Frequency-domain differential detection and equalisation of differentially encoded DS-CDMA signals

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Coherent frequency-domain equalisation (FDE) of DS-CDMA signals suffers from channel estimation error. Frequency-domain differential detection and equalisation (FDDDE) for the reception of differentially encoded DS-CDMA signals transmitted over a frequency-selective fading channel is proposed. At a transmitter, the differentially encoded data symbol is spread and transmitted. At a receiver, differential detection, equalisation and despreading are simultaneously performed in the frequency-domain. Compared with that of coherent FDE, FDDDE is much more robust against fast fading.

Introduction: The bit error rate (BER) performance of DS-CDMA systems in a frequency-selective fading channel can be improved significantly by using coherent frequency-domain equalisation (FDE) instead of Rake combining [1, 2]. However, coherent FDE requires accurate channel estimation and imperfect channel estimation results in performance degradation. For pilot-assisted channel estimation, the known pilot chip blocks need to be periodically transmitted [3]. In order to track against fast fading, the pilot block transmission rate must be increased. This reduces the transmission efficiency. Compared with coherent detection, differential detection is attractive owing to its simplicity and robustness against fast fading, but its BER performance is inferior to that of coherent detection since a delayed version of the received noisy signal is used as the phase reference. In this Letter, a frequency-domain differential detection and equalisation (FDDDE) scheme based on minimum mean square error (MMSE) criterion, which requires no channel estimation, is proposed. At a transmitter, the differentially encoded data symbol is spread and transmitted. At a receiver, differential detection, equalisation and despreading are performed simultaneously in the frequency-domain. A simple decision feedback filter is used to provide a noise-reduced reference signal and then narrow the performance gap between differential detection and coherent detection. Computer simulation results show that MMSE-FDDDE provides the BER performance very close to that of coherent MMSE-FDE in a slow fading environment, and is much more robust against the Doppler spread.

System model: Fig. 1 shows the DS-CDMA transmitter/receiver structure. At the transmitter, the data-modulated symbol sequence $\{a_m\}$ is first differentially encoded, that is, $b_m = a_m b_{m-1}$, $m \geq 1$ and $b_0 = 1$, where a_m is the mth data-modulated symbol with $|a_m| = 1$. Next, the differentially encoded data symbol b_m is spread by spreading code $c_m(t)$, $t = 0 \sim (SF-1)$, with spreading factor SF to obtain the chip sequence $s_m(t) = \sqrt{(2E_c/T_c)} b_m c_m(t)$, where E_c is the chip energy and T_c is the chip duration. Then, after insertion of N_g-chip guard interval (GI), the chip sequence), $\tilde{s}_m(t) = s_m(t)$, $t = -N_g \sim (SF-1)$, is transmitted over a frequency-selective fading channel.

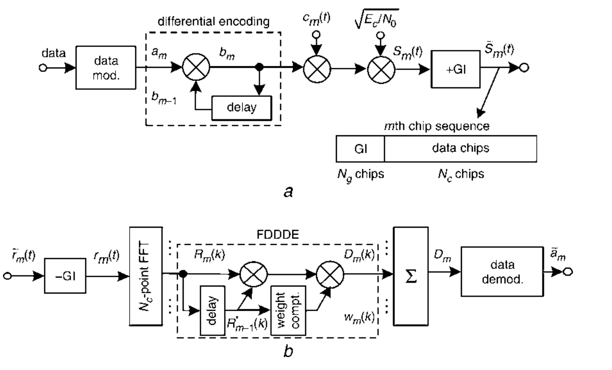

Fig. 1 *Transmitter/receiver structure*

a Transmitter
b Receiver

At the receiver, the GI is removed from the received chip sequence $\tilde{r}_m(t)$. The GI-removed received chip sequence $r_m(t)$ is transformed into N_c frequency components by N_c-point FFT, where $N_c = SF$ in this Letter, and then FDDDE is performed on each frequency component as follows

$$D_m(k) = w_m(k) R_m(k) R^*_{m-1}(k) \tag{1}$$

where $w_m(k)$ is the equalisation weight and $R_m(k)$ is the kth frequency component, given by

$$R_m(k) = \sqrt{2E_c/T_c} b_m C_m(k) H_m(k) + \Pi_m(k) \tag{2}$$

with $H_m(k)$ being the channel gain at the kth frequency of the mth block and $\Pi_m(k)$ the zero-mean noise component owing to the additive white Gaussian noise (AWGN) having power spectrum density N_0, and $C_m(k)$ the kth frequency component of $c_m(t)$. We have derived $w_m(k)$ based on MMSE criterion as

$$w_m(k) = \frac{C^*_m(k)/C^*_{m-1}(k)}{|R_{m-1}(k)|^2 + 2\sigma^2} \tag{3}$$

where $\sigma^2 = N_0/T_c$ is the noise power. The noise power can be measured at the receiver. $C_m(k)$ and $C_{m-1}(k)$ are all known to the receiver.

$R_{m-1}(k)$ is the reference signal for FDDDE. Since $R_{m-1}(k)$ is noisy, we apply infinite impulse response (IIR) filtering with decision feedback to obtain a noise-reduced reference. Using (2) and $b_m = a_m b_{m-1}$, we have

$$\hat{R}_{m-1}(k) = \alpha \hat{R}_{m-2}(k) \tilde{a}_{m-1} \frac{C_{m-1}(k)}{C_{m-2}(k)} + (1-\alpha) R_{m-1}(k) \tag{4}$$

with $\hat{R}_0(k) = C_0(k)$, where α $(0 \leq \alpha \leq 1)$ is the forgetting factor and $\tilde{a}_{m-1}$ is the $(m-1)$th detected symbol. $R_{m-1}(k)$ in (1) and (3) is replaced by $\hat{R}_{m-1}(k)$. The optimum value of the forgetting factor α depends on the channel condition. The despreading operation is just to take the summation of all the FDDDE outputs, $D_m(k)$, $k = 0 \sim (N_c-1)$

$$D_m = \sum_{k=0}^{N_c-1} D_m(k) \tag{5}$$

based on which decision is made on a_m to obtain $\tilde{a}_m$.

Simulation results: The BER performance of DS-CDMA with MMSE-FDDDE is evaluated by computer simulation. We assume block transmission with QPSK data modulation, $N_c = 256$ and $N_g = 32$. As for the propagation channel, an $L = 16$-path Rayleigh fading channel having the uniform power delay profile is considered. The lth path time delay τ_l is assumed to be $\tau_l = l$ chips and the maximum delay difference is less than the GI length (i.e., $L-1 < N_g$). The simulated performance of DS-CDMA with MMSE-FDDDE is compared with that of coherent MMSE-FDE [1, 2], which makes use of pilot-assisted channel estimation using delay-time domain windowing [4, 5]. For the pilot-assisted channel estimation, a group of P pilot chip blocks is periodically transmitted, each followed by $P \times D$ data chip blocks.

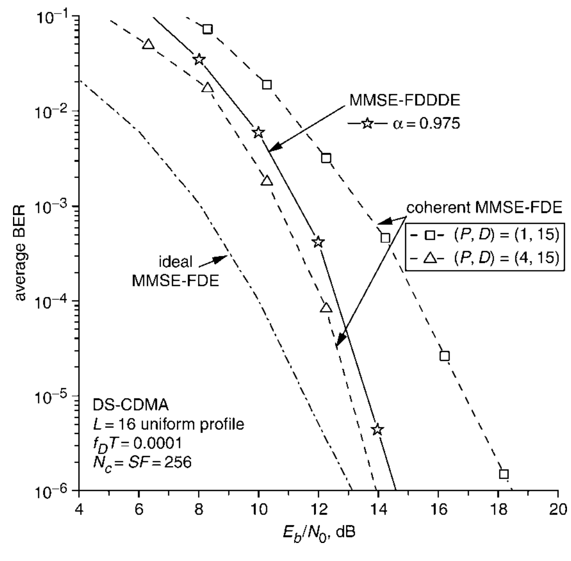

Fig. 2 *BER performance comparison between MMSE-FDDDE and coherent MMSE-FDE*

The simulated BER performance of DS-CDMA with MMSE-FDDDE is plotted in Fig. 2 for $SF = N_c = 256$ and $f_D T = 10^{-4}$, where f_D is the fading maximum Doppler frequency and $T = T_c(N_c + N_g)$ is the block duration. The forgetting factor α is optimised for $f_D T = 10^{-4}$ and it is $\alpha = 0.975$. It can be seen that with $\alpha = 0.975$, the BER performance of MMSE-FDDDE is similar to that of coherent MMSE-FDE with $(P, D) = (4, 15)$ and better than that of $(P, D) = (1, 15)$. Feeding back the past-detected symbols causes error propagation. In general, one decision error yields double symbol errors but does not propagate further [6]. It can be seen that MMSE-FDDDE with decision feedback still provides a good BER performance close to coherent MMSE-FDE. How the BER depends on $f_D T$ is shown in Fig. 3. With the increase in Doppler spread, coherent MMSE-FDE tends to lose the tracking ability, thereby exhibiting the significant performance degradation. Although MMSE-FDDDE is inferior to coherent MMSE-FDE for small $f_D T$, it is superior to coherent MMSE-FDE for large $f_D T$ values.

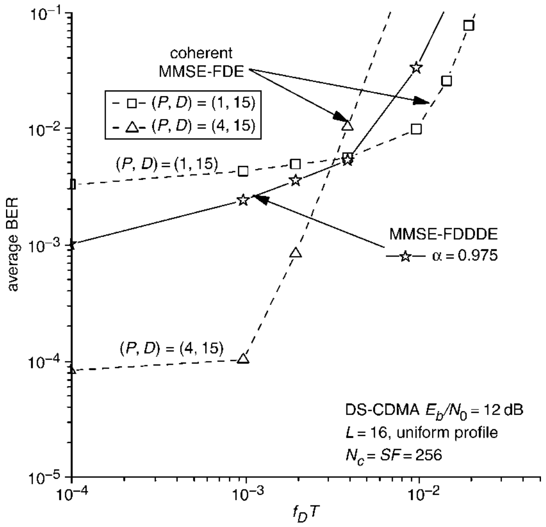

Fig. 3 *Impact of $f_D T$ on BER performance*

Conclusions: In this Letter, we proposed a frequency-domain differential detection and equalisation (FDDDE) based on MMSE criterion for the reception of differentially encoded DS-CDMA signals. At the receiver, differential detection, equalisation and despreading are simultaneously performed in the frequency-domain. The achievable BER performance in a frequency-selective Rayleigh fading channel was evaluated by computer simulation. It was confirmed by simulation results that the proposed MMSE-FDDDE is very robust against the Doppler spread.

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References

1 Vook, F.W., Thomas, T.A., and Baum, K.L.: 'Cyclic-prefix CDMA with antenna diversity'. Proc. IEEE VTC'02-Spring, May 2002, pp. 1002–1006

2 Adachi, F., Sao, T., and Itagaki, T.: 'Performance of multicode DS-CDMA using frequency domain equalization in frequency-selective fading channel', *Electron. Lett.*, 2003, **39**, (2), pp. 239–241

3 Takeda, K., and Adachi, F.: 'Pilot-assisted channel estimation based on MMSE criterion for DS-CDMA with frequency-domain equalization'. Proc. IEEE VTC'05-Spring, May 2005

4 Beek, J., *et al.*: 'On channel estimation in OFDM systems'. Proc. IEEE VTC'95, Chicago, USA, July 1995, pp. 815–819

5 Fukuhara, T., *et al.*: 'A novel channel estimation method for OFDM transmission technique under fast time-variant fading channel'. Proc. IEEE VTC'03-Spring, Jeju, Korea, April 2003, pp. 2343–2347

6 Adachi, F.: 'Reduced-state Viterbi differential detection using a recursively estimated phase reference for M-ary DPSK', *IEE Proc., Commun.*, 1995, **142**, pp. 263–270