AN ALIAS-FREE SUBBAND ADAPTIVE EQUALIZER FOR OFDM SYSTEM

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ABSTRACT

In this paper, we propose a subband adaptive digital filter (SBADF) for orthogonal frequency division multiplexing (OFDM) system. The proposed SBADF is able to carry out the exact system identification without the degradation effect of both the aliasing and the cross terms even under the critical sub-sampling. The inverse transfer function of the channel can be directly implemented after the system identification. The advantage of the proposed SBADF based equalizer is that it is not necessary to take into account of the delay in terms of the transmission path because of the frequency-domain equalization. Some simulation results show the efficiency of the proposed SBADF for OFDM system.

1. INTRODUCTION

Recently, the OFDM (Orthogonal Frequency Division Multiplexing) system, which is a special form of multicarrier modulation, has been paid a lot of attention in various applications of high speed wireless digital communication systems in order to support multi-media services such as digital terrestrial TV (DTTV), high data rate wireless LAN in the 5 GHz band (IEEE 802.11a), mobile telecommunications systems and so on [1]-[4]. The reason is that OFDM scheme is robust for multipath phasing problem because of the use of guard interval (GI) signal [5]. However, even if we can avoid ISI (Inter-symbol interference) problems by using the guard interval scheme, equalization of signals distortion is still necessary [6], [7].

In this paper, we propose an equalizer for OFDM system in view of that OFDM system is identical to DFT filter bank. The performance of subband adaptive digital filter (SBADF) would suffer from aliasing. This is mainly because rate conversion produces the degradation effect of aliasing. Some adaptive algorithms based on the subband technique have been proposed to overcome this problem [8]-[10]. In this paper, an equalization scheme for OFDM system, which is based on an alias-free SBADF [9],[10], will be discussed.

This paper is organized as follows. Section 2 shows the OFDM transmitter and receiver system as well as the necessity of equalizers. Section 3 proposes a subband adaptive equalizer for OFDM system. In Section 4, some computer simulation results show the efficiency of the proposed SBADF for OFDM system. Finally, conclusion of this paper is described in Section 5.

2. OFDM SYSTEM

In this section, the structure of the OFDM transmitter and receiver is shown. We show that the signal equalization is necessary even if guard interval is added to OFDM symbol. Moreover, we also show that equalization for OFDM system can be regarded as a subband adaptive filter in frequency domain.

2.1. Transmitter

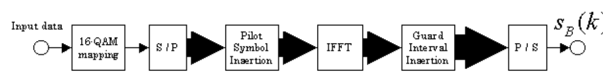

Fig. 1. Transmitter

A block diagram of the OFDM transmitter is shown in Fig.1. First, 4 bits in each sub-carrier are mapped into the I-Q plane by 16-QAM (Quadrature Amplitude Modulation) mapping scheme. Second, the I-Q mapped signals include pilot symbols as reference signals. Then the mapped signals are fed into a M point IFFT (Inverse Fast Fourier Transform). Third, a guard interval is added to each multiplexed symbol (OFDM symbol) to prevent the degradation caused by interference of the previous OFDM symbol.

The baseband OFDM symbol is $s_B(k)$ in Fig.1. The received OFDM symbol $s_R(k)$ is given by

$$s_R(k) = \sum_{u=-\infty}^{\infty} h(u) s_B(k-u) + n_c(k), \tag{1}$$

where $n_c(k)$ and $h(k)$ are additional noise, impulse response of channel, respectively.

2.2. Receiver

A block diagram of the OFDM receiver is shown in Fig.2. The guard interval is removed from the received OFDM symbol, then the OFDM symbol is converted into the I-Q mapped signal using a M point FFT (Fast

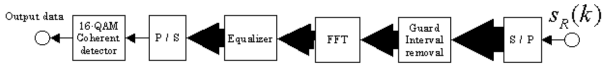

Fig. 2. Receiver

Fourier Transform) circuit. If the length of guard interval signal is shorter than the delay in terms of the channel, the received symbol does not contain ISI. Thus the received symbol $s_R(k)$ can be written by

$$x(Mk,l) = H(Mk,l)d(Mk,l) + N_B(Mk,l). \qquad (2)$$

where $x(Mk,l), M, k, l$ are demodulated signal, decimator function, symbol number, and carrier number, respectively. $d(Mk,l)$ is mapped signals.

Eq.(2) shows that the demodulated signal $x(Mk,l)$ is degraded by channel $H(l)$ and additional noise $N_B(Mk,l)$. Therefore, equalization of signal is necessary for OFDM system. Equalization in terms of Eq.(2) can be regarded as a subband adaptive digital equalizer in frequency domain. This is because the received symbols are demodulated by FFT circuit. Thus we propose a subband adaptive digital equalizer for OFDM system in the next section.

3. ADAPTIVE EQUALIZER USING DFT FILTER BANK

In this section, we propose a subband adaptive equalizer for OFDM system. First, the structure of an equalizer system is shown. Second, an adaptive algorithm is derived. Finally, we discuss an equalization for non-minimum phase channel.

3.1. Architecture

Fig.3 shows a proposed equalizer for OFDM system. The OFDM scheme itself can be categorized into the DFT filter bank with the critical sub-sampling so that this poly-phase architecture can be used for adaptive equalizer with multi-rate adaptive filtering. It is well know that the critically sampled filter banks cannot be used for adaptive filtering due to the degradation effects of both aliasing and cross term. However, the special class of DFT bank, whose impulse response in terms of each poly-phase component is unity, is alias-free at discrete frequency points so that it can be used for adaptive system identification with critical subsamping.

3.2. Cost Function

The error signal $\hat{e}(Mk,l)$ at time Mk is

$$\begin{aligned}\hat{e}(Mk,l) &= \sum_{i=1}^{k} e(Mi,l) \\ &= \sum_{i=1}^{k} \{x(Mi,l) - H(Mi,l)d(Mi,l)\} \\ &= \hat{x}(Mk,l) - \hat{H}(Mk,l)\hat{d}(Mk,l), \qquad (3)\end{aligned}$$

$*$denotes a complex conjugate

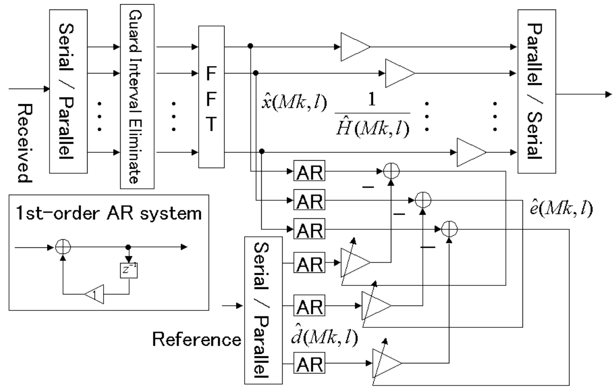

Fig. 3. Equalizer

where M, $e(k,l)$, $d(k,l)$, and $x(k,l)$ are decimation factor, error signal in k-th of symbol and l-th of sub-carrier, reference signals, and received signals, respectively. $H(Mk,l)$ is the transfer function of the channel at frequency $\frac{2\pi}{M}l$. $\hat{x}(Mk,l)$, and $\hat{d}(Mk,l)$ are shown as follows.

$$\hat{x}(Mk,l) = \sum_{i=1}^{k} x(Mk,l) \qquad (4)$$

$$\hat{d}(Mk,l) = \sum_{i=1}^{k} d(Mk,l) \qquad (5)$$

Eq.(4) and eq.(5) are calculated by 1st-order AR system as in Fig.3. Thus we get the cost function $J(Mk,l)$ with l-th sub-carrier at Mk time indices as

$$J(Mk,l) = \sum_{i=1}^{k} \hat{e}(Mi,l)\hat{e}^*(Mi,l). \qquad (6)$$

3.3. Adaptive algorithm

The gradient vector of the steepest-descent algorithm is given by

$$\begin{aligned}\nabla J(Mk,l) &= \frac{\partial J(Mk,l)}{\partial \hat{H}(Mk,l)} \\ &= -2p(Mk,l) + 2r(Mk,l)\hat{H}(Mk,l)(7)\end{aligned}$$

where $r(Mk,l)$ and $p(Mk,l)$ are defined as

$$r(Mk,l) = \sum_{i=1}^{k} \hat{d}(Mi,l)\hat{d}^*(Mi,l), \qquad (8)$$

$$p(Mk,l) = \sum_{i=1}^{k} \hat{x}(Mi,l)\hat{d}^*(Mi,l), \qquad (9)$$

respectively. $r(Mk,l)$ and $p(Mk,l)$ are the auto-correlation function of $\hat{x}(Mk,l)$, the cross-correlation function of

$\hat{x}(Mk,l)$ and $\hat{d}(Mk.l)$, respectively. Setting the gradient vector $\nabla J(Mk,l) = 0$, we get the optimum tap-weight vector $\hat{H}(Mk,l)$. Therefore, $\hat{H}(Mk,l)$ at l-th sub-carrier and time Mk is given by

$$\hat{H}(Mk,l) = \frac{p(Mk,l)}{r(Mk,l)}. \tag{10}$$

Fig.4 shows the proposed equalizer system including an adaptive algorithm.

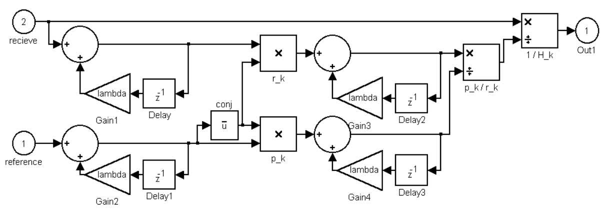

Fig. 4. Equalizer(simulink)

3.4. Subband equalizer for OFDM system

The transfer function $\hat{G}_k$ in terms of the equalizer can be directly obtained from eq.(7) as its inversion at each frequency l.

$$\hat{G}(Mk,l) = \frac{1}{\hat{H}(Mk,l)} \tag{11}$$

Thus the equalization in OFDM system can be easily done by multiplying $\hat{G}(Mk,l)$ with the received signal in each subband.

$$\begin{aligned} \tilde{d}(Mk,l) &= x(Mk,l)\cdot\hat{G}(Mk,l) \\ &= \frac{x(Mk,l)}{\hat{H}(Mk,l)} \\ &= d(Mk,l) + \frac{N_B(Mk,l)}{\hat{H}(Mk,l)} \end{aligned} \tag{12}$$

It is worthy to mention that the proposed subband equalizer does not need to take into account the system delay due to transmission path as shown in Fig.5. This is because the proposed equalization scheme can be carried out in the frequency domain.

In addition, it is not necessary for the proposed architecture to transform the equalized signals from frequency-domain to time-one since OFDM system is carried out in the frequency-domain.

4. SIMULATION

In order to investigate the total performance under various channel conditions such as AWGN and 2-path Rayleigh fading channel, BER performance is evaluated in this section.

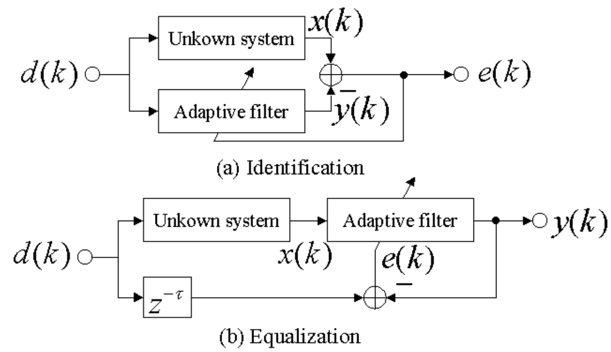

Fig. 5. System Identification and Equalizer

Length of source signal	2048×200
Modulation	16QAM-OFDM
FFT size (M)	2048
Number of Subcarriers	2048
Pilot Carrier	128
Guard Interval	128
Fading model	2-path Rayleigh fading, DUR = 5 dB, Delay = 10 sample

Table 1. simulation condition 1

4.1. Simulation 1

Table 1 shows simulation parameters. The simulation has been carried out under ideal synchronization. The channel is modeled with a 2-path Rayleigh channel. Moreover, pilot symbols are assumed to be inserted into OFDM symbol as shown in Fig.6.

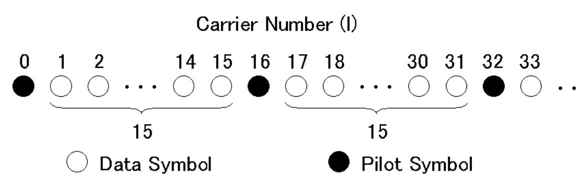

Fig. 6. pilot symbol

The comparison between BER with the proposed equalizer and without an equalizer is shown in Fig.7. The x-axis in Fig.7 is CNR (Carrier Noise Ratio) that is defined as follows.

$$\mathrm{CNR} = \frac{\sigma_x^2 \sum_{l=0}^{N-1} |H(Mk,l)|^2}{2N\sigma_n^2}, \tag{13}$$

where σ_x^2, σ_n^2 are variance of received signals, and variance of additional noise, respectively.

In Fig.7, it is clear that the BER performance is improved when the proposed equalizer is used.

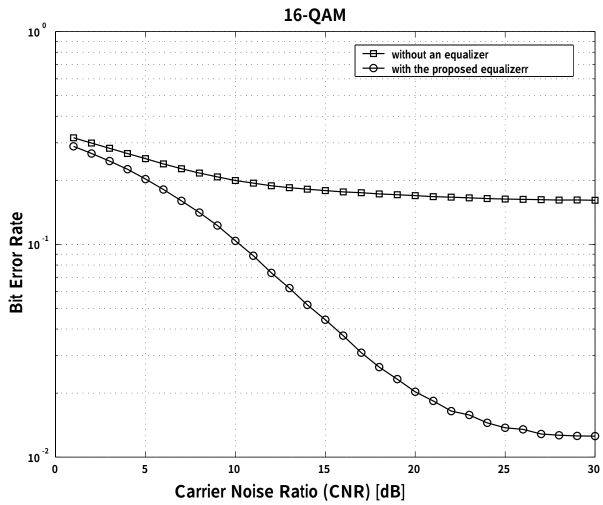

Fig. 7. BER performance on CNR

4.2. Simulation 2

Fading model	2-path Rayleigh fading, CNR = 5 dB, Delay = 10 sample

Table 2. simulation condition 2

Table 2 shows simulation parameters. The comparison between BER with the proposed equalizer and without an equalizer is shown in Fig.8. The x-axis of Fig.8 is DUR (Desired to Undesired Ratio). The simulation has been carried out under ideal synchronization. The channel model is non-minimum phase when DUR is negative.

In Fig.8, it is worthy to mention that the proposed equalizer works well even when DUR is negative which means the channel is non-minimum phase. This simulation result also confirms that the propose equalizer does not need any delays for non-minimum phase channels as discussed in Sec.3.4.

5. CONCLUSTION

In this report, a class of subband adaptive equalizer for OFDM system has been proposed. The proposed architecture has been derived from a DFT filter bank with critical sub-sampling. The computer simulations have been shown to verify the effectiveness of the proposed method.

The future work is to try simulation with the opposed equalizer in frequency selective fading channels.

6. REFERENCES

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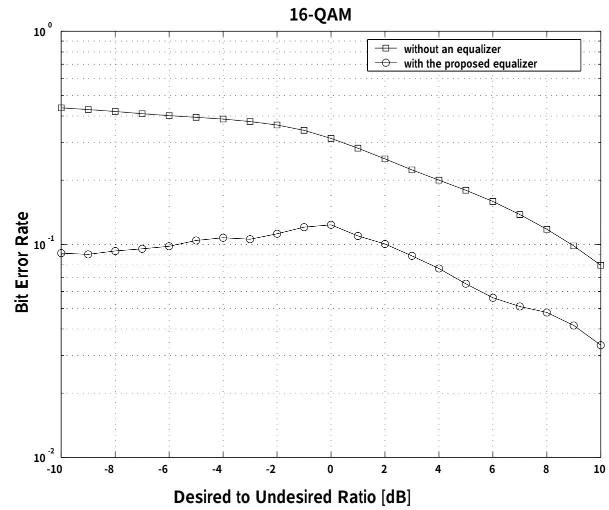

Fig. 8. BER performance on DUR

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