Further Results on Channel Estimation Based on Weighted Moving Average in T-DMB Receivers

Sung Ik Park and Heung Mook Kim
Broadcasting System Research Department
Electronics and Telecommunications Research Institute
Daejeon, South Korea
{psi76, hmkim}@etri.re.kr

Jin-Ho Chung
School of Electrical and Computer Engineering
Ulsan National Institute of Science and Technology
Ulsan, South Korea
jinho@unist.ac.kr

Jeongchang Kim
Dept. of Electronics and Communications Engineering
Korea Maritime University
Busan, South Korea
jchkim@hhu.ac.kr

***Abstract*—In this paper, we describe novel channel estimation schemes for terrestrial digital multimedia broadcasting (T-DMB) receivers and present further results on their performance under fading channels. In order to improve the performance, novel channel estimation schemes utilize the weighted moving average. Numerical results show that the novel channel estimation schemes outperform the conventional scheme with approximately 2~3dB in the symbol error rate performance under fading channels.**

Keywords-Channel estimation; moving average; orthogonal frequency division multiplexing (OFDM); T-DMB.

I. INTRODUCTION

In South Korea, the mobile broadcasting standard for the terrestrial digital multimedia broadcasting (T-DMB) is based on the Eureka-147 digital audio broadcasting (DAB) system [1]. In the T-DMB system, the orthogonal frequency division multiplexing (OFDM) is used for signal transmission [2][3]. The T-DMB system supports the broadcasting of moving pictures and their reception in harsh conditions such as places surrounded by high-rise buildings and highways where vehicles are moving at very high speed.

Recently, a coherent detection method has been developed to improve the reception performance of T-DMB receivers [4]. For the coherent detection, a one-tap equalizer in the frequency domain is used. The tap coefficients of the equalizer are obtained by estimating channel distortions and calculating the inverse of the estimated channel coefficients. However, the inverse of the channel coefficients can result in severe noise enhancement under deep fading channels.

In order to reduce the noise enhancement, several novel channel estimation schemes utilizing the weighted moving average were proposed in [3]. In this paper, we describe novel channel estimation schemes for T-DMB receivers and present further results on their performance under fading channels.

This paper is organized as follows. In Section II, the system model of the T-DMB system is presented. Section III describes the considered channel estimation schemes and numerical results are shown in Section IV. Finally, conclusions are drawn in Section V.

II. SYSTEM MODEL

In this section, we describe a system model for T-DMB systems. At the transmitter, binary bits are input and mapped into modulation symbols. After pilot insertion, the modulated signal $X[k]$ is input to an inverse fast Fourier transform (IFFT) block and transformed into time-domain signals. The cyclic prefix (CP) is inserted to prevent possible inter-symbol interference (ISI) between adjacent OFDM systems where a copy of the last part of the OFDM symbol is transmitted. The transmitted signal passes through the fading channel with additive white Gaussian noise (AWGN).

At the receiver, the CP is removed and the pilot based signal correction is performed after FFT [5]. There are two typical pilot patterns of the OFDM transmission systems [6]. For the block-type pilot pattern, the pilot signal is assigned to the specified OFDM symbols. Since the pilot signals are periodically sent in the time domain, the block-type pilot pattern is suitable to slow fading channels. For the comb-type pilot pattern, on the other hand, the pilot signals are uniformly distributed in the frequency domain for each OFDM symbol. Hence, the comb-type pilot pattern is suitable to fast fading channels. However, since the pilot signals are carried on the limited number of subcarriers, the channel state information for the data subcarriers should be estimated by interpolating with neighboring pilot subcarriers. As a result, the channel estimation performance with the comb-type pilot pattern is affected by the interpolation methods [8]. In the T-DMB system, the pilot signals are inserted at the fixed position in every 76 OFDM symbols. Hence, the pilot pattern in the T-DMB has the propensity of the block-type.

ISBN: 978-1-61208-284-4

III. CHANNEL ESTIMATION SCHEMES

The channel estimation of the T-DMB system consists of two stages. First, the received pilot signals are extracted from the pilot subcarriers. Next, the channel coefficients are obtained by comparing the received pilot signals with the known pilot signals. The received pilot signals $Y_p[k]$ are extracted from the received signals $Y[k]$ after FFT, and the reference channel coefficients for the equalizer are estimated in the frequency domain by comparing the extracted pilot signals $Y_p[k]$ and the known pilot signals $S_p[k]$.

Assuming the perfect synchronization, the received pilot signals $Y_p[k]$ can be written as $Y_p[k] = H[k] \cdot S_p[k] + W[k]$ where $H[k]$ denotes the channel transfer function, and $W[k]$ is the AWGN for the *k*-th pilot subcarrier after FFT. Also, we assume that the transmitted pilot signal $S_p[k]$ is known to the receiver. Therefore, the frequency response of the channel on the *k*-th pilot subcarrier, $\hat{H}[k]$, can be simply estimated as $\hat{H}[k] = Y_p[k] / S_p[k] = H[k] + \tilde{W}[k]$ where $\tilde{W}[k] = W[k] / S_p[k]$. The channel estimation scheme is based on the least square method [7].

Since the tap coefficients of the equalizer are obtained by calculating the inverse of the estimated channel coefficients, the severe noise enhancement is induced under deep fading channels. In order to reduce the noise enhancement, we adopt novel channel estimation schemes based on the *M*-point weighted moving average [3].

Let $\hat{H}_{\mathrm{w}}[k]$ be the estimated channel coefficients after the *M*-point weighted moving average at the *k*-th pilot subcarrier of the OFDM symbol. Then, $\hat{H}_{\mathrm{w}}[k]$ can be obtained as

$$\begin{aligned} \hat{H}_{\mathrm{w}}(k) &= \frac{1}{M} \sum_{j=-(M-1)/2}^{(M-1)/2} w_j \hat{H}[k+j] \\ &= \frac{1}{M} \sum_{j=-(M-1)/2}^{(M-1)/2} w_j \left\{ H(k+j) + \tilde{W}(k+j) \right\} \end{aligned} \tag{1}$$

where *M* is odd number and w_j is the *j*-th weight for moving average [3].

In this paper, six weighted moving average schemes of [3] are considered. The considered weighting values of the respective schemes are given in Table I. The quadratic, cubic, and Lagrange weighting values are derived from the quadratic, 4-point cubic, 4-point Lagrange interpolation filters, respectively [8]. Note that the variance of the equivalent noise term in (1) can be computed as

$$\frac{\sigma^2}{M} \left(\sum_{j=-(M-1)/2}^{(M-1)/2} w_j^2 \right). \tag{2}$$

Hence, the variance of the noise decreases with the increasing value of *M*. However, channel coefficients $\hat{H}[k]$ used in the weighted moving average can be severely varied due to the channel variation. This results in the distortion of the estimated channel response and thus, the performance degradation. Therefore, it is required to determine the average number of points by considering the trade-off between the accuracy of estimated channel coefficients and the noise reduction. Note that the considered moving average schemes are performed after the channel estimation.

TABLE I. WEIGHTS FOR MOVING AVERAGE [3]

Schemes	**Weight values**
Moving average (MA)	$w_j = 1, \ \lvert j \rvert \le (M-1)/2$
Selective MA	$w_j = \begin{cases} 0, & j = \arg\min\limits_j \lvert \hat{H}(k+j) \rvert \\ & \text{or } j = \arg\max\limits_j \lvert \hat{H}(k+j) \rvert, \ \lvert j \rvert \le (M-1)/2 \\ 1, & \text{otherwise} \end{cases}$
Linear weighted MA	$w_j = 1 - \left\lvert \frac{2j}{M+1} \right\rvert, \ \lvert j \rvert \le (M-1)/2$
Quadratic weighted MA	$w_j = \begin{cases} -18 \left\lvert \frac{j}{M+1} \right\rvert^2 + 1, & \lvert j \rvert < \frac{M+1}{6} \\ 9 \left\lvert \frac{j}{M+1} \right\rvert^2 - \frac{15}{2} \left\lvert \frac{j}{M+1} \right\rvert + \frac{3}{2}, & \frac{M+1}{6} \le \lvert j \rvert < \frac{M+1}{2} \end{cases}$
Cubic weighted MA	$w_j = \begin{cases} 96 \left\lvert \frac{j}{M+1} \right\rvert^3 - 40 \left\lvert \frac{j}{M+1} \right\rvert^2 + 1, \quad \lvert j \rvert < (M+1)/4 \\ -32 \left\lvert \frac{j}{M+1} \right\rvert^3 + 40 \left\lvert \frac{j}{M+1} \right\rvert^2 - 16 \left\lvert \frac{j}{M+1} \right\rvert + 2, \\ \qquad (M+1)/4 \le \lvert j \rvert < (M+1)/2 \end{cases}$
Lagrange weighted MA	$w_j = \begin{cases} 32 \left\lvert \frac{j}{M+1} \right\rvert^3 - 16 \left\lvert \frac{j}{M+1} \right\rvert^2 - 2 \left\lvert \frac{j}{M+1} \right\rvert + 1, \\ \qquad \lvert j \rvert < (M+1)/4 \\ -\frac{32}{3} \left\lvert \frac{j}{M+1} \right\rvert^3 + 16 \left\lvert \frac{j}{M+1} \right\rvert^2 - \frac{22}{3} \left\lvert \frac{j}{M+1} \right\rvert + 1, \\ \qquad (M+1)/4 \le \lvert j \rvert < (M+1)/2 \end{cases}$

IV. NUMERICAL RESULTS

In this paper, we present further results on the performance of the novel channel estimation schemes for T-DMB systems under fading channels via computer simulation. The channel model used for the simulations is Brazil Channel A [9]. Note that the Brazil channel A founded by the laboratory test in Brazil, represents the outdoor channel and is widely used in simulations for terrestrial digital television systems. We assume the perfect synchronization and known pilot signals at the receiver. We compare performances of the weighted moving average and conventional schemes. The T-DMB system is modeled based on transmission mode I of the Eureka-147 DAB system without any error correction coding scheme. Since the elementary symbol period T is $0.48828\mu\text{s}$ $(=1/2048\,\text{ms})$ for the sampling frequency of 2.048 MHz [1], the maximum delay of Brazil Channel A corresponds to about 12 elementary symbols. Note that the number of subcarriers, subcarrier spacing, OFDM symbol duration, and CP duration are 1536, 1kHz, $2551\cdot T$ (≈1.246 ms), and $504\cdot T$ (≈246 μs), respectively.

The performance measure considered in this paper is the symbol error rate (SER) after one-tap equalization with the inverse of estimated channel coefficients. The transmitted signals are mapped with π/4 differential quadrature phase shift keying (π/4-DQPSK) constellations. Fig. 1 shows the SER performance of the weighted moving average and conventional channel estimation schemes under Brazil Channel A with 10 Hz Doppler. As shown in Fig. 1, the weighted moving average schemes outperform the conventional scheme with approximately 2~3 dB under the fading channel. Note that the performances of MA, selective MA, linear weighted MA, and quadratic weighted MA schemes are similar. Compared to MA, selective MA, linear weighted MA, and quadratic weighted MA schemes, the performances of the cubic and Lagrange weight MA schemes are degraded due to the estimation error.

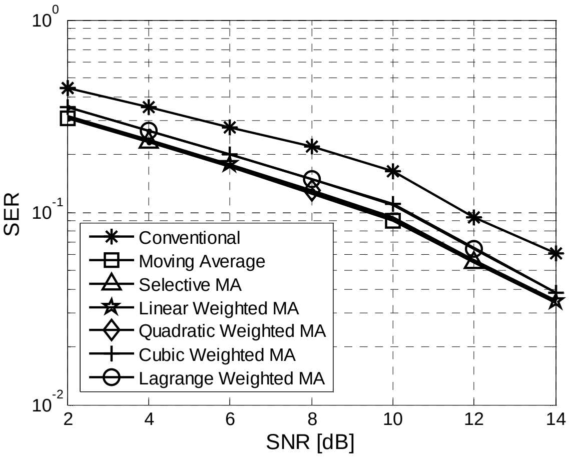

Figure 1. SER performance after equalization under Brazil Channel A with 10Hz Doppler

According to (1), the weighted moving average scheme requires M multiplications and $(M-1)$ additions. As shown in Table I, since the weight values of five schemes except for the selective MA scheme can be precalculated and stored for a given M, the complexity for weight values can be negligible. Also, for MA and selective MA schemes, since the weight values are one and zero, the multiplication is not required. Therefore, MA and selective MA schemes outperform the cubic and Lagrange weight MA schemes with the reduced complexity. Note that the comparison test for the estimated channel coefficients is additionally required for the selective MA scheme.

Note that the noise enhancement can be decreased with increasing number of points used for averaging. However, the accuracy of the channel estimation can be degraded with the large number of points for averaging due to the channel variation.

V. CONCLUSIONS

In this paper, we described novel channel estimation schemes based on the weighted moving average in order to improve the channel estimation performance in T-DMB receivers. The channel estimation schemes based on the weighted moving average outperform the conventional scheme with approximately 2-3 dB in SER performance after equalization under fading channels. Also, the channel estimation schemes with weighted moving average are expected to contribute to the performance improvement of the channel estimation in any OFDM systems.

Also, we are studying to further improve the channel estimation performance and reduce the complexity of the channels estimation by developing new interpolation schemes and optimizing the size of the moving window. Unfortunately, the Brazil A channel is the multipath profile for the static environment. Hence, we will use the well-known TU6 multipath channel [10] in order to consider a mobile environment in the urban area. Also, in this paper, the size of the moving window was not optimized for a mobile channel but was set to be values for static channels. Under a high speed mobile channel, since the channel is rapidly varied, the size of the moving window should be optimized.

ACKNOWLEDGMENT

This research was supported by the Ministry of Science, ICT and Future Planning, Rep. of Korea, under the support program supervised by the Korea Communications Agency (KCA) (Development of Terrestrial Broadcasting Technology for Next Generation DTV).

REFERENCES

[1] ETSI, "Radio broadcasting systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers," ETSI EN 300 401 v1.3.3, Sept. 2001.

[2] G. Lee, S. Cho, K.-T. Yang, Y. K. Hahm, and S. I. Lee, "Development of terrestrial DMB transmission system based on Eureka-147 DAB systems," IEEE Trans. Consumer Electron., vol. 51, no. 1, Feb. 2005, pp. 63-68.

[3] S. I. Park, J. Y. Lee, H. Lim, H. M. Kim, H. Kim, and J. S. Lim, "A novel channel estimation in T-DMB receivers," in Proc. of IEEE Wireless Communications and Networking Conference (WCNC), 2007, pp. 237-241.

[4] L. Thibault, D. Taylor, L. Zhang, J. Y. Chouinard, and R. Boudreau, "Advanced demodulation technique for COFDM in fast fading channels," International Broadcasting Convention, 2003, pp. 416-422.

[5] A. A. Hutter, R. Hasholzner, and J.S. Hammerschmidt, "Channel estimation for mobile OFDM systems," in Proc. of IEEE Vehicular Technology Conference, Amsterdam, Netherlands, Sept. 1999, pp. 305-309.

[6] Y. Zhao and A. Huang, "A novel channel estimation method for OFDM mobile communication systems based on pilot signals and transform-domain processing," in Proc. of IEEE 47th Vehicular Technology Conference, vol. 3, May. 1997, pp. 2089-2093.

[7] X. Wang, Y. Wu, J.-Y. Chouinard, S. Lu, and B. Caron, "A channel characterization technique using frequency domain

pilot time domain correlation method for DVB-T systems," IEEE Trans. Consumer Electron., vol. 49, Nov. 2003, pp. 949-957.

[8] T. M. Lehmann, C. Conner, and K. Spitzer, "Survey: Interpolation methods in medical image processing," IEEE Trans. Medical Imaging, vol. 18, no. 11, Nov. 1999, pp. 1049-1075.

[9] Mackenzie, ABERT/SET Group, "General description of laboratory tests," DTV Field Test Report in Brazil, July 2000.

[10] COST207, "Digital land mobile radio communications (final report)," Commission of the European Communities, Directorate General Telecommunications, Information Industries and Innovation, 1989, pp. 135–147.