Performance of Pulse Shaped OFDM for Interchannel Interference Reduction

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Abstract

Generally, the frequency offset makes ICI and degrades OFDM system performance. Thus, we propose a pulse shaped OFDM to give robustness against the frequency offset. The proposed OFDM system uses pulse shaping with smooth shape, instead of rectangular pulse shape, to reduce the power of ICI. The proposed scheme always gives performance gain in comparing with the convention one, when the frequency offset exists. In addition, the smoother pulse shape is employed in the proposed system, the more performance gain is obtained.

I. INTRODUCTION

Recently, the requirement for the broadband wireless communications becomes larger and larger over multipath channels. Viewing from the frequency domain, the channel characteristic of the multipath environment can be described by the frequency-selective fading. To combat this impairment, the Orthogonal Frequency Division Multiplexing (OFDM) transmission was introduced due to its robustness against the multipath fading channel by using parallel transmission. In addition, in the view of system, OFDM is a very attractive system with the robustness against multipath channels as well as several additional advantages, such as easy implementation using inverse-fast Fourier transform (IFFT) and fast Fourier transform (FFT) [1], high bandwidth efficiency by using overlapped orthogonal frequency set [2] and high order modulation, and good performance by using channel coding [3]. Due to those advantages, OFDM systems have been adopted, or are being under consideration, as a basis of several standards for broadband wireless communication systems, such as IEEE 802.16 broadband wireless access (BWA) systems [4] and IEEE 802.11a system [5].

Although the OFDM transmission is strong against multipath channels, it also has some disadvantages. One of them is that the frequency offset can degrade the performance of OFDM system. In the multicarrier system, the frequency offset breaks down the orthogonality among the subcarriers and makes inter-channel interference (ICI) as well as the rotation and attenuation of the useful signal component [6]. The ICI due to the frequency offset is main reason for the severe performance degradation in the multicarrier system.

To solve the frequency offset problems in the OFDM system, a frequency offset estimator is widely used [8]. Although frequency offset estimator reduces frequency offset value itself, it still has some problems such as non-perfect estimation of the frequency offset, increase in the system complexity and the sensitivity due to multipath fading channels. Thus, in this paper, we propose another solution, which is called pulse shaped OFDM, employing smooth pulse shape instead of rectangular pulse shape. The proposed pulse shaped OFDM does not eliminate frequency offset itself, but reduces ICI power, which is a main source of performance degradation in the OFDM system with the frequency offset.

This paper is organized as follows. Section II shows the effects of the frequency offset. In Section III, we propose the pulse shaped OFDM for the robustness against the multipath channel. In Section IV, we show the performance of the proposed pulse shaped OFDM with frequency offset by simulation study. Finally, we conclude this paper in Section V.

II. EFFECTS OF THE FREQUENCY OFFSET IN THE OFDM SYSTEM

In this section, we briefly summarize the effects of the frequency offset [7]. The transmitted signal, $s(t)$, is given as follows:

$$s(t) = \frac{1}{\sqrt{N}} \sum_{i=-\infty}^{+\infty} \sum_{k=0}^{N-1} X_{i,k} p(t-iT) e^{j2\pi(\frac{kT_s}{N}+f_c)t} \quad (1)$$

where N is the number of the subcarriers, $X_{i,k}$ is the transmitted symbol at the i-th OFDM block through the k-th subcarrier, T_s is the effective OFDM symbol duration, T is the OFDM symbol duration including the GI, f_c is the carrier frequency and $p(t-iT)$ is the pulse shape function with a rectangular shape. Although the transmitted signal

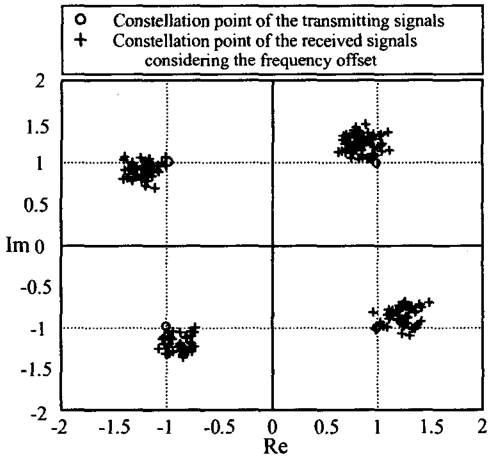

Figure 1: Constellation points of the transmitted and the received signal considering frequency offset, $\Delta f T_s = 3\%$

practically passes through the multipath channel, we use the simple additive white Gaussian noise (AWGN).

At the receiver, the received signal is down-converted and passes FFT to detect the transmitted data. In this process, we assume the perfect synchronization in timing and no existence of frequency offset. Then, the FFT output of the m-th subchannel at the i-th transmitted symbol is given as follows:

$$z_{i,m} = H_m X_{i,m} + N_m \tag{2}$$

where H_m is the channel transfer function, which is equal to the frequency response of the channel impulse response, $h(t)$, and N_m is the noise due to AWGN with the two-side power spectral density, $N_0/2$. The only effect of a multipath channel is the distortion of the desired signal, which is represented as the multiplication of the transmitted data, $X_{i,m}$, and the channel transfer function, H_m.

However, if we consider the frequency offset in the down-conversion processing, the FFT output of the m-th subchannel at the i-th transmitted symbol is affected by the ICI and given as follows:

$$z_{i,m} = \sum_{l=0}^{N-1} c_{l,m}(H_l X_{i,l}) + N_m \tag{3}$$

where $c_{l,m}$ is the weighting coefficient, which gives the contribution of the l-th input $X_{i,l}$ to the m-th output $z_{i,m}$ and is given as follows:

$$c_{l,m} = \frac{1}{N}\sum_{k=0}^{N-1} W^{(-l+m+\Delta f T_s)k} \tag{4}$$

where Δf is the frequency offset.

Figure 1 shows the constellation points of the transmitted and the received signals considering the frequency offset. The frequency offset makes two effects. One is the distortion of the desired signal, which is represented as the shifting of the mean constellation point of the received signal due to $c_{m,m}$. The other is the ICI. Although there is no AWGN, the scattering of the received signals occurs due to ICI, which plays a role of noise in the OFDM systems.

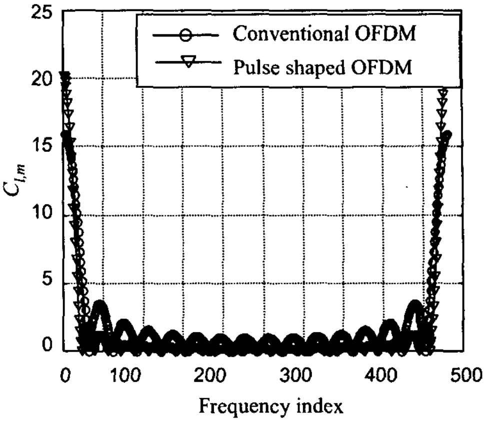

Figure 2: $c_{l,m}$ values in frequency domain

III. PROPOSED PULSE SHAPED OFDM SYSTEM

Although the frequency offset estimator easily reduces the frequency offset itself, it still has some problems: non-perfect estimation and increase in the system complexity. Thus, in this paper, we propose a pulse shaped OFDM, which is easily implemented and reduces the power of ICI.

A. *Basic Principle of the Pulse Shaping*

In this subsection, the basic principle of the pulse shaped OFDM is explained. Generally, the power of ICI is related to $c_{l,m}$ given in eq. (4). When the frequency offset does not exist, $c_{l,m}$ is zero for all $l \neq m$ due to orthogonality among subcarriers. However, with the frequency offset,$c_{l,m}$ has non-zero value. Note that the envelop of the $c_{l,m}$ is related with the pulse shaping function. For the conventional OFDM system, the pulse shaping function is rectangular pulse shape. For the rectangular pulse shape, the envelop of $c_{l,m}$ has large side robes. The pulse shaped OFDM uses different pulse shapes with small side robes in their envelop. Figures 2 show $c_{l,m}$ values in two OFDM systems with the frequency offset. For comparison, two types of OFDM systems are considered: the conventional OFDM with rectangular pulse shape and the pulse shaped OFDM with smooth pulse shape. Figure 2 shows the reduction of the envelop in $c_{l,m}$ significantly. Thus, the proposed pulse shaped OFDM reduces the power of ICI and has robustness against the frequency offset.

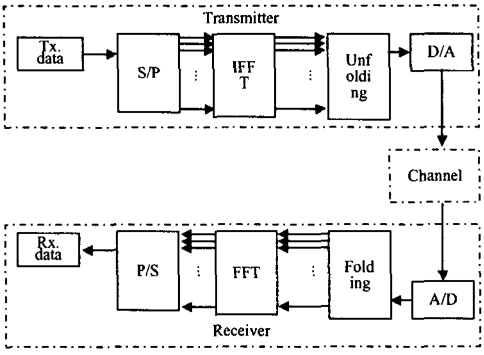

Figure 3: Proposed pulse shaped OFDM system using IFFT and FFT

Parameter	Value
No. of subcarrier	16
No. of virtual carrier	1
No. of data subcarrier	15
Guard interval	Not considered
Error correction code	Not considered
Channel model	only AWGN

Table 1: System parameter values

B. *Implementation of Pulse Shaped OFDM System*

Figure 3 shows the proposed pulse shaped OFDM system using IFFT and FFT. In general, the pulse shaping introduces overlap of the transmission symbols at the start and the end parts in the OFDM symbol. It is impossible to implement the partial overlap using IFFT and FFT, because they generate whole samples in the OFDM symbol, not partially. Thus, for easy implementation, we use unfolding and folding [9], which support the pulse shaping in the orthogonal transform with small computational complexity. By employing folding and unfolding, note that the structure of the proposed pulse shaped OFDM system did not change significantly and the only changed parts are folding and unfolding parts.

IV. PERFORMANCE EVALUATION

In this section, the performance of the proposed pulsed shaped OFDM system is shown and compared with that of the conventional OFDM system. To investigate the effect of the frequency offset, the simple AWGN channel with frequency offset is employed. In addition, for simplicity of the simulation, the small subcarrier OFDM system, whose parameters are given in Table 1, is employed. For the performance comparison, we use three types of pulse shapes: a rectangular pulse shape for conventional OFDM and two pulse shapes, shown in Figure 4, for the pulse shaped OFDM. Two different pulse shapes are employed for the performance comparison according to pulse shapes.

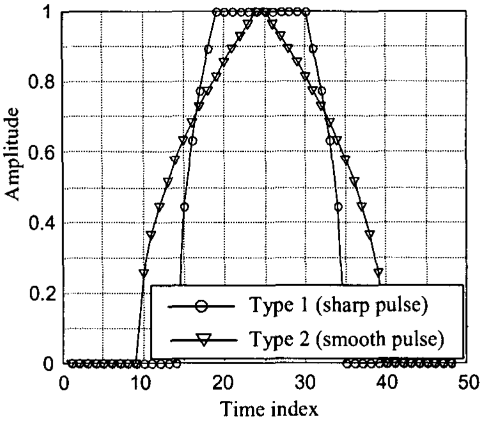

Figure 4: Two types of pulses for the proposed pulse shaped OFDM system

Figure 5 shows the unfolded transmission signals and the folded reception signals in the proposed pulsed shaped OFDM. When the unfolding is finished at the transmitter, one OFDM symbol consists of three parts: the first part includes last one third of the previous and first one third of the present symbols at the header, the second has only middle one third of the present symbol, and the third has last one third of the present and the first one third of the next symbol. By unfolding, the pulse shaping, including inter-symbol interference (ISI) inserted on purpose, can be achieved. At the receiver, the folding process has to be done to recover the transmission signal before unfolding. Figure 5 shows that the perfect reconstruction is obtained, when we compared the unfolded reception signal with the transmission signal of the conventional OFDM.

Figure 6 shows the bit error rate (BER) performance of the proposed pulse shaped OFDM according to the normalize frequency offset, which is normalized about subcarrier tone-spacing. When there is no frequency offset, three OFDM systems show similar performance. However, when the frequency offset exists, the conventional OFDM system makes significant performance degradation. When the normalized frequency offset is greater than 0.2, the conventional OFDM can not support BER equal to 10^{-3}. In the pulse shaped OFDM system, the proposed technique improves performance, when the frequency offset exists. For example, when the normalized frequency offset is 0.1, type 1 and type 2 pulse shaped OFDM systems give about 0.6 and 1.4dB gain in $E-b/N_0$ comparing with that of the conventional one. The performance gain increases as the normalized frequency offset increases. In addition, when

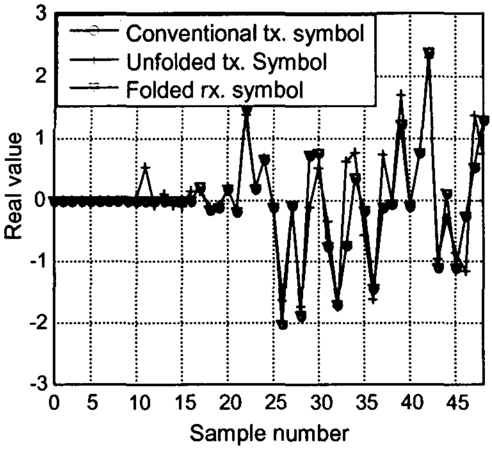

Figure 5: Unfolded transmission signal and folded reception signal in the pulse shaped OFDM

we compare two performance of pulse shaped OFDM systems, type 2 shows better performance than type 1. It is because that as the pulse shape is smoother in time domain, the more reduction in side robe occurs in frequency domain.

V. CONCLUSIONS

In general, the frequency offset significantly degrades the performance of the OFDM system. Therefore, we proposed a pulse shaped OFDM system to give robustness against the frequency offset. The proposed OFDM used pulse shaping with smooth shape instead of rectangular pulse shape to reduce the power of ICI. In its implementation, the unfolding and the folding were employed for easy implementation using existing IFFT and FFT.

According to simulation results, the unfolding and the folding perfectly reconstructed the original signal and could be used for pulse shaping. In the BER performance, the proposed OFDM system always gave the performance gain comparing with the convention one, when the frequency offset existed. In addition, the smoother pulse shape was employed in the proposed system, the more performance gain was obtained.

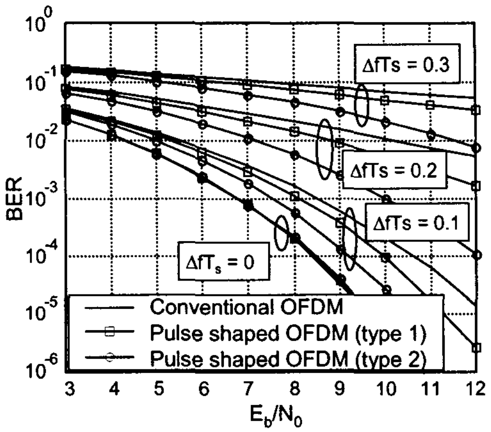

Figure 6: BER performance of the proposed pulse shaped OFDM according to the normalized frequency offset

REFERENCES

[1] L. J. Cimini, Jr., "Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing," *IEEE Trans. Commun.*, vol. COM-33, no. 7, pp. 665–675, July 1985.

[2] W. Huang and M. Nakagawa, "Channel coding with MPSK/orthogonal multi-carrier transmission," in *Proc. IEEE ICC '96*, Dallas, TX, USA, June 1996, pp. 1313–1317.

[3] W. Hwang, Y. Lee, S.-G. Kim, and K. Kim, "Performance analysis of a block coded BPSK/OMC modulation," in *Proc. KITE Summer Conf.*, Gwangju, Korea, June 1997, vol. 20, no. 1, pp. 75-78, (in Korean).

[4] I. Koffman and V. Roman, "Broadband wireless access solutions based on OFDM access in IEEE 802.16," *IEEE Commun. Mag.*, vol. 40, no. 4, pp. 96–103, Apr. 2002.

[5] "Supplement to IEEE standard for information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements. Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: High-speed physical layer in the 5 GHz band," IEEE Std 802.11a-1999, 1999.

[6] T. Pollet and M. Moeneclaey, "The effect of carrier frequency offset on the performance of band limited single carrier and OFDM signals," in *Proc. GLOBECOM'96*, New York, NY, Nov. 1996, pp. 719-723.

[7] Y. Kho, K. Oh, and K. Cho, "Performance Bound of the OFDM Transmission with the Frequency Offset," *ITC-CSCC 2000*, pp. 521-524, July 2003.

[8] M. Morelli and U. Mengali, "An improved frequency offset estimator," IEEE comm. Letters, vol. 3, no. 3, pp. 75-77, Mar. 1999.

[9] H. S. Malvar, *Signal Processing with Lapped Transforms*. Artech House, 1992.