Iterative Extrapolation for Channel Equalization in DVB-T receivers

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ABSTRACT

This paper proposes an iterative extrapolation method to improve the channel-equalization performance in DVB-T receivers. The coefficients of a one-tap equalizer are conventionally obtained by inversing of the estimated channel coefficients. Inversion of the channel coefficients, however, requires an infinite gain and causes infinite noise enhancement at those frequencies corresponding to spectral nulls. To reduce the noise enhancement at spectral nulls, we smooth spectral null by iteratively extrapolating based on time-domain approach. Simulation results show that the proposed method improves the channel-equalization performance in terms of symbol error rates in DVB-T receivers at all SNRs.

Keywords: Noise Enhancement, Equalization, DVB-T, OFDM

1. INTRODUCTION

In Digital Video Broadcasting-Terrestrial (DVB-T), the European digital terrestrial television standard [1], Orthogonal Frequency Division Multiplexing (OFDM) has been adopted for signal transmission. In OFDM system, if the number of carriers is sufficiently large, the channel transfer function becomes virtually non-selective within the bandwidth of individual carriers. Focusing on one particular carrier, the influence of multi path fading is directly connected with attenuation and a phase distortion. In OFDM system, the guard interval is inserted at the transmitter to prevent possible inter-symbol interference (ISI). Assuming the orthogonality among the sub-carriers is maintained in the OFDM system and multi-path delay is less than the guard interval, a frequency domain one-tap equalizer could be used for each sub-channel to correct the amplitude and phase distortions [2-3]. Extensive research on OFDM channel equalization has already been carried out [3-5]. However, conventional equalizers such as zero-forcing (ZF) and Minimum Mean Square Error (MMSE) equalizers have some drawbacks. The coefficients of the one-tap ZF equalizers are obtained by inversing the estimated channel coefficients. In case that a channel has deep nulls, the equalization performance may suffer from the noise enhancement caused by an extremely large coefficient of the equalizer.

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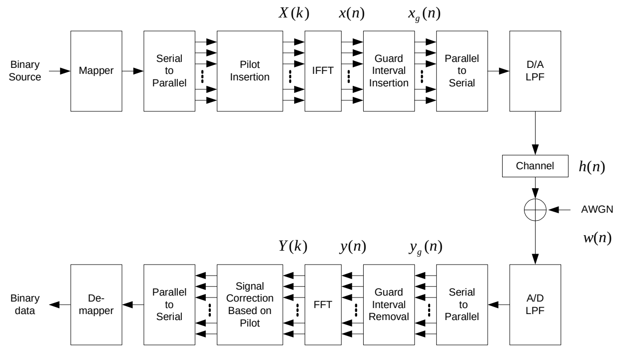

Fig.1: *Baseband model of the DVB-T system.*

MMSE equalizers can be used to avoid the noise enhancement but require previous knowledge of the system's noise variance and have a computational complexity [6]. In this paper, we overcome the noise enhancement of one-tap ZF equalizer by an iterative extrapolation method which makes deep nulls be mild.

This paper is organized as follows. In Section 2, the pilot-based OFDM system, channel estimation method, and the equalization problem are presented. Section 3 describes the proposed iterative extrapolation method for a one-tap equalizer in the OFDM system. Simulation results given in Section 4 show that the proposed method improve the SER (Symbol Error Rate) performance obtained after one-tap equalization, compared to the conventional equalization method in DVB-T receiver. Section 5 concludes the paper.

2. SYSTEM DESCRIPTION

2.1 Baseband model of a pilot-based OFDM system.

Fig.1 shows a baseband model of a typical pilot-based OFDM system [7]. The binary information data are grouped and mapped according to the modulation scheme such as 16 QAM (Quadrature Amplitude Modulation), 64 QAM. After pilot insertion, the modulated data are inputted to an IFFT (inverse fast Fourier transform) block and are transformed into time-domain signals. The guard interval is inserted to prevent possible ISI in OFDM systems using a cyclic prefix (CP) which contains a copy of the last part of the OFDM symbol. The transmitted signal is then passed a frequency selective multi-path fading channel with additive white Gaussian noise (AWGN). At the receiver, the guard interval is removed and the received samples are sent to an FFT block to demultiplex the multi-carrier signal. In OFDM transmission schemes, there are two major types of pilot arrangement. The first kind is referred to a block-type. The pilot signal is assigned to a particular OFDM symbol, which is sent periodically in time domain. The second one is a comb-type. The pilot signals are uniformly distributed within each OFDM symbol. Since only some sub-carriers contain the pilots, the channel response corresponding to non-pilot sub-carriers will be estimated by interpolating neighboring pilot sub-channels [7].

2.2 Channel Estimation in DVB-T system.

In the DVB-T system, pilot cells are inserted every four OFDM symbols at the same position and are uniformly distributed every twelve sub-carriers within each OFDM symbol. Hence the pilot pattern in DVB-T has the propensity of both the block-type and the comb-type. To estimate the channel coefficients, we adopted the pilot-insertion type approximation in four consecutive OFDM symbols, which construct one block with the same channel coefficients at the same pilot positions and block-based channel estimation scheme [8]. When the duration of the channel impulse response is shorter than the guard interval, there is no ISI. Assuming also that there is no synchronization error, their relationship between $Y_p(k)$, $X_p(k)$ and the channel transfer function at the pilot frequencies $H_p(k)$ can be formulated as:

$$Y_p(k) = H_p(k) \cdot X_p(k) + W_p(k), \qquad (1)$$

where $W_p(k)$ is AWGN for the *k*-th sub-carrier after FFT [9] and the subscript *p* denotes a pilot. For the pilot sub-carriers, the transmitted information $X_p(k)$ is known to the receiver. Therefore, the frequency response of the channel at the pilot frequencies can be estimated simply using:

$$\hat{H}_p(k) = \frac{Y_p(k)}{X_p(k)} = H_p(k) + W_p'(k), \qquad (2)$$

where $W_p'(k)$ is the noise effect existing at the estimated channel coefficients. Channel estimation scheme in (2) is based on the Least Square (LS) method [10]. In order to estimate the channel coefficients at data sub-carriers, the channel information at pilot frequencies is used for interpolation. In this paper, we consider a piecewise linear interpolation method [11]. The formula of the piecewise linear interpolation is given as:

$$h_{Lin}(x) = \begin{cases} 1-|x|, & 0 \le |x| < 1 \\ 0, & \text{elsewhere} \end{cases} \qquad (3)$$

After interpolation, we can obtain all channel coefficients $\hat{H}(k)$.

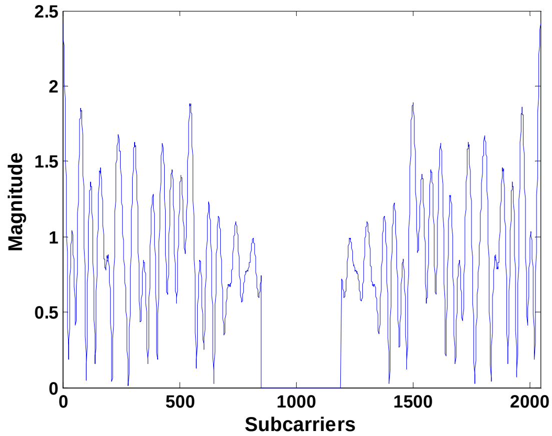

Fig.2: *Block Estimated channel coefficients in the DVB-T receiver with guard band.*

2.3 Equalization Problem.

Let $h(n)$ be the channel impulse response and $H(k)$ its Fourier transform, i.e., the channel transfer function. If the number of carriers is sufficiently large, the channel transfer function becomes virtually non-selective within the bandwidth of individual carriers. Focusing on one particular carrier, the influence of multi-path fading reduces to attenuation and a phase rotation. For an OFDM system, assuming a multi-path delay is less than the guard interval, a frequency domain one-tap equalizer could be used for each sub-channel to correct the amplitude and phase distortions [2-3]. The inversion of the estimated channel coefficients are used for one-tap equalizer coefficients. This inversion scheme is based on the zero-forcing (ZF) criterion [12] which aims at cancelling ISI regardless of the noise level. The ZF criterion, however, does not have a solution if the channel transfer function has spectral nulls in the signal bandwidth. Inversion of the channel transfer function requires an infinite gain and leads to infinite noise enhancement at those frequencies corresponding to spectral nulls.

3. ITERATIVE EXTRAPOLATION METHOD

As described in the previous section, the one-tap equalizer may cause noise enhancement when deep nulls exist in the channel frequency response, resulting system performance degradation. We show one example of the

Table 1: *Multi-path Profile (Brazil channel D)*

Delay (μs)	Amplitude (dB)
0.0	-0.1
+0.48	-3.9
+2.07	-2.6
+2.90	-1.3
+5.71	0.0
+5.78	-2.8

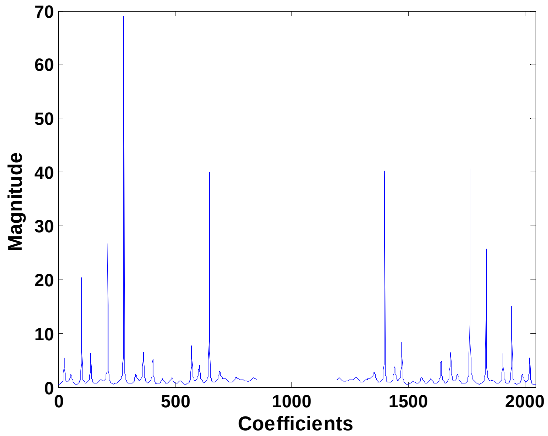

Fig.3: *Coefficients of the equalizer in the DVB-T receiver.*

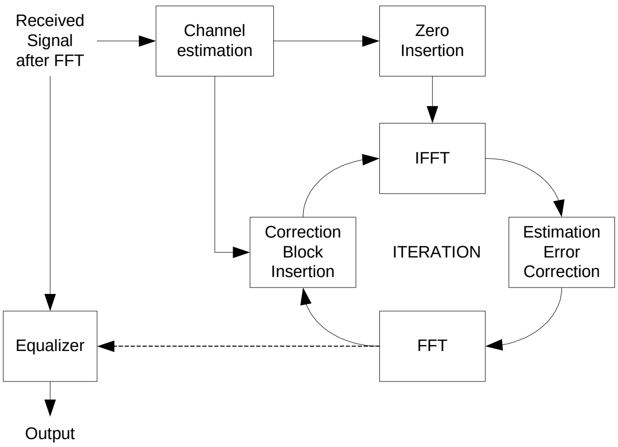

Fig.4: *Block diagram of the proposed method.*

noise enhancement case through computer simulation. The channel profile used for this simulation was "Brazil channel D," which is the indoor channel used for the Laboratory Test in Brazil [13]. The channel information is given in Table 1.

Fig. 2 shows the estimated channel coefficients in a DVB-T receiver with the guard band. DVB-T mode is 2K and the constellation scheme is 16 QAM. As shown in Fig.2, there exist deep spectral nulls. Fig. 3 shows the coefficients of the equalizer, which has very large coefficients at those frequencies corresponding to spectral nulls. These large coefficients cause noise enhancement and thus degrade the system performance. To compensate the noise enhancement and improve the equalization performance, we use an iteratively extrapolating method based on time-domain approach to make deep nulls be mild.

Fig. 4 shows a block diagram of the proposed extrapolation method. First, we estimate channel coefficients using the received signal after FFT. Then, zeros are inserted in the guard band as the same procedure at the transmitter. In an IFFT block, estimated channel coefficients with the inserted zeros $\hat{H}_Z(k)$, are transformed into time-domain coefficients $\hat{h}(n)$. Fig. 5(a)

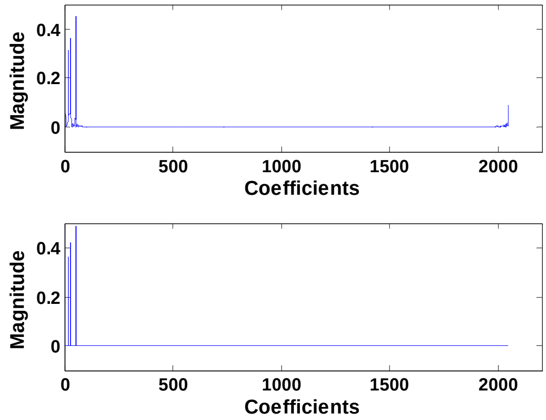

Fig.5: *Channel impulse response. (a) Estimated channel impulse response. (b) Original channel impulse response.*

and (b) show the estimated channel impulse response and the original channel response, respectively. Comparing Fig. 5(a) with (b), some residual coefficients are appeared at the end of the estimated channel impulse response. Since it is desirable that those coefficients should be minimized for the precise channel estimation, we remove them at the estimation-error-correction block. After the error correction, modified coefficients are sent to the FFT block to be transformed into frequency-domain coefficients. Through these procedures, we can get new coefficients. At the next iteration, we also use the estimated channel coefficients in the in-band but insert the new coefficients obtained by the first iteration instead of zeros in the guard band. Through these iterative procedures, we can make the spectral nulls in the channel transfer function be mild. The coefficients of the one-tap equalizer, therefore, are smaller than those of conventional equalizers. These small coefficients reduce noise and lead to the improvement of equalization performance.

4. SIMULATION RESULTS

We performe1d computer simulations to verify the performance of the proposed method applied to the DVB-T system. The channel profile was "Brazil channel D" the same as in section 3.

DVB-T system parameters used in the simulation are shown in Table 2. We assumed that there were no synchronization error and no Doppler spread since the purpose of the proposed method lies in enhancing the

Table 2: *Simulation Parameters*

Parameters	Specifications
DVB-T mode	2K
Number of carriers	1705
OFDM symbol duration	224 μs
Guard Interval	1/4 (512)
Signal Constellation	16 QAM
Channel Model	Brazil channel D

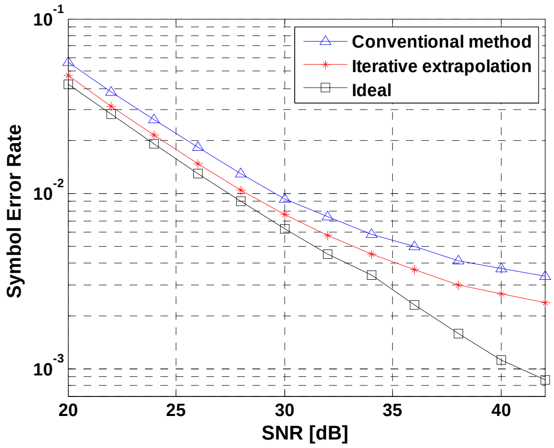

Fig.6: *SER performance of the proposed equalization method.*

performance of the channel equalization. We did not apply any channel coding scheme. DVB-T mode was decided to fix onto the 2K and 8 MHz derivative of the standard. Moreover, we chose the guard interval to be greater than the maximum delay spread in order to avoid ISI. Transmitted data were mapped based on 16 QAM. We used the piecewise linear interpolation for channel estimation. The length of the interpolation filter was 7.

Fig. 6 is the SER curves of the channel equalization with and without the proposed method. The legends of "Conventional method" and "Ideal" denote the equalizer with the coefficients obtained by inverting the estimated channel coefficients and that with the ideal channel coefficients, respectively. The iteration number for the iterative extrapolation was 10. We can verify that the proposed method improves the SER performance of the conventional equalizer at all signal-to-noise ratios (SNRs). The performance improvement is remarkable at high SNRs.

5. CONCLUSION

We proposed an iterative extrapolation method for channel equalization in DVB-T receivers. The proposed method improved the channel equalization performance effectively at all SNR conditions in terms of the SER by smoothing deep nulls of severe channels. The proposed method is expected to contribute to the performance improvement of channel-equalization in any OFDM systems operating under slow-fading channels.

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