Performance Analysis of Adaptive MMSE Receiver for CDMA Downlink

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요 약

본 논문에서는 선형 채널 등화기를 이용하여 다중 경로 페이딩 채널을 등화시킨 후 적응형 필터에 의하여 MAI를 제거 시킴으로써 수신기의 성능을 향상시킬 수 있는 적응형 MMSE 수신기를 제안하였다. 제안된 수신기의 구조적인 특징으로는 채널계수의 정확한 추정을 위하여 파일럿 채널을 사용하였으며, 사용자 신호에 주기적으로 보호심볼을 둠으로써 채널 추정의 정확도를 높혔다. 이와 더불어 보호심볼의 주기적 삽입으로 인하여 채널 등화기의 길이가 짧아지게되어 계산상의 복잡성도 줄였다. 특히 적응형 부호-정합 필터(AMMSE)를 사용하여 사용자 수가 많을 경우에도 성능개선에 매우 효과적일 수 있도록 하였고, SNR이 높을경우 그 개선 정도가 훨씬 큼을 알 수 있었다.

ABSTRACT

In this paper, we proposed adaptive MMSE receiver, which use channel equalizer to eliminate the interference due to multi-path fading and adaptive filter to eliminate the multiple access interference. The unique features of proposed receiver schemes are as following. We use pilot channel to estimate the channel coefficients exactly and guard symbols which are inserted periodically to estimate channel coefficients exactly without interference from user signals. The length of channel equalizer also can be reduced with the help of guard symbols. Especially utilizing adaptive code-matched filter(AMMSE) when the user population is high and SNR is not low we accepts excellent performance improvement.

키워드

DS-CDMA, MMSE, channel equalizer, pilot channel

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Ⅰ. INTRODUCTION

Presently, in the downlink of IS-95 CDMA systems standard a number of user are activated simultaneously in the same frequency band, only separeted by the orthogonal spreading codes. But due to a multipath propagation and a frequency-selective fading, the orthogonality between user codes are destroyed and the performance of receiver are degraded by a multiple-access interference (MAI). Furthemore, we have much difficulty in applying a complicated algorithms developed for base station to a mobile station.

Therefore, various adaptive algorithms based on a stocastic gradient method and a minimum mean-squared-error(MMSE) criterion applicable to a mobile station are proposed[1-3].

Up to now, such algorithms have almost exclusively been designed for the uplink. Since the downlink may be interpreted as a special case of the uplink, all data detection algorithms derived for the uplink can be applied to the downlink as well. However, for the following downlink-specific characteristics it is possible and it may be reasonable to develope special algorithms for the down link[4-7] :

- ▶All K user signals appear at the mobile station after transmission over one and the same channel.
- ▶Only the data symbols addressed to that individual mobile station have to be detected.
- ▶The data detection algorithms should be simple in order to be able to provide mobile terminals of small size and low power consumption.

In this paper, we proposed adaptive MMSE receiver, which uses channel equalizer to reduce the interference due to a multi-path fading followed by adaptive filter to eliminate the multiple access interference(MAI). The unique features of proposed receiver schemes are as following. We use pilot channel to estimate the channel coefficients and guard symbols in user data which are inserted periodically to estimate channel coefficients exactly without interference from user signals. As the data block between two guard symbols is equalized, the length of channel equalizer also can be reduced. A conventional matched detection performs reasonably well, but a simple adaptive code matched detection is required in the heavy load condition.

This paper is organized as follows. The downlink signal model is described in Section II. In Section III, proposed adaptive single-user receiver is described. Especially we describe the channel estimation method using pilot channel, MMSE channel equalizer and data detection method. Simulation results are presented and discussed in Section IV. We conclude in Section V.

Ⅱ. DOWNLINK SIGNAL MODEL

The received signal model after pilot channel subtraction is introduced in Figure 1. In this system, equalization is performed each data block between guard symbols, an expression for one data block is used.

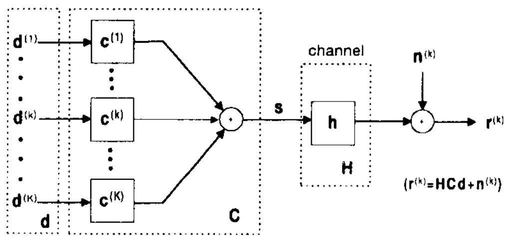

Fig. 1 Downlink received signal model of DS/CDMA system

Where $\mathbf{d}^{(k)}$, $k=1...K$, is the transmitted data vector of kth user and $d \in \{+1,-1\}$. Therefore user data matrix is given by

$$\mathbf{d} = \left(\mathbf{d}^{(1)T}, \mathbf{d}^{(2)T}, \ldots, \mathbf{d}^{(K)T}\right)^T \quad \text{……………………………… (1)}$$

$\mathbf{c}^{(k)}$, $k = 1 \ldots K$, is user-specific code, $c \in \{+1, -1\}$, and user code matrix is

$$\mathbf{C} = [\mathbf{c}_0^{(k)}, \mathbf{c}_1^{(k)}, \ldots \mathbf{c}_{Q-1}^{(k)}]^T \quad \text{………………………………… (2)}$$

The matrix $\mathbf{C}$ has dimension $(NQ) \times (KN)$, where N and Q is the length of data block and the spreading gain, respectively.

$\mathbf{h}$ is channel impluse response matrix, and

$$\mathbf{h} = [h_0, h_1, \ldots, h_{W-1}]^T \quad \text{……………………………………… (3)}$$

where W is maximum multipath delayed time expressed as chip period. Please note, in the downlink all user signals experience one and the same channel. Thus the matrix $\mathbf{H}$ has the dimension of $(NQ + W - 1) \times (NQ)$ and

$$\mathbf{H} = \left(\mathbf{H}_{i,j}\right) \ ; \ i = 1, \ldots, NQ + W - 1, \ \ j = 1, \ldots, NQ \quad \text{……. (4)}$$

As a result, the received signal vector is given by

$$\mathbf{r}^{(k)} = \mathbf{HCd} + \mathbf{n}^{(k)} = \mathbf{Hs} + \mathbf{n}^{(k)} \quad \text{………………………… (5)}$$

where $\mathbf{s} = \mathbf{Cd}$.

III. ADAPTIVE SINGLE-USER RECEIVER

Figure 2 shows a block diagram of the adaptive single-user receiver using proposed multipath channel equalizer.

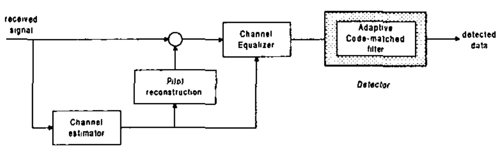

Fig. 2 Block diagram of Adaptive Single-User Detector using multipath channel equalizer

A. Channel Estimator using Pilot Channel

In a multipath fading, the channel impulse response is time variable and it is possible to estimate the channel impulse response by pilot signal in a receiver. There are two method using pilot signal such as multiplexing method which insert pilot signal into the received signal and pilot channel method which using individual pilot channel. In the downlink of the DS/CDMA, the pilot channel method is much effective. Transmission data are divided into blocks with J symbols. For convenience, if we assume all the pilot symbols are {+1}, then an channel estimator produce an estimation of the channel gain and sequences of channel estimation is interpolated to generate fading gains in the period of data block. Figure 3 shows received signal structure near a guard symbol period.

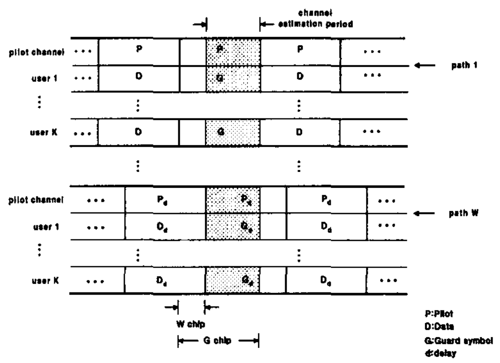

Fig. 3 Received signal structure near a guard symbol period

As the multipath delayed components of the last data may still interfere pilot signal initial W chips of guard symbol period, the rest $G - W$ chip samples are used by channel estimator. The estimator is a RAKE type receiver matched to partial code for pilot channel. The output of the channel estimator is given by

$$\hat{\mathbf{g}} = \mathbf{C}_P \mathbf{g} + \mathbf{n}_P \quad \text{…………………………………………… (6)}$$

where, $\hat{\mathbf{g}}$ is channel estimation vector in a guard symbol period $\hat{\mathbf{g}} = [\hat{g}_1, \ldots, \hat{g}_W]^T$, and $\mathbf{g}$ is channel coefficient vector in a channel estimation period within guard symbol period $\mathbf{g} = [g_1, \cdots, g_W]^T$, and $\mathbf{n}_P$ is an additive noise vector with variance σ_n^2. The channel estimation $\hat{\mathbf{g}}$ suffer from inter-path interferences due to a multipath fading, which can be eliminated by simple decorrelator. As a result, we get channel estimation in the guard symbol period given by

$$\mathbf{Z} = \mathbf{C}_P^{-1}\hat{\mathbf{g}} = \mathbf{g} + \mathbf{C}_P^{-1}\mathbf{n}_P \quad \cdots\cdots (7)$$

where, the partial correlation matrix $\mathbf{C}_P$ and it's inverse can be calculated with ease.

To generate the whole fading gains within data block MMSE-interpolator is used. Therefore, the estimation of fading gains in the data block are interpolated as follow,

$$\hat{\mathbf{H}}[n] = \mathbf{W} \cdot \mathbf{Z}[n] \quad \cdots\cdots (8)$$

where, $\hat{\mathbf{H}}[n] = \left(\hat{\mathbf{h}}[1], \hat{\mathbf{h}}[2], ..., \hat{\mathbf{h}}[p]\right)^T$ is the output of interpolator in nth block, the interpolator $\mathbf{W}$ has $(p \times J)$ dimension, the input vector of the interpolator $\mathbf{Z}[n]$ has $(J \times 1)$ dimension and $p = NQ + W - 1$.

B. Multipath Channel Equalizer

The received vector $\mathbf{r}^{(k)}$ is passed to channel equalizer to remove multipath channel effect, then produce $\hat{\mathbf{s}}^{(k)}$, an estimation of signal $\mathbf{s}$. For convenience, considering the special case of the covariance matrix $\mathbf{R}_n$ of the noise vector being equal to $\sigma^2\mathbf{I}$ and the covariance matrix $\mathbf{R}_d$ of the combined data vector being equal to $\mathbf{I}$, with $\mathbf{I}$ the identity matrix and σ^2 the variance of each noise component. Then, the estimated value of $\mathbf{s}$ is

$$\hat{\mathbf{s}}^{(k)} = \hat{\mathbf{H}}\,\mathbf{r}^{(k)} \quad \cdots\cdots (9)$$

If we use the MMSE criterion, the output of equalizer is given by

$$\hat{\mathbf{s}}_{mmse}^{(k)} = \left(\mathbf{H}^{*T}\mathbf{H} + \sigma^2\mathbf{R}_s^{-1}\right)^{-1}\mathbf{H}^{*T}\mathbf{r}^{(k)} \quad \cdots\cdots (10)$$

where, the covariance matrix $\mathbf{R}_s$ of the $\mathbf{s}$ has $(NQ) \times (NQ)$ dimension.

C. Data Detection using Adaptive code matched filter

In this section, specific data detection algorithms for the downlink situation performing single-user detection are derived which are based on MMSE(code-matched filter) and AMMSE(adaptive code-matched filter) block equalization.

The continuous-valued estimate of $\mathbf{d}^{(k)}$ determined by the MMSE block equalizer becomes

$$\hat{\mathbf{d}}_{mmse}^{(k)} = \mathbf{C}^{(k)*T}\left(\mathbf{H}^{*T}\mathbf{H} + \sigma^2\mathbf{R}_s^{-1}\right)^{-1}\mathbf{H}^{*T}\mathbf{r}^{(k)} \quad \cdots\cdots (11)$$

Equation (11) can be approximated by[8]

$$\tilde{\mathbf{d}}_{mmse}^{(k)} = \mathbf{C}^{(k)*T}\left(\mathbf{H}^{*T}\mathbf{H} + \frac{\sigma^2}{K}\mathbf{I}\right)^{-1}\mathbf{H}^{*T}\mathbf{r}^{(k)} \quad \cdots\cdots (12)$$

Even though the interference due to multipath fading is removed from received sample by the multipath channel equalizer, The kth user signal is suffer from the other user signal. If the user population is very low, conventional code-matched filter detection performs reasonably well but when user population approaches the spreading gain (G), the performance may degrade due to high level of MAI. Therefore in this paper, the channel equalizer output is passed to the adaptive MMSE code matched filter in order to reduce MAI. Figure 4 shows a block diagram of the proposed adaptive MMSE (AMMSE) receiver utilizing channel equalizer and pilot channel. The pilot channel with enhanced power level to estimate channel gain with high accuracy, then subtracted from received signal samples.

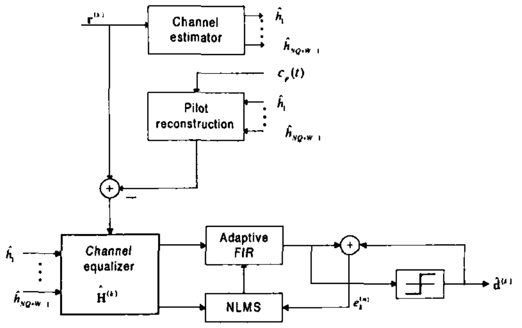

Fig. 4 Block diagram of AMMSE receiver

Assuming that AMMSE filter equalize the output of channel equalizer $\hat{\mathbf{s}}$, symbol by symbol, the coefficients of adaptive code matched filter is given by

$$\mathbf{W}_k^{(n)} = \left[w_k^{(n)}(0),\cdots,w_k^{(n)}(Q-1)\right]^T \quad \cdots\cdots (13)$$

where, filter coefficients are computed using stochastic gradient algorithm as follow

$$\mathbf{W}_k^{(n)} = \mathbf{W}_k^{(n-1)} - 2\mu_k^{(n-1)} \cdot e_k^{*(n-1)}\hat{s} \quad \cdots\cdots (14)$$

IV. NUMERICAL RESULTS

In this section, we present the performance of the proposed adaptive MMSE-receiver utilizing multipath channel equalizer. For the purpose of comparison, we considered two types of receivers , which are list as follows.

- ▶ A receiver with MMSE channel Equalizer and Code-matched Filter receiver (MMSE-MF)
- ▶ A receiver with MMSE channel Equalizer and adaptive MMSE receiver (MMSE-AMMSE)

And simulations were conducted under the assumptions of two path fading channel with a equal power and random delay , maximum multipath path delay of 10 chip periods, normalized maximum fade rate $f_d \cdot T$ of 0.01, Gold codes with 31 periods as PN codes and guard symbol insertion period is 5 symbols.

Figure 5 shows a simulation results to compare the performance of data detectors. As shown, conventional code matched filter detection performs well with small user population , for example K=10, but the performance difference becomes large as the number of user increase which is not the case in MMSE-AMMSE receiver.

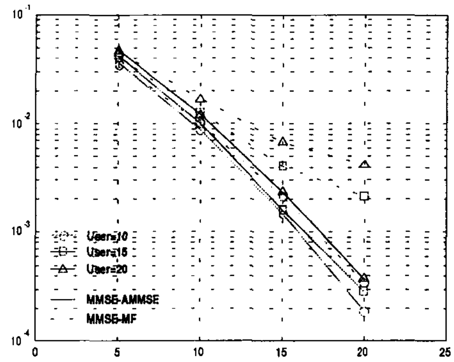

Fig. 5 Performance of receiver utilizing practical channel estimator

We also compare the performance of proposed receiver according pilot power variation and the result is presented in Figure 6. As we can see, to use pilot power higher than 9dB does not improve the performance much.

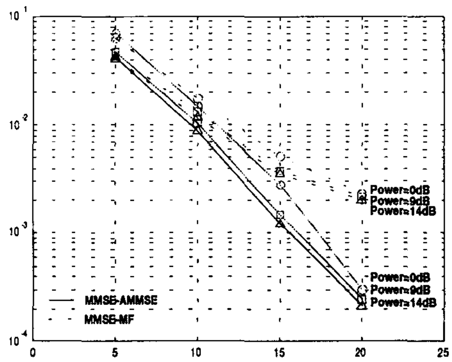

Fig. 6 Receiver performance vs. pilot power

In Figure 7, the BER performance of an adaptive single user receiver introduced by Markku J. Heikkila in [6] is compared with that of the proposed receiver in this paper. They used adaptive channel equalizer to reconstruct the orthogonality of Walsh code with length of 32 and conventional code matched filter for data detection. A multipath fading channel composed of three paths with equal power was assumed. It is shown that the performance of proposed adaptive receiver is about 1dB better.

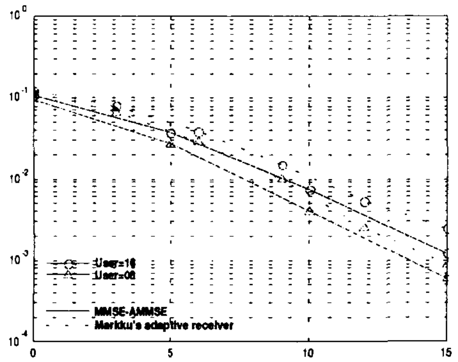

Fig. 7 A performance comparison of proposed receiver to Markku' s adaptive receiver

VI. CONCLUSIONS

In this paper, we proposed an adaptive MMSE receiver, which uses channel equalizer to remove multipath fading effect with relatively short tap length with the help of guard symbol and adaptive code matched filter detector in the DS/CDMA downlink. A pilot channel is used to estimate the channel coefficients, but channel coefficients are estimated at the interval of guard symbol where is no interference due to user data then interpolated. Simulation results shows that an adaptive code matched filter detector should be followed by instead of conventional code matched filter with high user population to improve the BER performance. It also shown that proposed receiver outperforms than a receiver using adaptive channel equalizer.

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