Design and Performance Evaluation of SW(Single extension Windowing)-Based CP-OFDM System for the Sharp OOB Spectrum

Byoung-hak Park, Heung-Gyoon Ryu
Department of Electronic Engineering
Chungbuk National University
Cheongju, Korea 361-763
bh9877@naver.com, ecomm@cbu.ac.kr

Abstract—In 5th Generation (5G), the Orthogonal Frequency Division Multiplexing (OFDM) system is adopted as a core modulation technique. OFDM has a problem of high Out-Of-Band (OOB) power which reduces spectral efficiency in frequency allocation problem. A lot of research is going on to solve this OOB power problem. For example, there are Filter Bank Multi-Carrier (FBMC), Universal Filtered Multi-Carrier (UFMC) and Weighted Overlap and add based (WOLA)-OFDM. In this paper, we use windowing method to reduce OOB power. However, if windowing is applied as it is, the part without CP is damaged. Therefore, we propose a Single extension Windowing (SW) system that performs windowing after a single extension is applied to the damaged part. In addition, we propose gradual waveform on data part for more OOB power reduction. We confirm trade-off between Bit Error Rate (BER) performance degradation and OOB power reduction. Simulation results show that the BER performance degradation caused by windowing can be overcome using SW system. The OOB power reduction effect through gradual waveform confirmed that there is a 3dB BER performance degradation when OOB power reduction of up to 8dB is obtained. In this paper, we compared OOB power between CP-OFDM with windowing and CP-OFDM with conventional CP-OFDM and evaluate the performance difference.

Keywords—OFDM; window; OOB power reduction; spectral efficiency; waveform

I. INTRODUCTION

In wireless communications, spectrum efficiency is very important because of the limited frequency resources. 5th Generation (5G), recently announced by the 3rd Generation Partnership Project (3GPP), adopts Orthogonal Frequency Division Multiplexing (OFDM) which was used for 4th Generation(4G) as a core modulation technique [1]. OFDM is a multi-carrier system in which a band is divided into multiple narrow subcarriers and transmitted. From the viewpoint of each subcarrier, it becomes a frequency non-selective fading channel. Therefore, it is robust to multipath channels. After mapping the symbols, the transmitter can map the symbols to each subcarrier through Inverse Discrete Fourier Transform (iDFT) operation. The OFDM symbol obtained after the iDFT operation can be expressed as equation (1) [6].

\[ x[n] = \frac{1}{\sqrt{N}} \sum_{k=-N/2}^{N/2-1} d_k e^{j2\pi kn/N} \]  

(1)

Fig. 1. CP-OFDM block diagram.

Fig. 1 is a block diagram of the conventional CP-OFDM. After the iDFT operation, the CP is inserted to effectively process the ISI caused by the multipath channel. The length of the CP is set by the maximum time delay length [7]. The maximum time delay length is related to the communication coverage. The CP utilizes the rear part of the OFDM symbol

main methods used in signal processing. Windowing is a method of waveform shaping using window functions. In the conventional OFDM symbol, the spectral leakage occurs due to the discontinuity at both ends in the shape of a rectangle. When the windowing is performed, the discontinuity at both ends is resolved, and the spectral leakage is reduced to lower the OOB power [5]. If windowing is applied to the conventional OFDM symbol, the data without CP is damaged. Therefore, in this paper, we extend the symbol for the damaged part to prevent data corruption. In addition, we apply the cosine function to the data part to further reduce the discontinuity of the symbol applied windowing. We confirm the BER performance degradation caused by waveshaping on the data portion and confirm the trade-off between spectral efficiency obtained by waveshaping.

II. SYSTEM MODEL

A. CP-OFDM system

OFDM is a multi-carrier modulation technique in which bands are divided into orthogonal narrow subcarriers and transmitted. From the viewpoint of each subcarrier, it becomes a frequency non-selective fading channel. Therefore, it is robust to multipath channels. After mapping the symbols, the transmitter can map the symbols to each subcarrier through Inverse Discrete Fourier Transform (iDFT) operation. The OFDM symbol obtained after the iDFT operation can be expressed as equation (1) [6].

\[ x[n] = \frac{1}{\sqrt{N}} \sum_{k=-N/2}^{N/2-1} d_k e^{j2\pi kn/N} \]  

(1)
and is used as a 1/4 length of the symbol in the general case. The receiver removes the CP and demodulates the symbols mapped to each subcarrier through a Discrete Fourier Transform (DFT) operation.

### B. SW-based CP-OFDM system

If windowing is applied to CP-OFDM, the CP part is not a data area, so data is not damaged. However, since the end that is not attached to the CP is a data area, data loss is caused by windowing. To prevent this, we propose a Single extension Windowing (SW) system that extends the symbol length by the windowing length. The extension length is extended by the windowing length. The part to be used for the extension comes from the beginning of the OFDM symbol. This can be seen in Fig. 2.

![Fig. 2. Comparison symbol waveform of SW based CP-OFDM system and conventional CP-OFDM system.](image)

When windowing is applied, OOB power is reduced, but the discontinuity is further relaxed by gently increasing the data portion for better performance. In this paper, waveform shaping is performed using cosine function. However, in this case, since the data portion is damaged, performance degradation occurs in the Bit Error Rate (BER). It is necessary to determine the trade-off between performance deterioration of BER and OOB power and set the maximum amplitude appropriately according to system requirements. Fig. 2 shows the existing CP-OFDM symbols and a single extended windowing CP-OFDM. Fig. 3 shows the block diagram of SW-based CP-OFDM.

![Fig. 3. SW-based CP-OFDM block diagram.](image)

The difference from the conventional CP-OFDM is the extension and waveshaping block. After Extension and waveshaping, symbol is transmitted. Next, when the windowing part is removed from the receiver, it is erased together with the extended part. And the remaining part is demodulated through the same processing as the existing CP-OFDM.

#### C. Window function

Windowing is based on a window function. There are various kinds of window functions. The feature of the window function is that both ends are zero and have a maximum value mainly in the middle part. The window function is also based on some function. For example, there are Hann, Blackman, Nutshall, Flattop, and Gaussian window based on the cosine or Gaussian distribution. In this paper, we used Hann window. The waveform shown as Fig. 4.

![Fig. 4. Hann window waveform.](image)

Window functions have their own frequency characteristics and can be used according to the purpose. Windowing has the feature of reducing spectral leakage, which solves the problem of high OOB power, which is a disadvantage of CP-OFDM. Hann window can be expressed by equation (2) [8].

\[
w[n] = 0.5 - 0.5 \cos \left( \frac{2\pi n}{N-1} \right), \quad (0 \leq n \leq N - 1)
\]

When windowing is actually applied to CP-OFDM, a window is created as long as the sample length, and a waveform is applied to both ends of the CP-OFDM in half based on the center portion.

### III. SIMULATION RESULT AND ANALYSIS

#### TABLE I. SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>System model</td>
<td>SW-based CP-OFDM</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>FFT size</td>
<td>128</td>
</tr>
<tr>
<td>Active subcarriers</td>
<td>80</td>
</tr>
<tr>
<td>CP length</td>
<td>32</td>
</tr>
<tr>
<td>Channel</td>
<td>AWGN</td>
</tr>
<tr>
<td>Window type</td>
<td>Hann</td>
</tr>
<tr>
<td>waveshaping</td>
<td>( \cos \left( \frac{k x}{2} \right) \cdot ( -k \leq x \leq k) ) ( k = {0.5, 0.6, 0.8} )</td>
</tr>
<tr>
<td>Window length</td>
<td>8</td>
</tr>
<tr>
<td>Extension length</td>
<td>8</td>
</tr>
</tbody>
</table>

In this paper, we design SW-based CP-OFDM system and evaluate BER performance and spectral characteristics. Also, when the amplitude is moderate, the spectral change is investigated and the trade-off between BER performance is confirmed. The simulation environment is configured as
shown in Table 1. The modulation level used the BPSK. The total number of subcarriers is 128, and the number of subcarriers actually used is 80. The CP length is 32, which is 1/4 of the total number of subcarriers. We simulated the AWGN channel and used the Hann window. The length of the window is used as 8 on both ends, and thus the symbol length is increased by 8. The cosine function is used as a function to waveform shape the amplitude of the data part. The range of the cosine function was changed and the degree of spectrum change and BER performance deterioration is confirmed.

Fig. 5 and Fig. 6 show the symbol shapes of CP-OFDM and SW-based CP-OFDM.

Fig. 7 shows the frequency characteristics according to symbol shapes. CP-OFDM is -43dB and SW-based CP-OFDM is down to -78dB.

Fig. 8 shows the spectrum comparison of the conventional CP-OFDM and the SW-based CP-OFDM. It is confirmed that CP-OFDM is -30dB and the SW-based CP-OFDM is -56dB.

Fig. 9 shows the waveform comparison of cosine shaped SW-based CP-OFDM.

Fig. 10 shows the spectrum comparison of cosine shaped SW-based CP-OFDM.
Fig. 9 shows the shape of a CP-OFDM symbol with a cosine-shaped amplitude waveform. The application range of the cosine function is set by equation (3).

\[ w(x) = \cos \left( \frac{\pi x}{2} \right), \quad (-k \leq x \leq k) \]  

(3)

Fig. 10 shows the spectrum comparison when Fig. 10, which is waveform shaped with cosine, is applied. At \( k=0 \), SW-based CP-OFDM exhibited -56dB. And -59dB when the range variable \( k = 0.5 \). At \( k = 0.6 \), OOB power was -59dB similar to \( k = 0.5 \). It is confirmed that OOB power of -64 dB is exhibited when \( k = 0.8 \).

Fig. 11 compares the BER performances of the CP-OFDM waveform-shaped with cosine. When \( k = 0 \), it was the same as the theoretical value. When \( k = 0.5 \), the difference between the theoretical value and 1 dB was obtained. The difference was 1.8dB for \( k = 0.6 \) and 3dB for \( k = 0.8 \).

IV. CONCLUSIONS

In this paper, we designed SW-based CP-OFDM to reduce OOB power of conventional CP-OFDM. It is confirmed that BER performance is the same as that of conventional CP-OFDM in windowing due to the effect of SW system. In addition, when windowing, OOB is 26dB lower than the CP-OFDM. It is confirmed that the OOB power decreases as cosine shaping. It was confirmed that there was a difference of 8dB before application and at maximum application. And the BER performance degradation is confirmed. The maximum performance degradation in the simulation is 3dB. Thus, the waveform shaping of the data portion through the cosine results in a low OOB power effect, but there is a trade-off in performance degradation at the BER. Therefore, it is very important to adjust the degree of gentle form in the design of the system to suit the target performance.

ACKNOWLEDGMENT

“This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government ministry of Education (No. 2016R1D1A1B01008046).”

REFERENCES