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# New channel estimation algorithm for W-CDMA reverse link using pilot symbols over fast Rayleigh-fading multipath channels

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**Abstract:** This paper presents channel estimation of an asynchronous W-CDMA reverse link using the interpolation and moving average algorithm in frequency-selective Rayleigh fading channel. The proposed algorithm is an interpolated decision-directed (IDD) block-wise moving average (BWMA) algorithm.The IDD-BWMA algorithm performs two-stage processes. The first stage performs data decision to make a virtual pilot channel by using linear interpolation channel estimation scheme. Then, the second stage performs the channel estimation of the "block-wise moving average" type by using a virtual pilot channel obtained in the first stage. By using Monte-Carlo computer simulations, we show that the proposed channel estimator is superior to other estimation schemes such as the WMSA(K=1) and DD-RAKE at higher Doppler frequencies, especially.

## 1. Introduction

When we want to apply the absolute phase encoding schemes, we have to estimate carrier frequency as well as its phase variation due to fading with no ambiguity. To accurately estimate fading variation, pilot signal-aided techniques are widely used in wireless communication systems. Pilot symbol-assisted modulation techniques (PSAM) [1,2] in which a known pilot symbol sequence and information symbol sequence are multiplexed in the time domain. The PSAM techniques actively use the smooth variation characteristic of the fading waveform, which is modeled as a band-limited Gaussian random process. Therefore, using the channel information at the known pilot positions, the channel estimate at the data positions can be obtained through some filtering techniques like a Gaussian filter [3], a Wiener filter [1,4], or a weighted multi-slot averaging (WMSA) filter [5].

The channel estimation scheme [6] using decision-directed mode uses the random data symbols as well as pilot symbols. However, this estimator has the problem of error propagation due to incorrect decision of the random data symbols.

In this paper, we propose the IDD-BWMA channel estimator, which has no error propagation and reduces error rate in decision-directed mode. The proposed scheme is to combine the interpolated compensation of data symbols and the sliding averaging filter based on the block-wise data symbols of virtual pilot channel. This paper considers an asynchronous W-CDMA reverse link with $K$ users based on a pilot symbol-assisted modulation, QPSK data modulation, complex-spreading of direct sequence.

The organization of this paper is as follows. A system model based on wideband DS-CDMA system is given in Section 2. In Section 3, the proposed channel estimation scheme is derived and analyzed. Performance results are provided in Section 4, and Section 5 concludes the paper.

## 2. System Description

### 2.1 Transmitter Model

The transmitted signals of mobile stations for a DS/CDMA QPSK are given by

$$s(t) = \mathrm{Re}[\ \sum_{k=1}^{K} \underline{d}_k(t)\cdot\underline{b}_k(t)e^{j(\omega_c t+\varphi)}\ ] \tag{1}$$

where $\omega_c$ represents the carrier frequency, $\varphi$ is the initial phase, and underline means a complex value.

The signal $\underline{d}_k(t) = d_k^d(t) + jd_k^c(t)$ and $\underline{b}_k(t) = b_k^I(t) + jb_k^Q(t)$ denotes the transmitted symbol and scrambling code sequence waveform of the $k$-th user. The symbol rate $T$ is an integer multiple of a chip rate $T_c$, i.e., $T=N\,T_c$, where $N$ represents the processing gain.

### 2.2 Channel Model

The channel impulse response $\underline{h}(t)$, is commonly modeled as a wide-sense stationary uncorrelated scattering (WSSUS) zero-mean white Gaussian process. In this paper, the channel model is assumed to be the frequency-selective Rayleigh fading channel with a possible frequency offset ($\Delta\omega$) between the transmitter and receiver. The baseband channel impulse response can be represented as

$$\underline{h}(t) = \sum_{l=1}^{P} \alpha_l(t)\delta(t-\tau_l)e^{j(\Delta\omega t+\theta_l(t))} \tag{2}$$

where $\alpha_l$, $\tau_l$, and $\theta_l$ are the channel gain, phase, and time delay of the $l$-th path, respectively. We assumed that the path amplitude $\alpha_l$ is a Rayleigh distributed random variable with its average power $E[(\alpha_l)^2] \equiv 2\rho$, and the $l$-th path phase $\theta_l$ is a uniformly distributed random variable over the interval $[0,2\pi)$.

### 2.3 Receiver Model

In the multipath Rayleigh fading channel, the received signal consists of a sum of delayed, phase shifted, and attenuated replicas of the transmitted signal. Also, the received signal is further corrupted by multiple access interference (MAI) and thermal noise $n(t)$, which is modeled as additive white Gaussian noise (AWGN) with two-sided spectral density $N_o / 2$. Therefore, the complex baseband received signal can be expressed as

$$\underline{r}(t) = \sum_{k=1}^{K} \sum_{l=1}^{P} \alpha_l(t) \cdot \underline{d}_k(t-\tau_l) \underline{b}_k(t-\tau_l) e^{j(\Delta\omega t + \theta_l(t))} + \underline{n}(t) \quad (3)$$

Fig. 1 shows a block diagram of the reverse link receiver. We assume that the $p$-th path timing information $\tau_p$ is obtained through the synchronization process. So, the input signal to the fingers in RAKE receiver at optimal sampling instant may be separated into the signal components expressed by $U_S$, and three noise components represented by $U_{SI}$, $U_{MAI}$, and $U_N$. The first noise component $U_{SI}$ is the "self interference" due to the desired user's all unreslovable multipath, the second component $U_{MAI}$ is the "multiple access interference" due to all path of other users, and the third component $U_N$ is thermal noise with a Gaussian random variable. With these definitions, we can now write the input signal of the $q$-th user's RAKE receiver

$$\begin{aligned} \underline{U}^q &= [\underline{U}_1^q, \underline{U}_2^q, \cdots, \underline{U}_l^q, \cdots, \underline{U}_P^q]^T \\ &= \underline{U}_S^q + \underline{U}_{SI}^q + \underline{U}_{MAI}^q + \underline{U}_N^q \end{aligned} \quad (4)$$

where $[.]^T$ denotes the transpose of a matrix.

## 3. The Proposed Channel Estimator

In this paper, we deal with W-CDMA dedicated uplink physical channel structure [7]. There are two types of dedicated physical channel, the dedicated physical data channel (DPDCH) and the dedicated physical control channel (DPCCH). Then, the pilot symbols of dedicated physical control channel are used to estimate the channel information for coherent detection. In this work, we assume that the input value of the estimator is the sum of $N$ chips.

The proposed algorithm is the interpolated decision-directed scheme for block-wise moving averaging. We will represent the process of symbol-based estimator as the filter-structured estimator with symbol tap interval. Fig. 2 describes the structure of the proposed channel estimation algorithm. Our approach to channel estimation scheme in fast fading channel has the two-stage process. The principle of each stage is presented as follows.

### 3.1 Virtual Pilot Channel using Interpolated Decision-Directed Scheme

The proposed estimator performs more reliable data decision by using the linear interpolation channel estimator. The linear interpolation technique is to compensate data symbols through the linear equation of the pilot symbols of present slot and future slot. As a result, the estimated value $\breve{\underline{U}}$ is obtained using the present and future averaged-pilot symbols $\breve{\underline{U}}_{pre}$, $\breve{\underline{U}}_{next}$ as shown in Fig. 2(a). And then, the decision circuit determines tentative data symbols $\breve{\underline{d}}_q^c(m)$. The decided data symbol $\breve{\underline{d}}_q^c(m)$ is fed back to eliminate the data symbol phase. Therefore, we can make the DPCCH channel as a virtual pilot channel. In the decision-directed data $\breve{\underline{d}}_q^c(m)$, we can prevent from error propagation, which usually cannot be avoided in the decision-directed type. At $n$-th slot, then the estimated value of the $q$-th user for $p$-th path at the $m$-th symbol instant can be expressed as

$$\begin{aligned} \breve{\underline{U}}_p^{q,c}(n,m) &= (1 - m/L) \cdot \sum_{i=-K+1}^{0} \breve{\underline{U}}_{pre}(n+i) \\ &+ (m/L) \cdot \sum_{i=1}^{K} \breve{\underline{U}}_{next}(n+i), \quad 0 \le m < L \end{aligned} \quad (5)$$

where

$$\breve{\underline{U}}_{pre}(n) = \frac{1}{N_p \sqrt{p_q^c}} \sum_{m=1}^{N_p} \alpha(n) \underline{U}_p^{q,c}(n,m),$$

$$\breve{\underline{U}}_{next}(n+1) = \frac{1}{N_p \sqrt{p_q^c}} \sum_{m=1}^{N_p} \alpha(n+1) \underline{U}_p^{q,c}(n+1,m)$$

and $\underline{U}_p^{q,c}(n,m)$ is the the received complex control signal after despreading at $m$-th symbol of the $n$-th slot, and $L$ and $N_p$ is the number of symbols in a slot and the number of pilot symbols for averaging, respectively. Consequently, we can obtain the tentative decision value of the $m$-th symbol, $n$-th slot.

### 3.2 Block-wise moving average for data channel compensation

The second stage performs "block-wise moving average" operation using a virtual pilot channel made by the decision data of previous stage. The block-wise moving average function uses a linear filter as shown in Fig. 2(b). The estimate process of a virtual pilot channel is updated for every symbol. The $m$-th estimated value of the $q$-th user for $p$-th path can be written as

$$\begin{aligned} \hat{\underline{U}}_p^{q,c}(m) &= \hat{\underline{U}}_{S_p}^{q,c}(m) + \hat{\underline{U}}_{SI_p}^{q,c}(m) + \hat{\underline{U}}_{MAI_p}^{q,c}(m) + \hat{\underline{U}}_{N_p}^{q,c}(m) \\ &= \frac{1}{(N_c+1)\sqrt{p_q^c}} \sum_{w=-N_c/2}^{N_c/2} g_w \, \breve{\underline{d}}_q^c(m-w) \underline{U}_p^{q,c}(m-w) \end{aligned} \quad (6)$$

where $\sqrt{p_q^c}$ denotes control channel power for $q$-th user, and the averaging length $N_c$ means a multiple of the processing gain and the channelization code's period.

And also, the filter coefficient $\alpha(n)$, $\alpha(n+1)$ and $g_w$ is assumed to be a unit value.

Finally, we can obtain the decision value of the $m$-th symbol for $n$-th slot as follows:

$$\hat{\underline{d}}_q^d(m) = \text{sgn}[\hat{\underline{z}}_d(m)] \tag{7}$$

where

$$\hat{\underline{z}}_d(m) = \text{Re}[\sum_{l=1}^{P} \underline{U}_p^{q,d}(m - T_{d2}) \cdot (\hat{\underline{U}}_p^{q,c}(m))^*]$$

and $T_{d2}$ represents a few symbols delay for the synchronization of data channel compensation process.

## 4. Performance Results

In this paper, the chip rate is assumed to be 4.096MHz and the physical channel is organized in a frame with 16 slots. Each slot consists of 10 symols, 2560 chips and the symbol rates are 16Kbps before spreading.

We concentrate on fast fading in a multipath Rayleigh fading channel. By using Monte-Carlo computer simulation, we evaluated the bit error rate (BER) performance for various Doppler shift ($f_D$), bit energy / noise power ($E_b / N_0$), and filter taps. We compared the BER performance of the proposed algorithm to other algorithms such as general WMSA (K=1), decision-directed (DD) prediction filter.

First of all, Fig. 3 illustrates the BER performance versus $E_b / N_0$ for two kinds of maximum Doppler frequencies, i.e., $f_D$=20Hz and 320Hz for one (Fig. 3(a)) and three paths (Fig. 3(b)) with the same power. It is shown that the BER performance of the IDD-BWMA estimator is better than the general WMSA (K=1) and DD-prediction filter in the wide range of $E_b / N_0$. The BER performance difference between the IDD-BWMA estimator and WMSA (K=1) is above 5.0dB at BER= $5.0 \times 10^{-2}$ and 5.5dB at BER= $3.0 \times 10^{-3}$ for one and three path channels, respectively.

The BER versus the number of filter taps of the IDD-BWMA estimator for one and three paths is shown in Fig.4. The number of filter taps for best performance is more than 5 taps at $f_D$=20Hz and is optimal at 5 or 6 taps for $f_D$=320Hz. It means that channel estimator has performance advantage when we take more channel information at lower Doppler shift and less at higher Doppler shift.

## 5. Conclusions

In this paper, the performance of a new algorithm for channel estimation of the reverse link wideband DS-CDMA was presented in various channel environments such as Doppler shift of Rayleigh fading, $E_b / N_0$, and filter taps. The BER performance of the proposed algorithm is better than the general WMSA (K=1) and DD-prediction filter in the wide range of $E_b / N_0$. And also, by using the virtual pilot channel through interpolated decision-directed scheme in the first stage of IDD-BWMA estimator, we can obtain more reliable data decision than DD-RAKE with error propagation.

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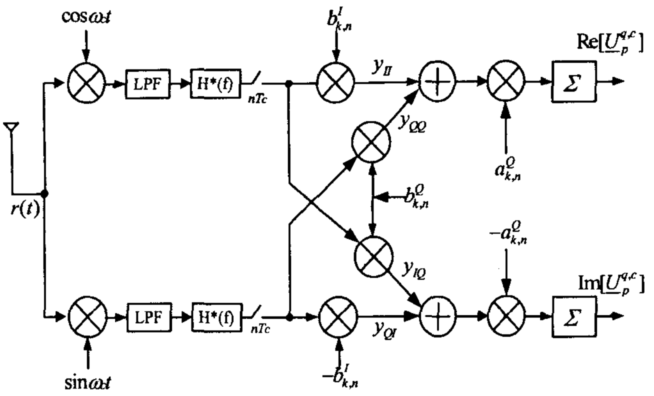
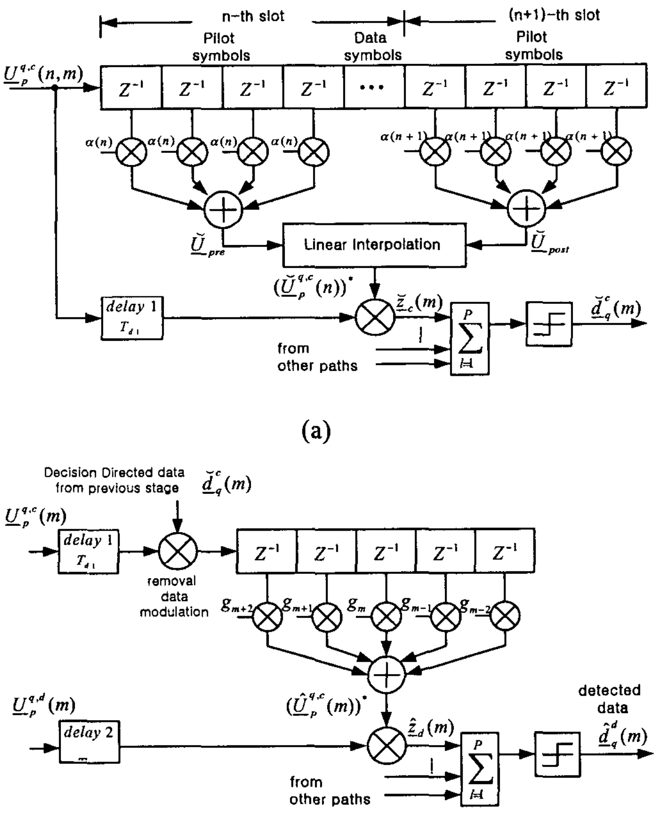


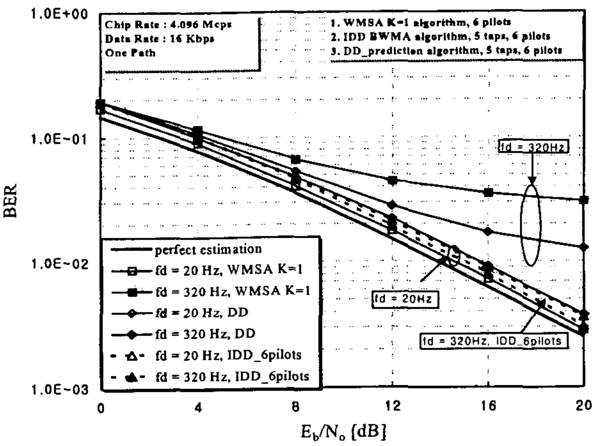
Fig. 1 Block diagram of the receiver structure



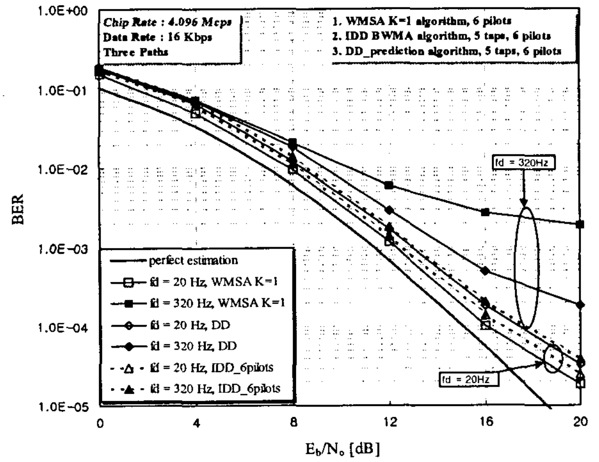
(a)

(b)

Fig. 2 Block diagram of the proposed IDD-BWMA channel estimator



(a) one path



(b) three paths

Fig. 3 BER versus $E_b / N_0$ for maximum Doppler frequency $f_D$ = 20Hz and 320Hz

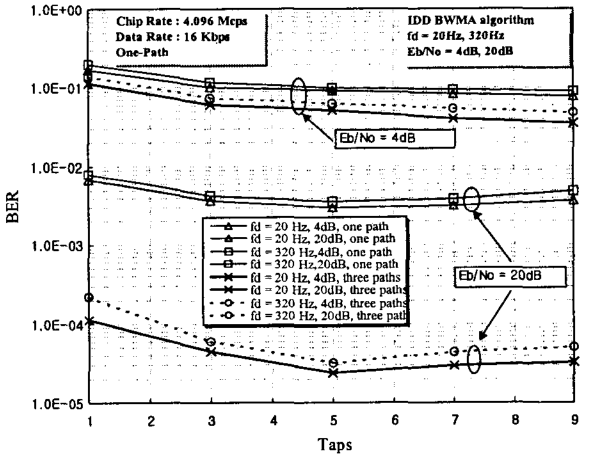


Fig. 4 BER versus the number of IDD-BWMA estimator filter taps for maximum Doppler frequency