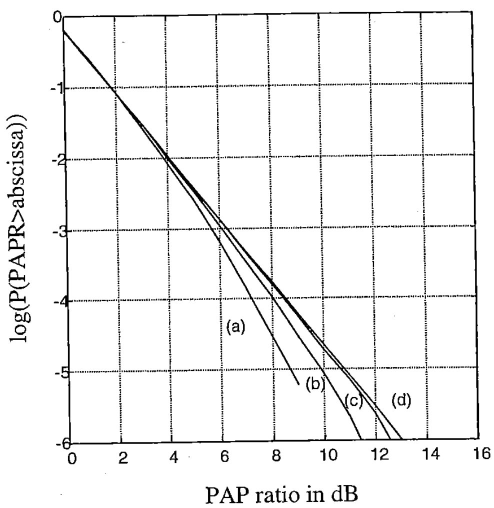

Figure 6.2 PAP distribution of an OFDM signal with (a) 12, (b) 24, (c) 48 and (d) an infinite number of subcarriers (pure Gaussian noise). Four times oversampling used in simulation, total number of simulated samples = 12 million.

Figure 6.2 shows the probability that the PAP ratio exceeds a certain value. We can see that the curves for various numbers of subcarriers are close to a Gaussian distribution (d) until the PAP value comes within a few dB from the maximum PAP level of $10\log N$, where N is the number of subcarriers.

What we want to derive now is the cumulative distribution function for the peak power per OFDM symbol. Assuming the samples are mutually uncorrelated—which is true for non-oversampling—the probability that the PAP ratio is below some threshold level can be written as

$$P(PAPR \le z) = F(z)^N = (1 - \exp(-z))^N \qquad (6.3)$$

This theoretical derivation is plotted against simulated values in Figure 6.3 for different values of N.

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