Design and Comparison of Discrete Wavelet Transform Based OFDM (DWT-OFDM) System

Jun-Gu Lee
Department of Electronics Engineering
Chungbuk National University
Cheongju, Korea 361-763
leejg1992@chungbuk.ac.kr

Heung-Gyoon Ryu
Department of Electronics Engineering
Chungbuk National University
Cheongju, Korea 361-763
ecomm@cbu.ac.kr

Abstract - **Orthogonal frequency division multiplexing (OFDM) that is typical for the current fourth generation mobile communication system, is a multi-carrier modulation (MCM) system that enables high-speed communication using multiple carriers. The existing OFDM scheme that maps symbols to subcarriers using an inverse fast Fourier transform (iFFT) operation uses a cyclic prefix (CP) to reduce inter-symbol interference in a multipath channel, which is a disadvantage of power and spectral efficiency respectively. Therefore, this paper aims to complement the existing shortcomings for next generation high-speed communication and to design more efficient MCM system. The proposed system uses IDWT (inverse discrete wavelet transform) operation instead of iFFT operation used in conventional OFDM. A wavelet transform is an operation that filters a signal using wavelet and scaling basis functions. Therefore, we compared the bit error rate (BER), spectral efficiency, and peak to average power ratio (PAPR) performance with the conventional OFDM system through the design of OFDM system based on wavelet transform. As a result, the conventional OFDM and wavelet-OFDM exhibited the same BER performance, and wavelet-OFDM using the Discrete Meyer wavelet had the same spectral efficiency as the conventional OFDM. In addition, all systems of wavelet-OFDM based on various wavelets confirm PAPR performance lower than conventional OFDM.**

***Keywords*— Wavelet transform, OFDM, PAPR, spectral efficiency; Discrete Meyer.**

I. INTRODUCTION

OFDM, which is currently used as a kind of fourth generation mobile communication system, is an MCM system that enables high-speed transmission using a plurality of carriers. In a single carrier method using one carrier, a multi-carrier scheme is used, and a fast Fourier transform operation is used to map symbols to a plurality of subcarriers. In this way, symbols are mapped to a plurality of subcarriers, where each subcarrier is orthogonal to one another on the time axis and overlaps on the frequency axis [1]. Therefore, the signal mapped to the subcarrier minimizes the problem using the CP so that inter-symbol interference does not occur in the multipath channel. However, the CP used in OFDM has a problem of wasting power and lower spectral efficiency than existing signals. In addition, the conventional OFDM system has a disadvantage of high PAPR. This has the problem that the signal passes through the amplifier and nonlinear distortion occurs above a certain level [2]. In this paper, we propose a new MCM system to overcome the disadvantages of OFDM. In the proposed system, the symbol is mapped by using IDWT instead of iFFT operation for the OFDM and the symbol recovered by the DWT in the receiver [3-4]. There have been some studies about the DWT-OFDM [5-6], but they are not enough. Therefore, we investigate and compare the several performances of OFDM system using IDWT such as spectrum efficiency, BER performance and PAPR distributions together.

II. WAVELET-OFDM SYSTEM

A. Wavelet transform

The wavelet transform means that the signal is expanded, decomposed and analyzed by using a basis function according to different wavelets. This signal analysis method is used to analyze transient signal analysis, image analysis, and communication system signals. The difference from the Fourier transform is that signals are generated in the form of transformation and expansion of each wavelet fixed function rather than in terms of trigonometric functions. Therefore, in this study, IDWT operation is performed by using different types of wavelet basis functions, and the performance change is examined, and the performance of the conventional OFDM scheme is compared and analyzed. The following is the IDWT formula used in system operation [4].

$$x(t) = \sum_{n} \sum_{\alpha=\mathrm{A}_0}^{\mathrm{A}-1} \sum_{\Delta=0}^{2^{\alpha}-1} \omega_{\alpha,\Delta}\varphi_{\alpha,\Delta}(t-nT_0)$$
$$+\sum_{n} \sum_{\Delta=0}^{2^{\mathrm{A}_0}-1} \gamma_{\mathrm{A}^0,\Delta}\phi_{\mathrm{A}^0,\Delta}(t-nT_0) \qquad (1)$$

Here, ω and γ are constants corresponding to the scale values, φ and ϕ are specific fixed functions for various wavelets. ϕ is a scale function and has various resolutions according to this value. φ is a wavelet function and is used for signal filtering. In the IDWT operation, the scale function serves as a low-pass filter and the wavelet function serves as a high-pass filter.

B. Wavelet and scaling functions

The following are the wavelet and scale functions used in the wavelet transform [3]. At first, equations (2) and (3) are the wavelet and scale functions representing the Discrete Meyer wavelets.

$$\phi(\omega) = \begin{cases} 1 & \text{if } |\omega| \le \frac{2\pi}{3} \\ \cos[\frac{\pi}{2}\nu\left(\frac{3}{4\pi}|\omega| - 1\right)] & \text{if } \frac{2\pi}{3} \le |\omega| \le \frac{4\pi}{3} \\ 0 & \text{otherwise} \end{cases}, \quad (2)$$

$$\varphi(\omega) = e^{i\omega/2}[\phi(\omega + 2\pi) + \phi(\omega - 2\pi)]\phi(\tfrac{\omega}{2}) \quad (3)$$

The following are the scale and wavelet functions of Daubechies wavelets.

$$\phi(t) = \textstyle\sum_{\Delta=-\infty}^{\infty} \alpha_\Delta \sqrt{2}\phi(2t - \Delta) \quad (4)$$

$$\varphi(t) = \textstyle\sum_{\Delta=-\infty}^{\infty} \beta_\Delta \sqrt{2}\phi(2t - \Delta) \quad (5)$$

The following are the scale and wavelet functions of the Haar wavelet.

$$\phi(t) = \begin{cases} 1 & \text{if } 0 \le t \le 1 \\ 0 & \text{otherwise,} \end{cases} \quad (6)$$

$$\varphi(t) = \begin{cases} 1 & \text{if } 0 < t \le 1/2 \\ -1 & \text{if } 1/2 < t \le 1 \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

The following shows the wavelet function and scale function of each wavelet.

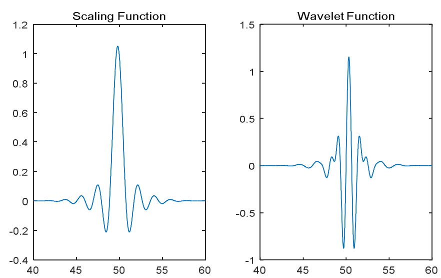

Figure 1. Scaling and wavelet function of Discrete Meyer

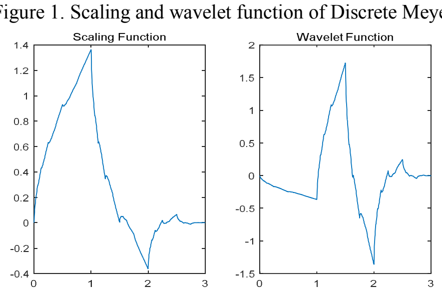

Figure 2. Scaling and wavelet function of Daubechies2.

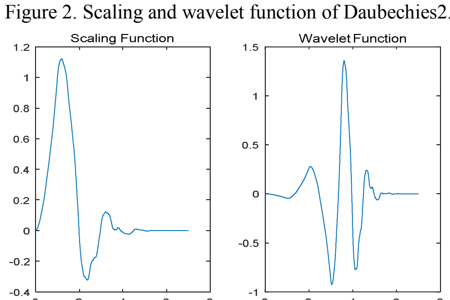

Figure 3. Scaling and wavelet function of Daubechies4.

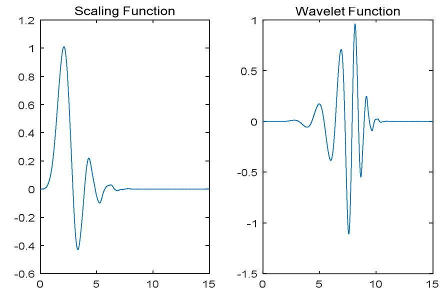

Figure 4. Scaling and wavelet function of Daubechies8.

III. Simulation Results and Analysis

In this paper, we have simulated the proposed Wavelet-OFDM system to analyze and verify the performance of each system model using MATLAB program.

The simulation was performed by specifying the symbol period according to the IEEE 802.11a standard. The symbol period after the conventional iFFT operation and the symbol period after the IDWT operation are set to 3.2us in the same manner as the standard, and the interval between the bandwidth and the subcarrier is measured. Then, the spectral efficiency according to the simulation result was calculated, respectively.

TABLE I. Simulation Parameters

Modulation	64 QAM
FFT size	64
Number of subcarriers	52
CP length	16
Channel	AWGN
Type of wavelet	Discrete Meyer Daubechies2 Daubechies4 Daubechies8 Haar

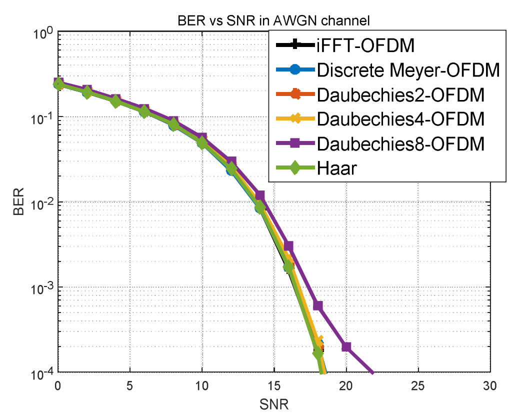

Figure 6. BER Comparison between Wavelet-OFDM and conventional DFT-OFDM.

Figure 6 shows the BER performances of the conventional OFDM system and Wavelet-OFDM system. As can be seen from the figure, the conventional OFDM system and the

OFDM system constructed using various wavelets showed almost the same BER performance. However, the system using Daubechies8 wavelet among wavelet-OFDM showed some performance degradation compared with other systems.

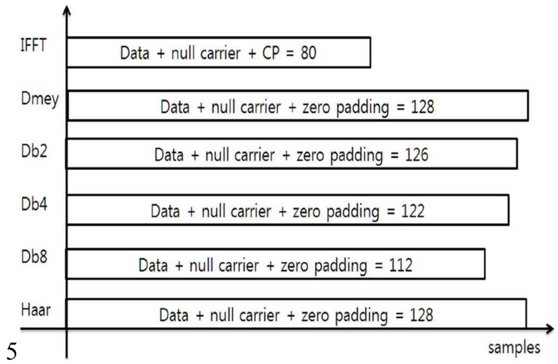

Figure 7. The number of samples that make up one symbol in each system.

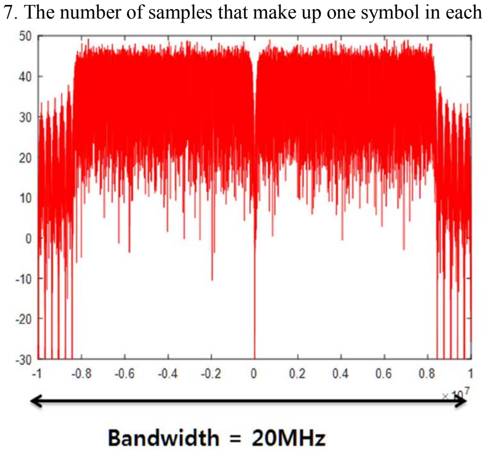

Figure 8. Spectrum of conventional OFDM.

Figure 7 shows the symbol length of a conventional OFDM and Wavelet-OFDM system as a sample. Here, the cycle per symbol is equal to 3.2 us. Therefore, the time per sample is different. For example, in OFDM using Discrete Meyer wavelet, 128 samples constitute one symbol and the period of the symbol is 3.2us, so the time per sample is 0.25ns. In addition, in the conventional OFDM system, since the period of the CP is added by 1/4 of the period of one symbol in addition to the period of one symbol, the period per symbol transmitted in the OFDM system is calculated as 4.0us added with 3.2us and 0.8us do. Therefore, the period per one sample of the OFDM system has a period of 0.5 ns because 80 samples are 4.0 us, and the simulation proceeds.

Figure 8 is the spectrum of the existing OFDM system according to the simulation environment [4]. As shown in Figure 8, the resulting bandwidth was measured at 20 MHz, as in the IEEE 802.11a standard. And we divide the measured bandwidth by the number of subcarriers and check the subcarrier spacing of each system.

Figure 9 through Figure 13 show the spectrums of wavelet-OFDM constructed using different wavelets. It can be confirmed that the bandwidths are different from each other due to the difference in the number of samples constituting one symbol and the shape of the wavelet function in each wavelet. Among them, the bandwidth of the Wavelet-OFDM system using the Discrete Meyer wavelet is the narrowest, and the out-of-band (OOB) is also lower than that of other wavelets. This seems to be an advantage of improving the frequency efficiency.

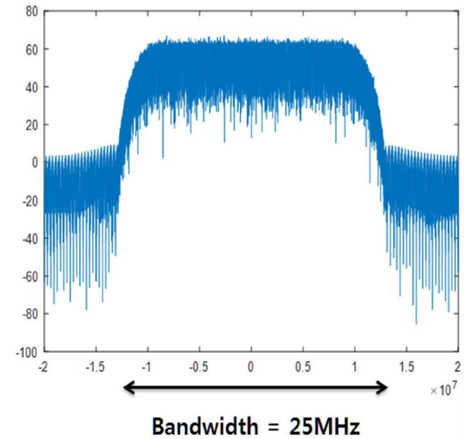

Figure 9. Spectrum of wavelet-OFDM using Discrete Meyer wavelet.

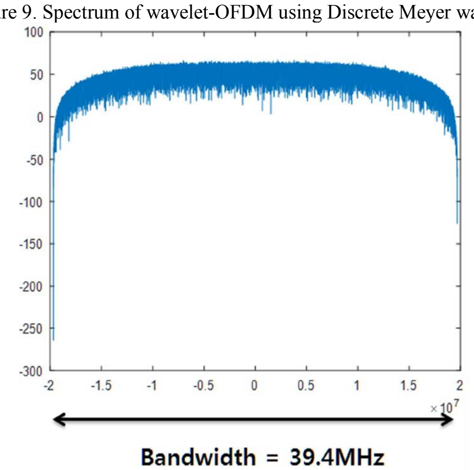

Figure 10. Spectrum of wavelet-OFDM using Daubechies2 wavelet.

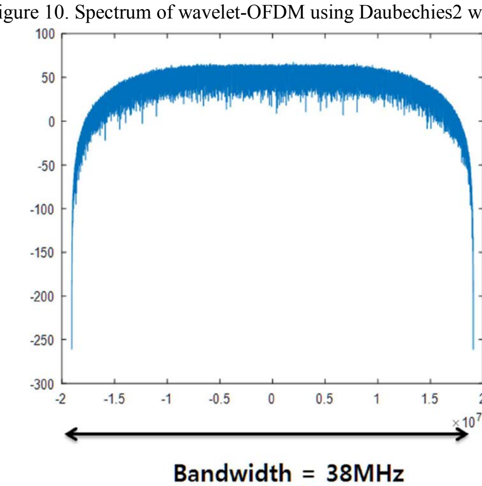

Figure 11. Spectrum of wavelet-OFDM using Daubechies4 wavelet.

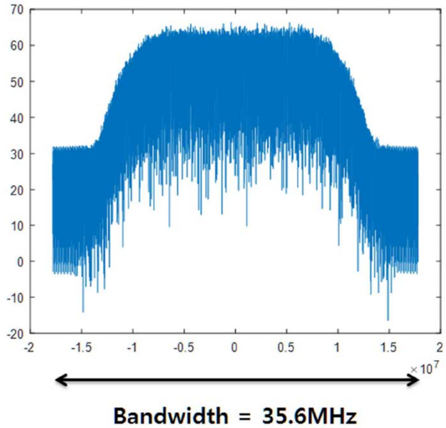

Figure 12. Spectrum of wavelet-OFDM using Daubechies8 wavelet

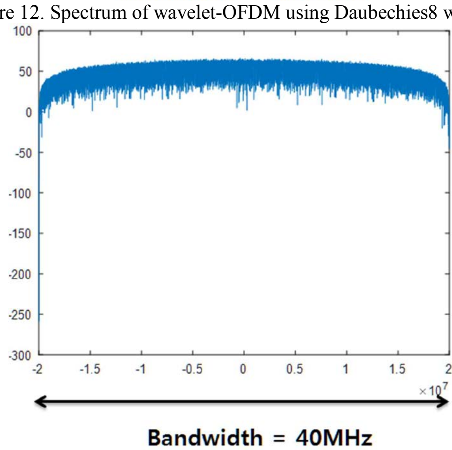

Figure 13. Spectrum of wavelet-OFDM using Haar wavelet

Table 2 summarizes the spectrum efficiency, bandwidth, and spacing between subcarriers for each system. The spectral efficiency of the OFDM system using existing iFFT operation is calculated as 2.7 bps / Hz. The wavelet-OFDM system using the Discrete Meyer wavelet has the same spectral efficiency as the conventional OFDM system. In the case of other wavelets, the spectral efficiency was worse than that of the conventional OFDM due to the difference of the symbol length due to the difference between the iFFT and the IDWT operation and the difference in the bandwidth.

TABLE II. SPECTRAL EFFICIENCY FOR EACH SYSTEMS

	Spectral efficiency (bps/Hz)	Bandwidth (Mhz)	Subcarrier spacing (KHz)
iFFT	2.7	20	312.5
Discrete Meyer	2.7	25	390.625
Daubechies2	1.7132	39.4	615.625
Daubechies4	1.7763	38	593.750
Daubechies8	1.8961	35.6	556.250
Haar	1.6875	40	625

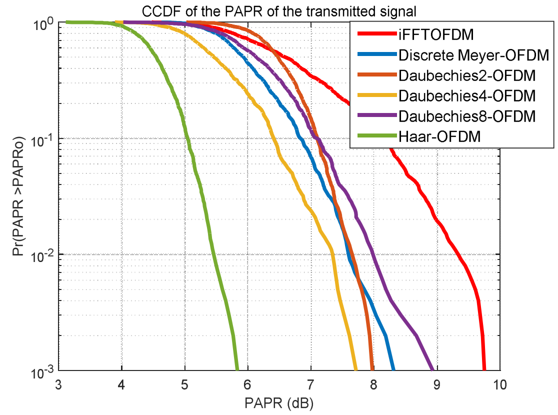

Figure 14. PAPR comparison of conventional OFDM and wavelet-OFDM

The following is a comparison of PAPR performance of conventional OFDM system and wavelet-OFDM system using several wavelets. As shown in Fig. 14, the difference between wavelet-OFDM and PAPR of existing OFDM becomes clear. The PAPR of the system using Haar wavelet was the lowest.

TABLE III. PERFORMANCE COMPARISON FOR EACH SYSTEMS

	Spectral efficiency (bps/Hz)	BER (dB)	PAPR (dB)
iFFT	2.7	18.3	9.8
Discrete Meyer	2.7	18.5	8.3
Daubechies2	1.7132	18.3	7.9
Daubechies4	1.7763	18.5	7.7
Daubechies8	1.8961	21.7	8.9
Haar	1.6875	18.3	5.8

Table 3 summarizes the three spectral efficiency, BER and PAPR performance of the system. BER performance was measured with SNR of 10^{-4}. As can be seen in the table, wavelet-OFDM system with BER and spectral efficiency most similar to existing OFDM system is a system using Discrete Meyer wavelet. Moreover, OFDM systems using Discrete Meyer wavelets have lower PAPR performance than conventional OFDM, and as shown in the spectrum, having low OOB characteristics is considered to be a great advantage. In the case of other wavelets, the wavelet with the best spectral efficiency is a system using Daubechies8, but the BER performance is different from other wavelet systems and PAPR is higher than other wavelet systems. In addition, the Haar wavelet has the lowest PAPR performance, but the spectral efficiency is also the lowest compared to other wavelets, so it is not suitable to replace the existing OFDM system. Therefore, the OFDM system using the Discrete Meyer wavelet solves the disadvantages of the conventional DFT-OFDM system and is considered to be the most suitable as the new MCM system.

IV. CONCLUSIONS

In this study, we try to devise a new MCM system that enables the next generation of high speed communication by complementing the existing shortcomings of OFDM, which is the current 4th generation mobile communication scheme. We propose an OFDM system based on IDWT operation as a new MCM scheme and compare its performance with existing OFDM. For more accurate comparison, the OFDM symbol period of the IEEE 802.11a standard is applied equally to all systems. As a result, conventional OFDM systems and wavelet-OFDM systems use Daubechies 8 wavelets. System showed almost similar BER performance. It is confirmed that the length per symbol after iFFT operation and the length per symbol after IDWT operation are expressed by the number of samples. Therefore, when the simulation is performed according to different sample periods, different bandwidths and spectral shapes are shown, and when the spectral efficiency is calculated based on this, the wavelet-OFDM system using the existing OFDM and Discrete Meyer wavelets has the same spectral efficiency respectively. However, when comparing PAPR performance, wavelet-OFDM using Discrete Meyer wavelet showed lower PAPR performance than conventional OFDM. As a result, the wavelet-OFDM system using the Discrete Meyer wavelet can replace the existing OFDM system based on the iFFT, since the spectral efficiency of the present OFDM system solves the high PAPR problem and the spectrum efficiency shows the same spectral efficiency without using CP It is thought to be a new MCM method.

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