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Frequency-domain Differential Detection and Equalization of Differentially Encoded DS-CDMA Signals

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1. Introduction

Similar to the single-carrier transmission [1], the bit error rate (BER) performance of DS-CDMA in a frequency-selective fading channel can be significantly improved with coherent frequency-domain equalization (FDE) instead of using Rake combining [2][3]. However, coherent FDE requires accurate channel estimation and the imperfect channel estimation results in the performance degradation. For pilot-assisted channel estimation, the known pilot chip blocks need to be periodically transmitted. For better tracking against fast fading, pilot block transmission rate must be increased with transmission efficiency reduced. In this paper, a frequency-domain differential detection and equalization (FDDDE) scheme that requires no channel estimation is proposed. At a transmitter, the differentially encoded data symbol is spread and transmitted. At a receiver, differential detection, equalization and despreading are simultaneously performed in the frequency-domain. Computer simulation results show that its BER performance is not only very close to that of coherent FDE detection but also much more robust against the Doppler spread.

2. System Model

Fig.1 shows the DS-CDMA transmitter/receiver structure. At a transmitter, the data-modulated symbol sequence 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 unity variance. Next, the differentially encoded data symbol sequence is spread by spreading code $c_m(t)$ with spreading factor SF. After spreading, the spread chip sequence is transformed into a sequence of N_c-chip blocks, where $N_c=SF$. Then, after insertion of N_g-chip guard interval (GI), the chip block sequence is transmitted.

At a receiver, each GI-removed chip block is transformed into N_c subcarrier components by N_c-point FFT and then FDDDE is performed on each subcarrier component as follows:

$$D_m(k) = w_{m-1}(k) R_m(k) R^*_{m-1}(k), \qquad (1)$$

where $w_{m-1}(k)$ is the equalization weight and $R_m(k)$ is the kth subcarrier component which is given by

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

with $H_m(k)$ being the channel gain at the kth subcarrier of

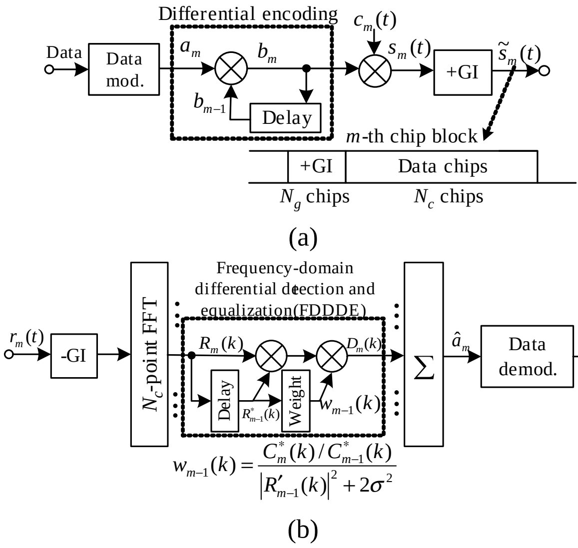

Fig.1. Transmitter/receiver structure for DS-CDMA

the mth block and $\Pi_m(k)$ the noise component due to the AWGN, E_c the average chip energy, T_c the chip duration, and $C_m(k)$ the kth subcarrier component of $c_m(t)$. We have derived $w_{m-1}(k)$ based on MMSE criterion as

$$w_{m-1}(k) = \frac{C^*_m(k)/C^*_{m-1}(k)}{\left|R_{m-1}(k)\right|^2 + 2\sigma^2_\Pi}, \qquad (3)$$

where σ^2_Π is the noise power, given by N_0/T_c with N_0 being the AWGN power spectrum density (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 Eq.(2) and $b_m = a_m b_{m-1}$, we have

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

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-1th data symbol replica obtained by the decision feedback. $R_{m-1}(k)$ in Eqs.(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 ~ (N_c-1):

$$\hat{a}_m = \sum_{k=0}^{N_c-1} D_m(k). \quad (5)$$

3. Computer Simulation

The BER performance of DS-CDMA with 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., $L-1 \le N_g$). The simulated performance of DS-CDMA with FDDDE is compared with that of coherent MMSE-FDE [2][3], which makes use of pilot-assisted channel estimation using delay-time domain windowing [4][5]. For the pilot-assisted channel estimation, P pilot blocks are periodically transmitted, followed by $P*D$ data chip blocks.

The simulated BER performance of DS-CDMA with FDDDE is plotted in Fig.2 for SF=256 and f_DT=10^{-4} (T=$T_c(N_c+N_g)$ is the block duration). The forgetting factor α is optimized for f_DT=10^{-4} and $\alpha = 0.975$ is used. It can be seen that with $\alpha = 0.975$, the BER performance of FDDDE using decision feedback 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 [6]. Generally one decision error yields double symbol errors but does not propagate further. Although double symbol errors are produced by one error propagation, it can be seen that FDDDE with real decision feedback still provides a good BER performance close to coherent FDE. How the BER depends on f_DT 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 FDDDE is inferior to coherent FDE for small f_DT, it is superior to coherent FDE for large f_DT values.

4. Conclusions

In this paper, we proposed a frequency-domain differential detection and equalization (FDDDE) for DS-CDMA. At the receiver, differential detection, equalization and despreading are simultaneously performed in the frequency-domain. The average BER performance was evaluated by computer simulation. It was confirmed by simulation results that the proposed FDDDE is very robust against the Doppler spread and outperforms coherent MMSE-FDE for large Doppler spreads.

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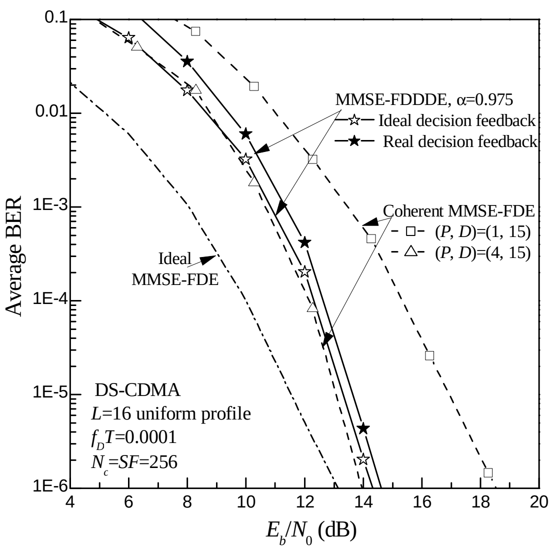

Fig.2. BER performance comparison between FDDDE and coherent FDE.

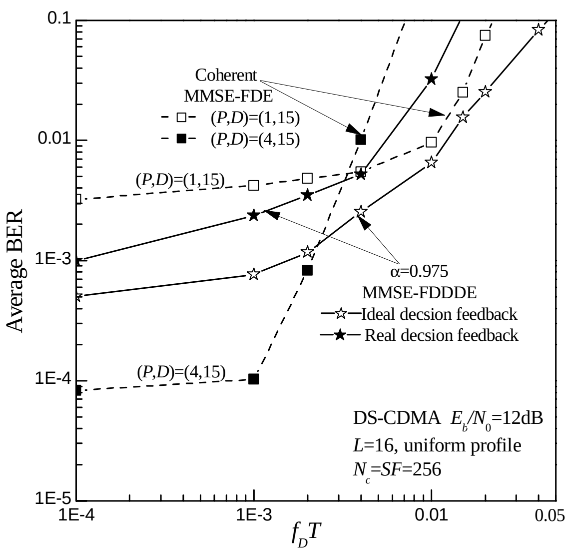

Fig.3. Impact of f_DT on BER performance.