Decision feedback channel estimation without prior knowledge of terminal mobility for SC-FDE

Atsuya Nakamura, Yukiko Shimbo, Shuhei Saito, Hirofumi Suganuma, and Fumiaki Maehara

Graduate School of Fundamental Science and Engineering, Waseda University, 3-4-1 Ohkubo, Shinjuku-ku, Tokyo 169-8555, Japan
a) fumiaki.m@waseda.jp

Abstract: An adaptive decision feedback channel estimation (DFCE) scheme using likelihood value comparisons in single-carrier frequency-domain equalization (SC-FDE) is presented here. Previously, we proposed a DFCE scheme for SC-FDE that realizes adaptive tracking of the channel variations with prior knowledge of the terminal mobilities obtained from moving speed information. However, the adaptive tracking method requires determination of an appropriate forgetting factor of the DFCE using the terminal speed information at the receiver. Thus, in this study, we adaptively control an appropriate forgetting factor that corresponds with the channel variations of the DFCE scheme without prior knowledge of the terminal speed. The novelty of the proposed approach is that the likelihood values for different forgetting factors are calculated from the forward error correction (FEC) decoding results, and the appropriate forgetting factor is then chosen by comparing the likelihood values to adjust to either noise-dominant or time-selectivity-dominant channel. The effectiveness of the proposed scheme is further demonstrated via computer simulations by comparisons with the traditional DFCE using the terminal speed information.

Keywords: single-carrier frequency-domain equalization (SC-FDE), time selective fading, decision feedback channel estimation (DFCE), forgetting factor, forward error correction (FEC)

Classification: Wireless Communication Technologies

References

[1] D. Falconer, S.L. Ariyavisitakul, A. Benyamin-Seeyar, and B. Eidson, “Frequency-domain equalization for single-carrier broadband wireless systems,” IEEE Commun. Mag., vol. 40, no. 4, pp. 58–66, Apr. 2002.
[2] N. Benvenuto, R. Dinis, D. Falconer, and S. Tomasin, “Single carrier modulation with nonlinear frequency domain equalization: An idea whose time has come—again,” Proc. IEEE, vol. 98, no. 1, pp. 69–96, Jan. 2010.
[3] F. Maehara, S. Goto, and F. Takahata, “Periodic spectrum transmission for single-carrier transmission frequency-domain equalization,” IEICE Trans. Commun., vol. E90-B, no. 6, pp. 1407–1414, June 2007.
[4] 3GPP TS 36.201 v8.1.0, “Evolved universal terrestrial radio access (E-UTRA); LTE physical layer-general description,” Nov. 2007.
1 Introduction

Single-carrier frequency-domain equalization (SC-FDE) is a promising technique for achieving high data-rate transmission, bandwidth efficiency, and mitigation of the effects of multipath fading, while reducing the peak-to-average transmitted power ratio (PAPR) [1, 2, 3]. Therefore, SC-FDE has already been adopted into uplink communications in recent mobile communication systems, such as 3GPP Long Term Evolution (LTE) or Evolved UTRA (E-UTRA) [4], and continues to be an attractive choice for next-generation 5G wireless communication systems [5, 6]. This is because the lower PAPR endows the mobile terminals with benefits, such as high transmit power efficiency and cost reduction for power amplifiers, which are especially important in millimeter-wave broadband communications [5, 6].

In the application of SC-FDE to mobile communications, it is essential to have robustness against time-selective fading channels owing to the terminal mobilities. This is because the time-selective fading channels generally degrade the bit error rate (BER) performances. Hence, decision feedback channel estimation (DFCE) is an attractive approach because its effectiveness has already been well verified and established in orthogonal frequency-division multiplexing (OFDM) [7, 8]. However, because mobile terminals are often surrounded by a wide range of time-selectivities, a forgetting factor that determines the tracking capability of the DFCE is expected to adaptively adjust to the actual channel conditions, which are categorized into noise-dominant and time-selectivity-dominant channels. Previously, we proposed an adaptive DFCE scheme for SC-FDE, which enabled adjustment of the actual channel conditions using the knowledge of the terminal speed [9]. Specifi-
cally, this scheme theoretically derives the effects of noise and time-selective fading using the terminal speed knowledge and then sets a forgetting factor according to the actual channel conditions. However, this method requires the acquisition of terminal speed information at the receiver.

Considering this background, we propose a DFCE scheme for SC-FDE that realizes adaptive tracking of the channel variations without knowledge of the terminal speed. In the proposed approach, we first examine different forgetting factors for either the noise-dominant or time-selectivity-dominant channel and then calculate the likelihood values for these factors from the forward error correction (FEC) decoding results [10]. To determine the appropriate forgetting factor, we compare these likelihood values to adjust them to the actual channel conditions. The effectiveness of the proposed scheme is demonstrated via computer simulations by comparisons with the traditional DFCE with terminal speed information.

2 Proposed method

2.1 System concept

Fig. 1(a) shows the system configuration for SC-FDE. At the transmitter, the coded bits are modulated according to an arbitrary modulation scheme, and the guard interval (GI) is added to the modulated signals to prevent inter-block interference (IBI). At the receiver, the obtained signals are converted to frequency-domain signals by fast Fourier transform (FFT) processing after removing the GI, and the minimum mean-square error (MMSE) equalization is performed for each subchannel. Moreover, the inverse fast Fourier transform (IFFT) is performed to obtain the time-domain signals, and channel decoding is used to correct the communication errors. Because SC-FDE reduces the PAPR compared with OFDM, SC-FDE is suitable for uplink communications in broadband mobile networks. Moreover, considering mobile communications, countermeasures are required for time-selective as well as frequency-selective fading. Thus, DFCE is a promising technique because it can be adopted as a countermeasure to time-selective fading in OFDM [7, 8].

In a previous work, we proposed an adaptive DFCE scheme for SC-FDE, where an appropriate forgetting factor is used to adjust to the actual channel conditions using knowledge of the terminal speed [9]. Fig. 1(b) shows the concept of DFCE using terminal speed information. As shown in Fig. 1(b), mobile terminals are often locally subject to different channel conditions; hence, appropriate forgetting factors are determined according to the conditions, such as noise-dominant and time-selectivity-dominant channels, to enhance the effectiveness of DFCE. In addition, Fig. 1(c) shows the basic concept of DFCE, where the initial channel estimate on the pilot symbols is consecutively updated with that of the data symbols via a decision feedback mechanism. Here, it should be noted that tracking the channel variations requires the channel estimates at each subchannel to be smoothed with the forgetting factor $\lambda$ in the time direction [9]. First, the transmit signal replica is generated from the previous channel estimate $\hat{H}_{m-1}(k)$, and the current channel estimate replica $\hat{H}_m(k)$ is calculated. Specifically, owing to low-speed movements in the noise-dominant channel, $\lambda_{\text{low}}$ is chosen such that proper noise suppression is achieved rather than tracking the channel variations; further, owing to high-speed
(c) Basic concept of DFCE

Fig. 1. Adaptive DFCE scheme for SC-FDE.

movements in the time-selectivity-dominant channel, $\lambda_{\text{high}}$ is chosen to achieve appropriate tracking of the channel variations. Then, the current channel estimate $\hat{H}_m(k)$ is calculated and updated as

$$\hat{H}_m(k) = \lambda \hat{H}_m(k) + (1 - \lambda) \hat{H}_{m-1}(k).$$

(1)

In this work, we propose a forgetting factor control for the DFCE scheme without information about the terminal mobility.

2.2 DFCE scheme without prior knowledge of terminal mobility

Fig. 2 shows the system configuration of the proposed method. As shown in Fig. 2, the previous channel estimates $\hat{H}_{m-1, \text{low}}(k)$ and $\hat{H}_{m-1, \text{high}}(k)$ are first calculated us-
ing two different forgetting factors, $\lambda_{\text{low}}$ and $\lambda_{\text{high}}$, respectively. Next, after applying FDE to the received signal $R_m(k)$ using $H_{m-1,\text{low}}(k)$ and $H_{m-1,\text{high}}(k)$, channel decoding is performed to obtain the average absolute values of the log-likelihood ratio (LLR) [11], namely $\bar{L}_{m,\text{low}}$ and $\bar{L}_{m,\text{high}}$, which correspond to the decoding results $d_{m,\text{low}}$ and $d_{m,\text{high}}$, respectively. Then, by comparisons with $\bar{L}_{m,\text{low}}$ and $\bar{L}_{m,\text{high}}$ at each block, and the decoding results $d_m$ and previous channel estimate $\bar{H}_{m-1}(k)$ corresponding to the higher absolute value of LLR are adopted as follows:

$$d_m = \begin{cases} d_{m,\text{low}} & (\bar{L}_{m,\text{low}} > \bar{L}_{m,\text{high}}) \\ d_{m,\text{high}} & (\bar{L}_{m,\text{low}} < \bar{L}_{m,\text{high}}) \end{cases},$$

$$\bar{H}_{m-1}(k) = \begin{cases} H_{m-1,\text{low}}(k) & (\bar{L}_{m,\text{low}} > \bar{L}_{m,\text{high}}) \\ H_{m-1,\text{high}}(k) & (\bar{L}_{m,\text{low}} < \bar{L}_{m,\text{high}}) \end{cases}.$$  

Furthermore, the current channel estimate replica $\bar{H}_m(k)$ is calculated from the transmit signal replica $\bar{S}_m(k)$ generated by the decoded data $d_m$, and the smoothed channel estimates $\bar{H}_{m,\text{low}}(k)$ and $\bar{H}_{m,\text{high}}(k)$ are updated using $\lambda_{\text{low}}$ and $\lambda_{\text{high}}$, respectively, based on Eq. (1). By performing the above operations for each block, the proposed method appropriately tracks the channel variations without using terminal speed information.

### 3 Numerical results

In this section, we present the effectiveness of the proposed method in comparison with the general DFCE with a fixed forgetting factor and the traditional DFCE with terminal speed information obtained from computer simulations. In the performance evaluations, turbo coding and Max-Log-MAP decoding with coding rates of $R = 1/2$ and 7 iterations, respectively, are assumed as the FEC schemes. The FFT size $N_F$ is set to 256, and a 16-ray exponentially decaying model is assumed as the radio channel model, where the path separation is set to the sampling period $T_{\text{sam}}$, and the amplitude and phase of each ray are characterized by the Rayleigh and uniform distributions, respectively. Furthermore, the delay spread $\tau_{\text{rms}}$ is set to 4.0$T_{\text{sam}}$. It is noted that the duration of the GI $T_G$ is longer than the channel maximum delay; therefore, there is no effect of the IBI. Since the actual propagation channel is a mixture of noise and time-selective fading channels, the forgetting factor must be set by considering the effects of noise even in strong time-selective fading channels. Therefore, this scheme adopts the forgetting factors $\lambda_{\text{low}} = 0.2$
Fig. 3. BER performance versus average CNR.

and $\lambda_{\text{high}} = 0.8$ for the noise-dominant and time-selectivity-dominant channels, respectively, for which the tracking capabilities were proven in [9]. The performance evaluations are carried out with a Doppler frequency parameter normalized by the frame length $T_F$ consisting of 2 pilot and 20 data blocks. In addition, to improve the accuracy of DFCE, the proposed method utilizes the modified least squares (LS) channel estimation [12].

Fig. 3 shows the relationship between the BER performance and the average carrier-to-noise ratio (CNR) of the proposed scheme, where 16QAM is assumed as the modulation scheme. In Fig. 3, the performances of the general DFCE with a fixed forgetting factor and traditional DFCE with knowledge of the terminal speed [9] are shown for reference. It should be noted that the normalized maximum Doppler frequencies $f_{D,T} = 1.0 \times 10^{-2}$ and $1.0 \times 10^{-1}$ correspond to the noise-dominant and time-selectivity-dominant channels, respectively. It is observed from Fig. 3(a) that the proposed scheme provides almost the same BER as the general DFCE with $\lambda = 0.2$ or traditional DFCE with knowledge of the terminal speed, while prioritizing the noise suppression capability in the noise-dominant channel. In contrast, it is found from Fig. 3(b) that the proposed scheme allows adaptive tracking or improvement of the BER compared with the traditional DFCE. This is because the proposed scheme can hold the tracking capability of channel variations appropriately by comparisons with the LLR values of the two different forgetting factors.

4 Conclusion

In this paper, we proposed a DFCE scheme for SC-FDE without prior knowledge of the terminal mobility. In the proposed approach, the tracking capability of channel variation is realized by comparing the likelihood values for different forgetting factors from the FEC decoding results, which consequently adjusts the forgetting factor based on actual channel dominance. The numerical results showed that the proposed scheme can adaptively choose the appropriate forgetting factor according to the actual channel conditions, such as noise-dominant or time-selectivity-dominant channel, thereby retaining good BER performance irrespective of channel dominance.