Collaboration Projects

Methods for Reducing Peak Power in OFDM Transmission

OFDM is a very important, fundamental wireless transmission technology that has been used in many wireless communications systems in recent years. We have been conducting research on methods of reducing peak power, which is one of the issues in practical implementation of OFDM. This research was conducted jointly with the Mobile Communication Laboratory (Professor Masaharu Hata and Associate Professor Shigeru Tomisato), Graduate School of Natural Science and Technology, Okayama University.

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1. Introduction

Many recent mobile communications systems, such as the 3rd Generation Partnership Project (3GPP)-Long Term Evolution (LTE) as well as the Institute of Electrical and Electronics Engineers (IEEE) 802.11 wireless LAN technology and digital terrestrial television broadcasting systems such as the Integrated Services Digital Broadcasting for Terrestrial (ISDB-T), use the Orthogonal Frequency Division Multiplexing (OFDM) scheme as the fundamental transmission technology, in order to satisfy the recent demand for high data-rate transmission. In higher data-rate transmission, each transmission symbol must be sent in a shorter amount of time, which results in increasing amounts of degradation in the quality of the received signal due to factors like reflection from buildings. OFDM uses multiple low-speed subcarriers bundled together, making it robust with respect to the effects of these types of reflections.

However, implementation of OFDM has an issue in that signal peaks can occur that are extremely high compared to the average power of the transmission signal (hereinafter referred to as "signal peaks"). Inputting these excessively large signals into a transmission amplifier can result in signal distortion at its output and degradation of transmission quality, or splatter to nearby systems. The distortion caused by these large signal peaks can be reduced by using devices with excellent input/output characteristics, but this also results in increased power consumption. Because of this, it is desirable to decrease the level of peaks occurring in the transmission signal.

Various methods for suppressing these signal peaks have been proposed in the past. The authors have been studying clipping[*1] and filtering[*2] peak-reduction methods that are very effective in reducing peak power and do not require peak-reduction control information [1]. In order to improve both the amount of processing required and the effect of peak-reduction, so that we establish a more effective OFDM transmission method, we propose the following two modifications to these peak-reduction methods.

- A stepped threshold method for

*1 **Clipping**: Processing whereby sections of the input signal that are larger in magnitude than a fixed value are replaced by a regulated level before output.

*2 **Filtering**: Processing where the relative magnitudes of frequency components of the input signal are modified before output.

generating a peak-reduction signal for a peak-reduction-signal subcarrier

- A method for reducing the processing required for the peak-reduction method, taking into consideration implementation on mobile terminals.

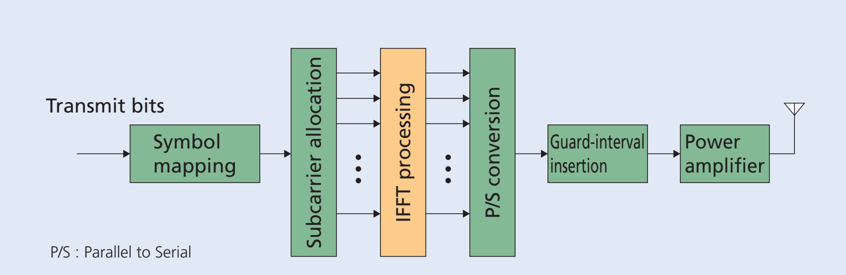

Figure 1 Block diagram of general transmitter architecture

This research has been conducted jointly with the Mobile Communication Laboratory of the Graduate School of Natural Science and Technology, Okayama University, which has lead the research in peak-reduction methods using clipping and filtering techniques.

In this article, we first describe the basic principles of the OFDM scheme and the mechanisms that result in generation of signal peaks. We then explain the two peak-power reduction methods mentioned above.

2. OFDM and Methods for Reducing Peak Power

The architecture of a transmitter utilizing the OFDM scheme is shown in **Figure 1**. With digital communication, all information (voice, files, etc.) is sent as series of data bits: binary digits consisting zeros and ones. The data-bits are mapped to symbols represented as vectors by using a symbol-mapping section. There are various modulation methods used for this mapping, such as Quadrature Phase Shift Keying (QPSK)[*3], and 16 Quadrature Amplitude Modulation (16QAM)[*4]. Next, in the Inverse Fast Fourier Transform (IFFT)[*5] section, multiple symbols are input simultaneously, and these are transmitted in parallel on individual subcarriers. A subcarrier is a sinusoidal wave differing from the carrier frequency, whose phase and amplitude is set based on the symbol being transmitted. The OFDM signal is then generated by combining these subcarrier signals (**Figure 2**).

In the IFFT section, many different symbols are input at the same time, creating various combinations of symbols, which may result in extremely large signal peaks, depending on the combination of the symbols being sent.

One method for reducing these peaks has been proposed in [2] earlier, and is called clipping and filtering. Clipping (cutting off the signal peak) can lower peak levels, however, it also generates undesired signal components (i.e. in-band[*6] and out-of-band peak-reduction signals). In particular, out-of-band peak reduction signals may be a source of interference to other systems, so these signals must be strictly limited.

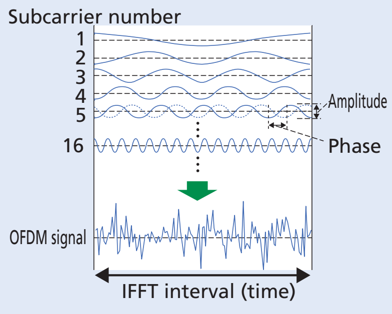

Figure 2 OFDM signal generation

With clipping and filtering methods, filtering is used to suppress out-of-band peak-reduction signals. In peak-reduction processing, clipping and filtering can be repeatedly applied to achieve a large clipping effect while controlling noise imposed on the data signal.

3. Generating Peak-reducing Signals for Peak Reduction Subcarriers

3.1 Proposed Method

One well-known method that can provide good peak-reduction effects is to dedicate some of the subcarriers for peak-reduction only, and not use them for signal transmission.

The authors have proposed a

*3 **QPSK**: A signal transmission method that changes the phase of the radio wave among four different patterns. With this method, there are four types of symbol, each of which symbol can represent two bits of data.

*4 **16QAM**: A signal transmission method that uses 16 different combinations of phase and amplitude in the radio wave. In this case there are 16 different symbols, each of which represents four bits of data.

*5 **IFFT**: A method for efficiently computing the time signal series corresponding to input frequency components (discrete data). The number of IFFT points is the number of discrete data points used when performing the conversion.

*6 **In-band**: The range of frequencies allocated to a particular system.

method earlier, which uses the clipping and filtering method to generate peak reduction signals for several dedicated peak reduction subcarriers [3].

With this method, in order to suppress the frequency components of the peak reduction signal both in-band and out-of-band, a peak-reduction component (with the architecture in **Figure 3**) is introduced just before the IFFT processing section in Fig. 1. In this newly added section for generating the peak-reduction signal, a time domain signal is generated using an IFFT, and peaks in the time domain signal are extracted using a signal-peak detector.

Then, with the fixed-threshold method, the frequency component of the peak signal is computed using an FFT[*7], and only levels that will not cause problems for data reception are permitted in the signal band used for data transmission. The subcarriers dedicated for the peak-reduction signals allow higher-level signals than the data-signal subcarriers (**Figure 4** (a)). The higher the levels allowed in the peak-reduction signal, the greater the peak-reducing effect possible, but the peak reduction signal introduces noise into the data-signal transmission.

In addition to this fixed-threshold method, we have proposed a method to reduce signal peaks which has even better peak reducing effect and is called the stepped threshold method [3]. Specifically, peak-reduction is done in multiple steps. Here we focus on the case for two steps. When generating the peak reduction signal in the first step, only the peak reduction signal in the peak-reduction subcarrier is permitted. In the second step, when generating the peak reduction signal, adding peak-reduction signal for the data transmission signal band is also permitted (Fig. 4 (b)). In this way, a greater peak reduction effect can be derived by using the peak-reduction subcarrier more effectively.

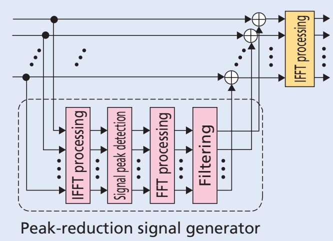

Figure 3 Peak reduction and IFFT processing

3.2 Performance Evaluation

The Complementary Cumulative Distribution Function (CCDF) characteristics of the Peak to Average Power Ratios (PAPR) for signals when applying the stepped-threshold and fixed-threshold methods are shown in **Figure 5**. Here the CCDF is the probability that a signal with PAPR that exceeds the value on the horizontal axis in the figure will occur for a generated OFDM symbol. The characteristic for the case when peak-reduction is not applied is also shown in the figure. For the purposes of this evaluation, we set the target PAPR at approximately 6 dB.

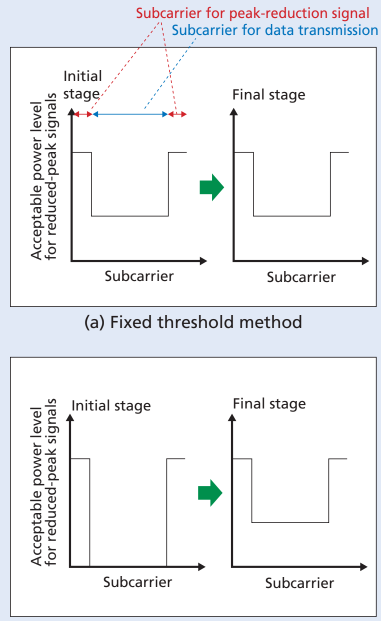

Figure 4 Acceptable levels for reduced-peak signals (in-band only)

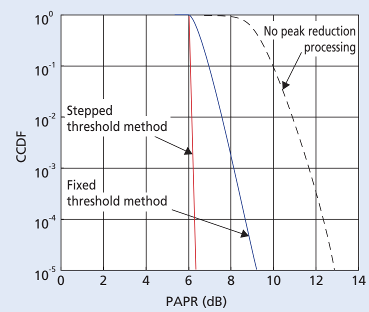

Figure 5 Probability of signal peak occurrence

The results show that the stepped-threshold method achieved almost the target level, but with the fixed-threshold method, peaks 3 dB larger than the target level occurred at CCDF = 10^{-4}. Because of this, the stepped-threshold method allows the use of power ampli-

*7 **FFT**: A method for efficiently calculating frequency components from a time signal series.

fiers with approximately 2.5 dB smaller dynamic range[*8] than fixed-threshold method to achieve the same out-of-band radiation.

This shows that greater peak-reducing effect can be achieved with a peak-reduction subcarrier by changing the threshold step-wise in this way.

4. Complexity Reduction in Clipping and Filtering Method

4.1 Proposed Method

An issue that arises when applying PAPR reduction methods is the amount of processing required. In particular, for transmission on mobile communications systems, peak-reduction processing is more important on mobile terminal side where power consumption and processing capability are severely limited. Thus, reducing the processing requirements of peak reduction should be studied.

In addition, for OFDM transmissions, multiple users share the same band in many cases, and each single user is allocated only a portion of the subcarriers out of all available subcarriers. Here we assume that a block of successive subcarriers are allocated to each user as shown in **Figure 6**.

We have proposed a scheme for reducing the processing complexity in the peak reduction and IFFT sections as in **Figure 7** [4]. In this scheme, the FFT and IFFT used in the first stage of peak reduction are performed using a small number of points, and the number of points is increased at a final stage. This allows the peak-reduction signal in the first stages to be generated with less processing power because fewer points are used in the FFT and IFFT. However, reducing the number of FFT points used in the first stage too much would limit the number of subcarriers that could be used for the reduction. Consequently this effects the acceptable amount of peak reduction signal permitted, and can result in a decrease in peak-reducing effect and deterioration of the Bit Error Rate (BER).

4.2 Performance Evaluation

Figure 8 shows the results of evaluating the effectiveness of peak reduction when generating the peak-reduction signal over multiple iterations. In this evaluation the total number of subcarriers was 1,024, with 64 subcarriers assigned to each user. Also, when applying the computation reduction, in all but the final stage, the peak-reduction processing was done with the numbers of points shown in the figure.

The figure shows that when using a 256-point FFT in the first stage, the resulting PAPR was almost the same as the case when the amount of computation was not reduced at all.

The proposed method, with a 256-point FFT at earlier stages and with four iterations, can be done with less processing power than with 1,024-point FFT and two iterations, although this may depend on the FFT and IFFT implementations.

We also studied degradation of the BER, and found that almost no degra-

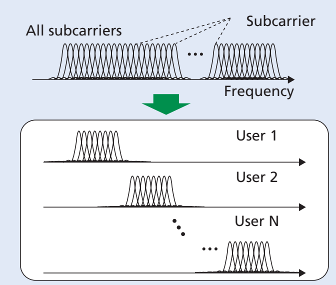

Figure 6 Subcarrier allocation method

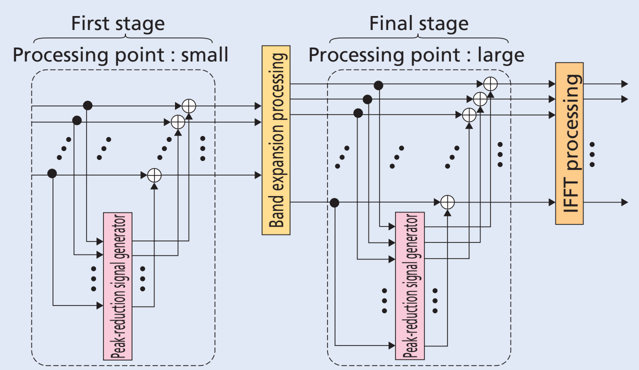

Figure 7 Peak-reduction and IFFT processing section

*8 **Dynamic range**: The range of input/output signal that can be processed without distortion.

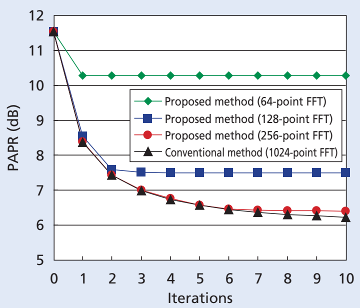

Figure 8 Peak-reduction effects from iteration

dation of the BER occurred [5], if the number of processing points was set to more than 2.5 times the number of sub-carriers used per user.

5. Conclusion

In this article, we have given an overview of our two proposals for PAPR reduction, which is one of the difficult issues to be overcome in practical implementations of OFDM. We also confirmed the effectiveness of these new methods by computer simulation. In the future, we would like to use the results of this study for next generation mobile communications systems.

References

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