Peak Reduction Schemes in OFDM Transmission

We present an overview of our study on peak reduction schemes for Orthogonal Frequency Division Multiplexing, which is an important issue in the practical deployment of this transmission scheme. This reseach 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

Orthogonal Frequency Division Multiplexing (OFDM) is one of the most important techniques for recent wireless communication systems deployed by wireless LAN, Worldwide interoperability for Microwave Access (WiMAX)[*1], 3rd Generation Partnership Project Long Term Evolution (3GPP LTE)[*2], and other standards. A notable advantage of OFDM is its robustness against inter-symbol interference under multipath environments, which is typical of wireless communication. Reflection of waves from buildings and other objects creates multi-paths between a transmitter and a receiver. If some of reflected signals are received with large delay compared with symbol periods, they cause inter-symbol interference. Recent demand for high-speed transmission requires that each signal be transferred in a shorter time period, which makes degradation by inter-symbol interference critical. To deal with this problem, OFDM transmits multiple signals in parallel using low-speed radio channels (subcarriers) with different frequencies, whose symbol periods on each subcarrier have a longer span. This makes OFDM highly robust to multipath effects.

On the other hand, large peaks appear on the transmit signals when OFDM is applied. If those peaks are input into a non-linear device like the power amplifier on a transmitter, transmit signals become distorted. The distortion increases bit error rate at the receiver and also increases the out-of-band emission which interferes with radio signals on neighboring frequency bands. The use of devices with superior input/output characteristics can ease the distortion caused by large peak signals, which however leads to high power consumption and high equipment cost. It is therefore desirable that peak signals on transmit signals are small.

Various schemes have been proposed for reducing the peak signals. We focus on peak reduction schemes based on a method of clipping and filtering which achieves a large peak reduction without control information associated with the peak reduction [1]. We conducted this research jointly with the Mobile Communication Laboratory at Okayama University Graduate School of Natural Science and Technology, the forefront of this research.

In this article, we first describe the basic principle of OFDM and the generation of peak signals, and then outline two of our proposals:

- A peak reduction scheme that limits peak-reduction signals on each subcarrier
- A peak-reduction-signal generation scheme for subcarriers dedicated to peak-reduction signals

2. Principle of OFDM and Peak Signal Generation

Figure 1 shows the configuration of a transmitter applying OFDM. In digital communications, all information (such as speech and data files) is transmitted as a bit sequence of 0s and 1s. Those bits are mapped into symbols[*3] represented as vectors in the symbol-mapping section. The method of mapping

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*1 WiMAX: A wireless communication system based on the IEEE802.16 standard defined by IEEE, a worldwide standardization body.

*2 3GPP LTE: A standard being studied as an enhancement of Third-Generation communication systems at 3GPP, an organization standardizing Third-Generation communication systems (FOMA).

*3 Symbol: In this article, a vector that determines the amplitude and phase of a radio wave at the time of modulation. A symbol is determined by one or more information bits to be transmitted.

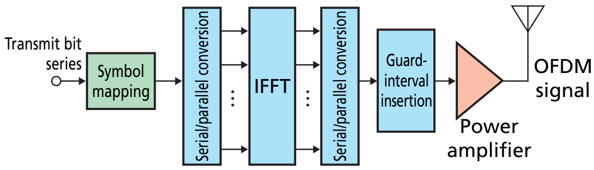

Figure 1 Transmitter configuration

depends on the modulation scheme (such as Quadrature Phase Shift Keying (QPSK)[*4] or 16 Quadrature Amplitude Modulation (16QAM)[*5]). Next, multiple symbols are input to the Inverse Fast Fourier Transform (IFFT)[*6] section and they are multiplexed to a signal time-sequence composed of the same number of subcarriers, which are sine waves of different frequencies. The phase and amplitude of each subcarrier are set according to the symbols carried on the subcarrier (**Figure 2**). Changing phase shifts sine waves cyclically. Combining these signals yields an OFDM signal.

As explained above, multiple symbols are input simultaneously into the IFFT section, and more than a thousand symbols can be multiplexed. A variety of symbol combinations are therefore possible, and some of them produce large peaks in OFDM signals.

A clipping and filtering method has been proposed as a scheme for peak reduction (hereinafter referred to as "conventional method") [1]. Clipping peak signals is equivalent to adding peak-reduction signals both inside and outside of the occupied band, although the power of peak-reduction signals are comparatively low with respect to signal power. The power radiated outside the band causes interference to other systems and is generally restricted severely. For this reason, out-of-band peak-reduction signals are suppressed by filtering in this method.

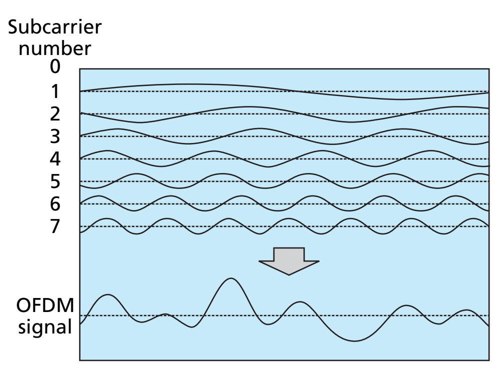

Figure 2 OFDM signal (time domain)

3. Peak-reduction Scheme Limiting Peak-reduction Signals in Each Subcarrier

3.1 Research Background

Signals to multiple users can be multiplexed in an OFDM symbol by allocating different sets of subcarriers to different users. At the same time, recent communication systems have come to adopt the Adaptive Modulation and Coding Scheme (AMCS), which dynamically changes coding and modulation scheme based on radio channel conditions to make high-speed transmission possible. As a consequence, different modulation schemes can be applied in an OFDM symbol. **Figure 3** shows an example of such conditions.

The conventional method does not control peak-reduction signals inside of the occupied band, which means that peak reduction signals spread uniformly over the occupied band. From the viewpoint of signal detection, the peak reduction signal is just noise, which makes bit error rate high. In addition, bits transmitted using a high modulation order are less robust against noise.

3.2 Proposed Scheme

Our proposed scheme controls the power of inserted peak-reduction signals on each subcarrier according to the applied modulation scheme [2]. To achieve this in a transmitter, we have to replace the IFFT section in Fig. 1 with the blocks shown in **Figure 4**. In this scheme, a peak detection process inputs a generated OFDM signal and extracts only peak components from temporal OFDM signals. The resulting signals are input to a Fast Fourier Transform (FFT)[*7] section and are converted to

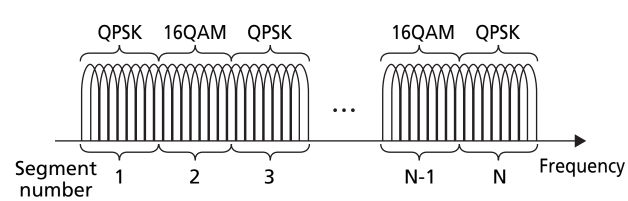

Figure 3 Example of an OFDM signal (frequency domain) and allocation of modulation systems

*4 QPSK: A scheme transmitting signals with 4 patterns of phases. In this case, each symbol takes one of predetermined 4 complex values and the number of bits mapped onto one symbol is 2.

*5 16QAM: A scheme transmitting signals with 16 patterns of combinations of the phase and amplitude. In this case, each symbol takes one of predetermined 16 complex values and the number of bits mapped onto one symbol is 4.

*6 IFFT: A method which converts a signal series in the frequency domain to one in the time domain.

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

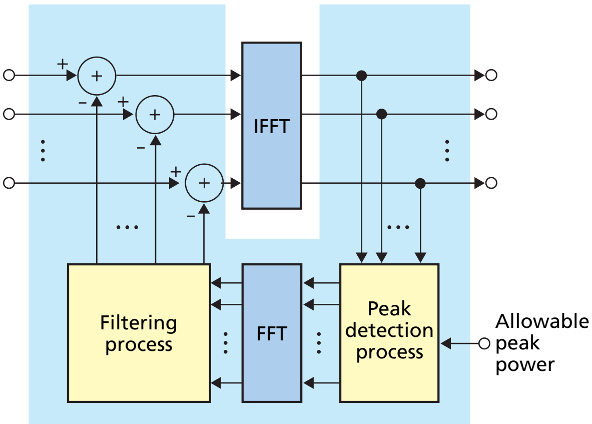

Figure 4 Partial configuration of transmitter performing the proposed process

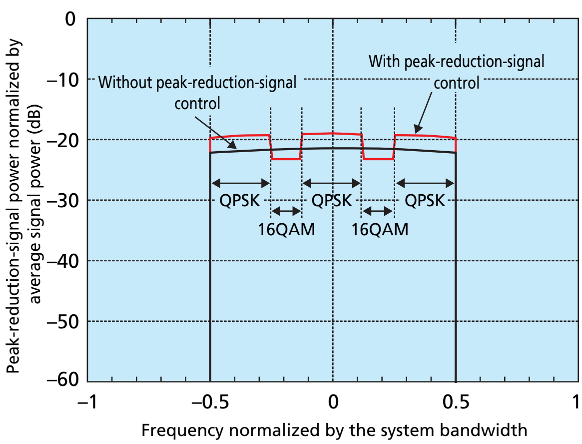

Figure 5 Frequency characteristics of peak-reduction signals

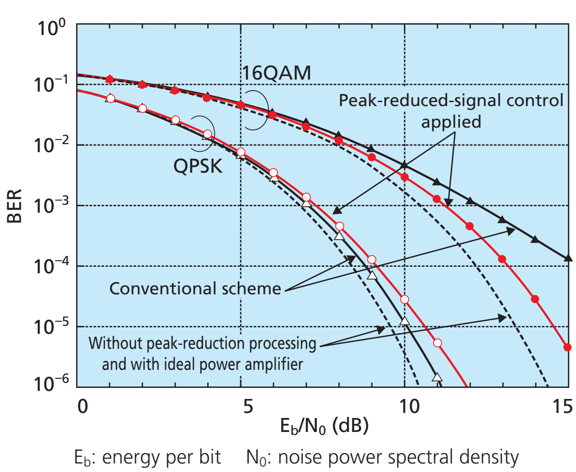

Figure 6 BER characteristics

the signal components of the peak signals on each subcarrier. Then, in addition to suppressing out-of-band peak-reduction signals, the filtering controls the power of peak-reduction signals added to subcarriers that use a modulation scheme with low resistance to noise. This processing can be repeated several times to mitigate peak regrowth by filtering.

3.3 Performance Evaluation

This evaluation assumes OFDM transmission with 128 subcarriers and QPSK or 16QAM applied to each subcarrier. For subcarriers applying 16QAM, the filtering process described above keeps the power of added peak-reduction signals under a fixed value.

Figure 5 shows the power of peak-reduction signals inserted into each subcarrier, which is obtained by computer simulations. The results show that the proposed control process keeps the power of peak-reduction signals small on frequency bands where signals are transmitted with 16QAM, which is less robust against noise.

Figure 6 shows Bit-Error-Rate (BER) of information transmitted by QPSK and 16QAM. Here, the final target level of Peak to Average Power Ratio (PAPR)[*8] is set to be 6 dB. If we focus on BER = 10^{-4} in the QPSK case, our proposal and conventional method shows almost the same results. On the other hand, significant improvement in the 16QAM case is obtained by our method compared with the conventional method.

4. Peak-reduced-signal Generation Scheme for Subcarriers Dedicated to Peak-reduction Signals

4.1 Proposed Scheme

For a cellular system, it is expected that some subcarriers within a particular cell will be left unused to prevent interference with neighboring cells. Such subcarriers can be utilized for peak reduction signals by limiting their power to values under a fixed level. We extend the scheme proposed in Chapter 3 (hereinafter referred to as "peak signal control scheme") to one applicable to such conditions (hereinafter referred to as "extended peak signal control scheme"). In this extended scheme, the same operation is applied to temporary OFDM signals, but the allowed power for peak-reduced signals is set larger for the sub-

*8 PAPR: Peak-signal-power to average-signal-power ratio.

carriers dedicated to peak-reduction signals than that for subcarriers transmitting data.

4.2 Performance Evaluation

In this evaluation, we assumed 64 subcarriers in total with 5 subcarriers on both sides allocated for only peak-reduced signals.

Figure 7 shows peak-reduction effects by peak signal control scheme and the extended peak signal control scheme.

As for the peak signal control scheme that keeps the power of each subcarrier under a fixed level, the Complementary Cumulative Distribution Function (CCDF) shows 10^{-4} against PAPR = 9 dB. The CCDF shows the probability that a peak with certain PAPR on OFDM symbols appears. For example, a signal with its power above 9 dB (8 times the average power) appears once every 10^4 OFDM symbols. The extended peak signal control scheme, on the other hand, generates a peak of PAPR = 6.5 dB with a probability of 10^{-4}. This means that a gain of nearly 3 dB is obtained against the peak signal control scheme, which corresponds to a reduction in peak-signal magnitude of about one half.

The results also show that the extended peak signal control scheme and the conventional method achieve almost the same PAPR, even though the extended peak signal control scheme is expected to achieve a lower BER than the conventional method since peak-reduction signals on data subcarriers are generated so as not to increase BER.

When the extended peak signal control scheme is applied, undesired signals are emitted on subcarriers that should be unused to ease inter-cell interference. However, the power transmitted on subcarriers dedicated to peak-reduced signals are about 1/20 of the power allocated to data signals, which is thought to be small enough to avoid inter-cell interference.

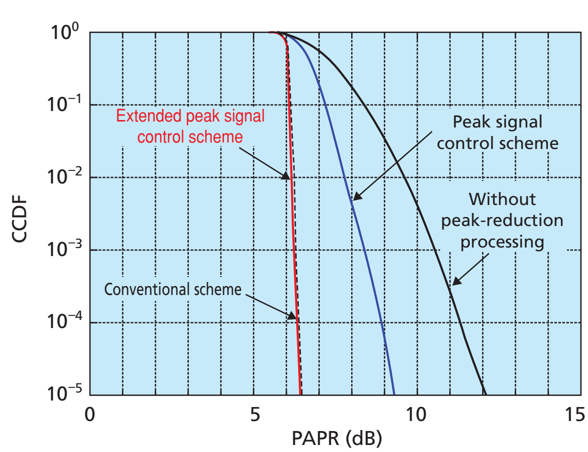

Figure 7 Peak appearance probability

5. Conclusion

We outlined two of our proposed schemes for a peak reduction technique, an important issue in the practical deployment of OFDM, based on a clipping and filtering method and demonstrated their effectiveness by computer simulations. We are going to continue this study to apply the results obtained here to WiMAX.

REFERENCES

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