DFE Equalization Method for Frequency Selective Rayleigh Fading Channel in Generalized OFDM Systems

박태윤, 최재호
전북대학교 공과대학 전자정보공학부
http://zion.chonbuk.ac.kr

Tae-Yoon Park & Jae-Ho Choi
Divsion of Electronics & Information Engineering, Chonbuk National University

Abstract

A new decision-feedback equalization technique for a filter bank-based orthogonal frequency division multiplexing (OFDM) data transmission system operating in a frequency selective multipath fading channel is presented in this paper. At the cost of relatively increased computational complexity in comparison to the conventional OFDM systems, the proposed system achieves a better performance in terms of bit error rates. The simulation results confirm the superiority and robustness of our method, particularly, in the low SNR channel environment.

I. Introduction

OFDM scheme is used widely in wireless communication applications such as wireless LAN and digital broadcasting. It comes naturally from the reason that the frequency division multiplexing method has several advantages over the time division multiplexing. Among those, the OFDM system combats better to frequency-selective multipath fading in a wireless environment while the given communication bandwidth can be effectively utilized. Moreover, by adopting a simple 1-tap equalizer and cyclic prefix it can negotiate inter-channel interference (ICI) and inter-symbol interference (ISI).

However, the cyclic prefix works like an overhead, and some extent of the total bandwidth should be consumed for the cyclic prefix. Sun and Tong proposed a DFE based OFDM method [1] that eliminates the use of any cyclic prefix such that the whole bandwidth is used for data transmission. Unlike the conventional OFDM, nevertheless, ICI and ISI remain in the received signal without using the cyclic prefix; and these interferences can't be suppressed sufficiently using plain DFE method due to the spectral properties of the FFT.

On the other hand, the general filter bank system using a much longer modulation filters has superior spectral properties in comparison to FFT, and the interferences can be handled more effectively. In this paper, we propose a new DFE-based equalization technique to a OFDM-like multi-carrier system using a generalized filter bank, and compare its performance to the traditional OFDM system.

II. Multi-Carrier Systems

1. Conventional OFDM System

On each subchannel the independent data stream is transmitted in the OFDM system and the transmitted signal of the conventional OFDM system is as follows:

$$x(t)=\sqrt{\frac{T_s}{NT_f}}\sum_{i=-\infty}^{\infty}\sum_{n=0}^{N-1}s_n(i)e^{j\frac{2\pi(n-\frac{N-1}{2})(t-iT)}{NT_f}}p(t-iT) \quad (1)$$

where T is the time duration of an OFDM symbol, T_s is a sampling period, and $1/T_f$ is overall bandwidth used by system. while $p(t)$ is a shaping pulse and $s_n(i)$ is a coded symbol transmitted through nth subchannel in ith OFDM symbol time. In this conventional OFDM,

이 논문은 전북대학교 정보통신연구소 우수대학원 지원사업 및 정보통신연구진흥원의 지원으로 얻어진 결과임

$T_s = T_f$, and $T = (N + G)T_s$ when G samples are used for guard time.

The signal $x(t)$ is transmitted through a wireless channel that has d paths, and received signal $y(t)$ can be expressed as follows:

$$y(t) = \sum_{j=1}^{d} \alpha_j(t)x(t - \tau_j) + n(t) \tag{2}$$

where $\alpha_j(t)$ represents complex attenuation factor in jth path of the transmission channel, τ_j is amount of time delay in jth path, and $n(t)$ is a additive white Gaussian noise. N_s samples are obtained in the receiver during a T period using the $1/T_s$ sampling frequency. The sample is expressed as $y_k(i) = y(iT + c + kT_s)$, where $k = 0, 1, ..., N_s - 1$ is the kth sampled value from the ith OFDM symbol, where c is the time that the first sample is taken and its vector form is $\mathbf{y}(i) = (y_0(i), ..., y_{N-1}(i))^T$. Now, assuming a maximum delay of the multi path channel $\tau_{\max} < T$, $\mathbf{y}(i)$ can be expressed as follows:

$$\mathbf{y}(i) = \mathbf{H}^{(0)}(i)\mathbf{s}(i) + \mathbf{H}^{(1)}(i)\mathbf{s}(i-1) + \mathbf{n}(i) \tag{3}$$

where $\mathbf{H}^{(m)}(i) = (\mathbf{C}^{(m)}(i)\mathbf{E}^{(m)}) \circ \tilde{\mathbf{F}}$, the elements of $\mathbf{C}^{(m)}(i)$ are $c_{k,j}^{(m)}(t) = \alpha_j(iT + c + kT_s)p(mT + c + kT_s - \tau_j)$, elements of $\mathbf{E}^{(m)} \in C^{d \times N}$ are $e_{j,n}^{(m)} = \exp[j2\pi(mT + c - \tau_j)n/(NT_f)]$, elements of $\tilde{\mathbf{F}} \in C^{N_s \times N}$ are $\tilde{f}_{k,n} = \exp[j2\pi nk/(NT_f/T_s)]/\sqrt{NT_f/T_s}$, and $\mathbf{s}(i) = (s_0(i), ..., s_{N-1}(i))^T$ is transmission symbol vector.

2. DFT-based OFDM System Without Guard Time

Eq. (1) can be applied without any modification in the OFDM system based on DFT without guard time. In this case, $T = NT_f$. If communication channel has multiple paths, there would be an overlapping between the adjacent OFDM symbols, hence inter-symbol interference (ISI) and inter-channel interference (ICI) occur resulting in the performance degradation.

3. Proposed Generalized Filter Bank Based OFDM

A generalized filter bank based system uses a prototype filter that has a longer impulse response. Because of this inherent filter bank property the resulting this type of OFDM symbol gets as twice as or more longer. The generalized filter bank can be constructed by modulating the lowpass filter prototype to form each subchannel. The transmitted signal synthesized by the generalized filter bank is as follows:

$$x(t) = \sum_{i=-\infty}^{\infty}\sum_{n=0}^{N-1} s_n(i)f_n(t - iT) \tag{4}$$

$$p_0(t)\cos\left(\pi(n+0.5)(\frac{t}{T} - \frac{1}{2N} - 1) - \frac{(-1)^n\pi}{4}\right)$$

where $p_0(t)$ is the prototype filter with orthogonal property, and its length is gT, i.e., $g = 2, 3, ...$

The received signal passed through the multi-path communication channel expressed in Eq. (2) can be expressed as:

$$y(t) = \sum_{j=1}^{d}\sum_{i=-\infty}^{\infty}\sum_{n=0}^{N-1} s_n(i)f_n(t - iT - \tau_j)\alpha_j(t) + n(t) \tag{5}$$

Similarly, the sampled received signal $y_k(i)$ is as follows:

$$y_k(i) = \sum_{j=1}^{d}\sum_{m=0}^{g}\sum_{n=0}^{N-1} s_n(i-m)f_n(mT + c + kT_s - \tau_j)\alpha_j(iT + c + kT_s) + n(iT + c + kT_s). \tag{6}$$

The $(i - m)$th transmitted symbol vector $\mathbf{s}(i - m)$ contributes to ith sampled vector $\mathbf{y}(i)$ in the receiver as much as $\mathbf{y}^{(m)}(i) = \mathbf{H}^{(m)}(i)\mathbf{s}(i - m)$ where the elements of the matrix $\mathbf{H}^{(m)}(i) \in C^{N_s \times N}$ are $h_{k,n}^{(m)}(i) = \Sigma_{j=1}^{d} f_n(mT + c + kT_s - \tau_j)\, \alpha_j(iT + c + kT_s)$. Therefore, the received vector $\mathbf{y}(i)$ can be represented as follow:

$$\mathbf{y}(i) = \sum_{m=0}^{g} \mathbf{H}^{(m)}\mathbf{s}(i - m) + \mathbf{n}(i) \tag{7}$$

III. Equalization Methods

1. Conventional OFDM System

Generally, the conventional OFDM system requires of a guard time period greater than the maximum delay spread $\tau_{\max}$ in order to avoid the influence from previous symbols in the present detection symbol. With a modest guard time used the sampled vector of the received signal could be expressed as $\mathbf{y}(i) = \mathbf{H}^{(0)}(i)\mathbf{s}(i) + \mathbf{n}(i)$. Since no ISI is involved, then, these received vector are multiplied by $\tilde{\mathbf{F}}^{*}$ for demodulation followed by 1-tap equalization that compensates the attenuation before retrieving the transmitted signal. The coefficients of the equalizer are the reciprocal of $\tilde{\mathbf{F}}^{*}\mathbf{H}^{(0)}[1,1,...,1]^T$.

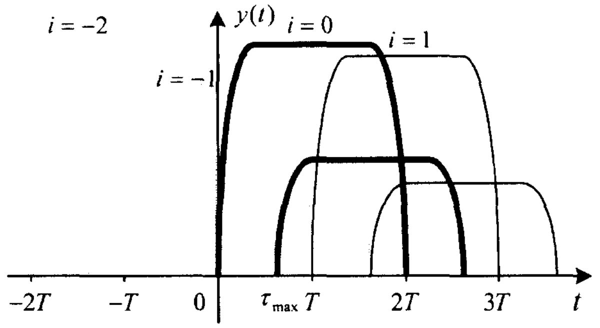

Fig. 1 Received filter bank-based OFDM signal (g = 2)

2. DFT-based OFDM System Without Guard Time

Similarly to the system discussed above, $\tau_{\max}$ is assumed to be less than T, so the estimated symbol $\mathbf{z}(i)$ for $\mathbf{s}(i)$ can be obtained as follows:

$$\begin{aligned}\mathbf{z}(i) &= \mathbf{F}_0(i)\mathbf{y}(i) - \mathbf{B}_1(i)\mathbf{y}(i-1)\\ \mathbf{F}_0(i) &= \mathbf{H}^{(0)*}(i)(\mathbf{H}^{(0)}(i)\mathbf{H}^{(0)*}(i)+\sigma^2\mathbf{I})^{-1}\\ \mathbf{B}_1(i) &= \mathbf{F}_0(i)\mathbf{H}^{(1)}(i)\end{aligned} \quad (8)$$

3. Proposed Generalized Filter Bank Based OFDM

In the filter-bank based system, the transmitted symbol is expanded as twice as or more longer in the length while the symbols are overlapped each other due to the inherent filter bank property. Fig. 1 shows the transmission symbol overlapping in the case of the filter genus g = 2 in a multipath environment.

In such a case, in order to recover a transmitted symbol $\mathbf{s}(i)$, we have to consider two received vectors $\mathbf{y}(i)$ and $\mathbf{y}(i+1)$. During this two received symbol time interval, there are contributions from four transmitted OFDM symbols, i.e., $\mathbf{s}(i-2)$, $\mathbf{s}(i-1)$, $\mathbf{s}(i)$, and $\mathbf{s}(i+1)$.

For the estimation of the ith transmitted OFDM symbol $\mathbf{s}(i)$, two received vectors $\mathbf{y}(i)$ and $\mathbf{y}(i+1)$ be expressed as follows:

$$\begin{aligned}\mathbf{y}(i) &= \mathbf{H}^{(0)}(i)\mathbf{s}(i)+\mathbf{H}^{(1)}(i)\mathbf{s}(i-1)+\mathbf{H}^{(2)}(i)\mathbf{s}(i-2)+\mathbf{n}(i)\\ \mathbf{y}(i+1) &= \mathbf{H}^{(0)}(i+1)\mathbf{s}(i+1)+\mathbf{H}^{(1)}(i+1)\mathbf{s}(i)\\ &\quad +\mathbf{H}^{(2)}(i+1)\mathbf{s}(i-1)+\mathbf{n}(i+1)\end{aligned} \quad (9)$$

If we assumed that previous received symbols were correctly recovered, the decision feedback filter operation can be expressed as follows:

$$\begin{aligned}\mathbf{y}'(i) &= \mathbf{y}(i)-\mathbf{H}^{(1)}(i)\hat{\mathbf{s}}(i-1)-\mathbf{H}^{(2)}(i)\hat{\mathbf{s}}(i-2)\\ \mathbf{y}'(i+1) &= \mathbf{y}(i+1)-\mathbf{H}^{(2)}(i+1)\hat{\mathbf{s}}(i-1)\end{aligned} \quad (10)$$

We can rearrange Eq. (10) into the matrix form as follows:

$$\begin{bmatrix}\mathbf{y}'(i)\\ \mathbf{y}'(i+1)\end{bmatrix} = \begin{bmatrix}\mathbf{y}(i)\\ \mathbf{y}(i+1)\end{bmatrix} - \mathbf{B}_1(i)\begin{bmatrix}\hat{\mathbf{s}}(i-1)\\ \hat{\mathbf{s}}(i-2)\end{bmatrix}$$

$$\mathbf{B}_1(i) = \begin{bmatrix}\mathbf{H}^{(1)}(i) & \mathbf{H}^{(2)}(i)\\ \mathbf{H}^{(2)}(i+1) & \mathbf{0}\end{bmatrix} \quad (11)$$

Assuming that $\hat{\mathbf{s}}(i)=\mathbf{s}(i)$ again, Eq. (10) can be rewritten as follows:

$$\begin{aligned}\mathbf{y}'(i) &= \mathbf{H}^{(0)}(i)\mathbf{s}(i)+\mathbf{n}(i)\\ \mathbf{y}'(i+1) &= \mathbf{H}^{(0)}(i+1)\mathbf{s}(i+1)+\mathbf{H}^{(1)}(i+1)\mathbf{s}(i)+\mathbf{n}(i+1)\end{aligned} \quad (12)$$

or Eq.(12) in the matrix form,

$$\begin{bmatrix}\mathbf{y}'(i)\\ \mathbf{y}'(i+1)\end{bmatrix} = \begin{bmatrix}\mathbf{0} & \mathbf{H}^{(0)}(i)\\ \mathbf{H}^{(0)}(i+1) & \mathbf{H}^{(1)}(i+1)\end{bmatrix}\begin{bmatrix}\mathbf{s}(i+1)\\ \mathbf{s}(i)\end{bmatrix} + \begin{bmatrix}\mathbf{n}(i)\\ \mathbf{n}(i+1)\end{bmatrix} \quad (13)$$

From this equation, $\mathbf{z}(i)$, that is the estimation of $\mathbf{s}(i)$, can be obtained using a feed-forward filter as follows:

$$\begin{bmatrix}\mathbf{z}(i+1)\\ \mathbf{z}(i)\end{bmatrix} = \mathbf{F}_0(i)\begin{bmatrix}\mathbf{y}'(i)\\ \mathbf{y}'(i+1)\end{bmatrix}, \quad (14)$$

$$\text{where } \mathbf{F}_0(i) = \mathbf{H}^*(i)\left(\mathbf{H}(i)\mathbf{H}^*(i)+\sigma^2\mathbf{I}\right)^{-1}$$

$$\mathbf{H}(i) = \begin{bmatrix}\mathbf{0} & \mathbf{H}^{(0)}(i)\\ \mathbf{H}^{(0)}(i+1) & \mathbf{H}^{(1)}(i+1)\end{bmatrix}$$

Fig. 2 shows the structure of the DFE receiver for the generalized filter bank-based OFDM system. with overlapping factor g = 2.

IV. Computer Simulation

A set of simulations is performed for comparing the performances of the three OFDM systems. There are several common parameters used in WAND configuration. Typically, The parameters are the time duration of an OFDM symbol T = 1.2 μs and the

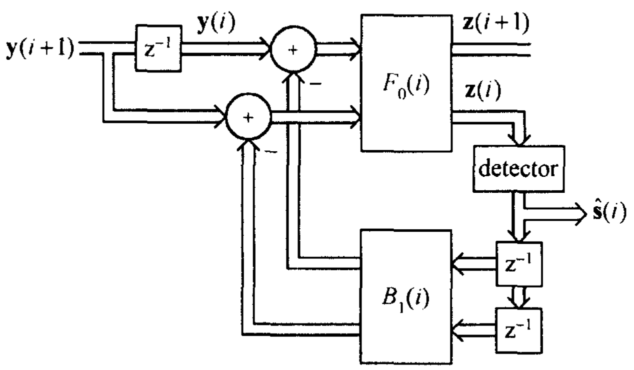

Fig. 2 DFE structure of the generalized filter bank-based OFDM system with g = 2

number of subchannels N = 16. We used d = 4 rays of Rayleigh faded mobile paths, and the delays of the each paths are 0, 0.02, 0.05 and 0.1 μs. The power profile of each path is 0.5, 0.25, 0.15 and 0.1, respectively. Moreover, we suppose that the channel is time-invariant during the time interval of a burst transmission of 100 OFDM symbols; and 500 bursts are transmitted for the performance evaluation using the transmission symbol $s_n(i)$ encoded by 8-PSK.

1. Conventional OFDM System

The parameters c = 0.4 μs, N_s = N, and T_f = T_s = 0.05 μs are used. The shaping pulse for OFDM signal $p(t)$ is as follows:

$$p(t) = \begin{cases} 1, & \beta / W \le t \le 1/W \\ \sqrt{\left(1 - \sin \dfrac{\pi W (t + 1/2W)}{\beta}\right) \Big/ 2}, & 0 \le t < \dfrac{\beta}{W} \text{ or } \dfrac{1}{W} < t < \dfrac{1+\beta}{W} \\ 0, & \text{elsewhere} \end{cases} \tag{15}$$

where b = 0.2 and W = 5/6 MHz.

2. DFT-based OFDM System Without Guard Time

The parameters used are c = 0 μs, N_s = $2N$, T_f = 0.075 μs, and T_s = $T_f/2$ = 0.0375 μs while exactly same the shaping pulse is utilized as in Eq. (15).

3. Proposed Generalized Filter Bank Based OFDM

The same parameter as the DFT-based OFDM system are used as c = 0 μs, N_s = $2N$, T_f = 0.075 μs, and T_s = 0.0375 μs. However, in contrast to above two systems, the shaping pulse replaced by the lowpass filter prototype $p_0(t)$ with a overlapping factor g = 2 is used as follows:

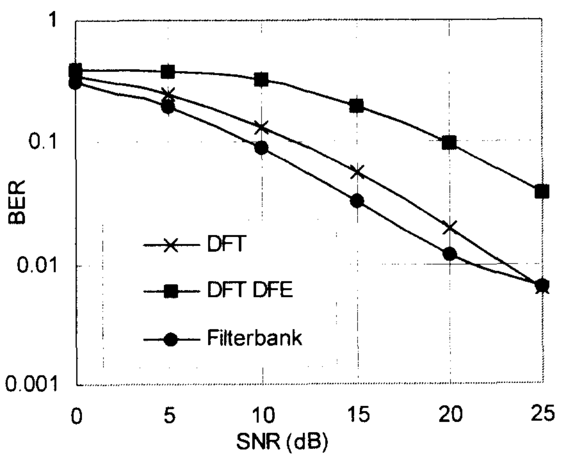

Fig. 3 Performance comparison: BER in simulation

$$p_0(t) = \begin{cases} 2\sin\left(\dfrac{(2t/T+1)\pi}{4N}\right), & 0 \le t \le 2T \\ 0 & \text{elsewhere} \end{cases} \tag{16}$$

Figure 3 shows the simulation results of the three systems in terms of bit error rate over various signal-to-noise ratios.

V. Conclusions

A novel decision feedback equalization method for compromising frequency selective fading channel effects in the generalized filter bank based orthogonal frequency division multiplexing system is presented. The simulation results verified the superb performance of our method over the conventional ones in terms of BER particularly in the low SNR environment.

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