Per-Survivor Processing Sequence Detection for DS/CDMA Systems with Pilot and Traffic Channels

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***Abstract*—A per-survivor processing (PSP) sequence detection receiver is proposed for DS/CDMA systems with pilot and traffic channels. The proposed receiver jointly estimates channel parameters and data symbols from pilot and traffic channels, and is derived by modifying the receiver in [1]. As a result, the new receiver can outperform the receiver in [1] in exchange for additional computation. Computer simulation results demonstrate the advantage of the proposed receiver over existing ones.**

***Index Terms*—DS/CDMA, fading, per-survivor processing.**

I. INTRODUCTION

MOTIVATED by the fact that next generation CDMA systems [2] provide a pilot channel as well as a traffic channel in the reverse link, several techniques that jointly estimate channel parameters and data symbols from both pilot and traffic channels have been proposed. These include an adaptive sequence detector [1] and a technique that is based on the use of tentative decisions for channel estimation [3].

This letter attempts to improve on these receivers. Specifically, a modification to the receiver in [1] is proposed. It will be shown through simulation that the proposed receiver can outperform existing ones.

II. SYSTEM MODEL

Consider an asynchronous CDMA system with K users operating over multipath fading channels with L distinct propagation paths. The signal transmitted from the kth user, $s_k(t)$, is an M-ary PSK signal with the following complex envelope:

$$s_k(t) = \sum_{n=-\infty}^{+\infty} [G_p W^p(t-nT) + G_q W_k^q(t-nT) b_k(n)] \cdot a_k(t) \tag{1}$$

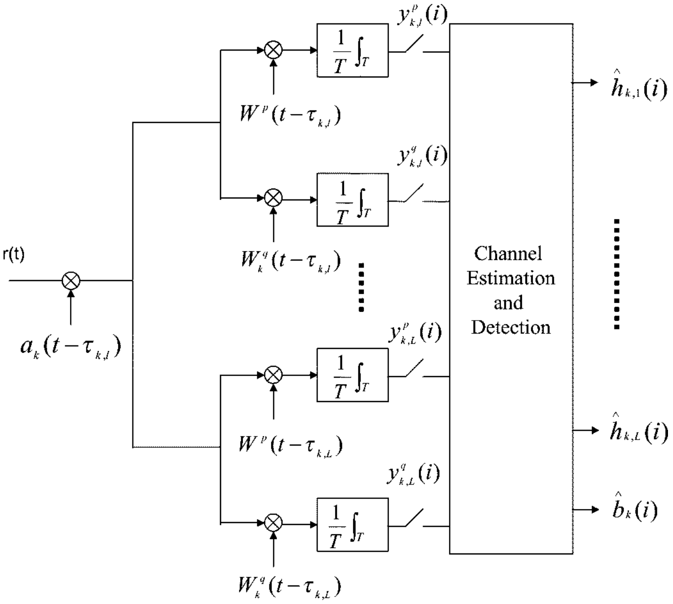

Fig. 1. Baseband equivalent receiver structure.

where G_p^2 and G_q^2 denote the pilot and traffic channel power, respectively; $b_k(n) \in \{e^{j(2\pi/M\gamma)}, \gamma = 0, 1, \ldots, M-1\}$ is the kth user information symbol at the nth time interval; $W^p(t)$ and $W_k^q(t)$ represent Walsh sequences for spreading, which correspond to the pilot and traffic channels, respectively; and $a_k(t)$ is the kth user's scrambling pseudo-noise (PN) sequence waveform. The period of the Walsh sequence is equal to the symbol period T, and $T = NT_c$ where T_c is the chip period and N is the processing gain. The received signal can be expressed as

$$r(t) = \sum_{k=1}^{K} \sum_{l=1}^{L} h_{k,l}(t) s_k(t - \tau_{k,l}) + \eta(t) \tag{2}$$

where $\{h_{k,l}(t)\}$ are the channel coefficients; $\tau_{k,l}$ is the delay associated with the kth user's lth path; and $\eta(t)$ is a zero-mean white Gaussian noise. The received signal $r(t)$ is descrambled, despread, and then sampled with frequency $1/T$ (Fig. 1). Let $y^p_{k,l}(i)$ and $y^q_{k,l}(i)$ denote the sampled pilot and traffic signals after despreading. Then

$$\begin{aligned} y^p_{k,l}(i) &= \frac{1}{T} \int_{iT}^{(i+1)T} r(t) W^p(t - iT - \tau_{k,l}) a_k(t - \tau_{k,l})\, dt \\ &= G_p h_{k,l}(i) + v^p_{k,l}(i) \end{aligned} \tag{3}$$

$$\begin{aligned} y^q_{k,l}(i) &= \frac{1}{T} \int_{iT}^{(i+1)T} r(t) W^q_k(t - iT - \tau_{k,l}) a_k(t - \tau_{k,l})\, dt \\ &= G_q h_{k,l}(i) b_k(i) + v^q_{k,l}(i) \end{aligned} \tag{4}$$

Manuscript received December 13, 2000. The associate editor coordinating the review of this letter and approving it for publication was Dr. Z. Zvonar.

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Publisher Item Identifier S 1089-7798(01)07671-2.

where $v^p_{k,l}(i)$ and $v^q_{k,l}(i)$ represent the sum of the multiple access interference (MAI) and noise, respectively. Using vector notations, (3) and (4) can be rewritten as

$$\begin{aligned}\mathbf{Y}_{k,l}(i) &\triangleq \begin{bmatrix} y^p_{k,l}(i) \\ y^q_{k,l}(i)\end{bmatrix} \\ &= h_{k,l}(i)\begin{bmatrix} G_p & 0\\ 0 & G_q\end{bmatrix}\begin{bmatrix}1\\ b_k(i)\end{bmatrix} + \begin{bmatrix} v^p_{k,l}(i)\\ v^q_{k,l}(i)\end{bmatrix} \\ &\triangleq h_{k,l}(i)\mathbf{G}\mathbf{b}_k(i)+\mathbf{v}_{k,l}(i).\end{aligned} \tag{5}$$

III. ADAPTIVE SEQUENCE DETECTOR

The cost function for the channel estimator in [1] is given by

$$\mathcal{E}_k(i) = \sum_{l=1}^{L}\sum_{n=1}^{i}\lambda^{i-n}\left\|\mathbf{Y}_{k,l}(n) - \hat{h}_{k,l}(i)\mathbf{G}\mathbf{b}_k(n)\right\|^2 \tag{6}$$

where λ, $0 < \lambda \leq 1$, is the forgetting factor. By solving $\partial\mathcal{E}_k(i)/\partial\hat{h}_{k,l}(i) = 0$ and through some approximation, the following recursive channel estimator is obtained:

$$\hat{h}_{k,l}(i) = \lambda\cdot\hat{h}_{k,l}(i-1) + (1-\lambda)\cdot H_l\left[b_k(i)\right] \tag{7}$$

where

$$H_l\left[b_k(i)\right] = \left[\frac{G_p}{G_p^2+G_q^2}\,y^p_{k,l}(i) + \frac{G_q}{G_p^2+G_q^2}\,y^q_{k,l}(i)b_k^*(i)\right]. \tag{8}$$

The adaptive sequence detector in [1] is based on a trellis diagram with M states, where M is the size of the signal constellation and each state takes one of the symbol values $\{e^{j(2\pi/M)\gamma}, \gamma = 0, 1, \ldots, M-1\}$. The detector updates $\hat{h}_{k,l}(i)$ for all paths entering each state, and thus M^2 channel estimates are evaluated for each time i. The path metric is calculated using the cost in (6). When updating the channel estimate and path metric, the hypothesized input symbol associated with the state is used in place of $b_k(i)$ in (6) and (7). The symbols are detected by back-tracing the path with the minimum path metric.

The proposed PSP receiver is derived through the following modifications.

1) The channel is only updated for the survivors in the trellis paths, thereby yielding a PSP algorithm [4].
2) When calculating the path metric, λ is set to 1 in (6). The forgetting factor λ is necessary in deriving the recursive channel estimator in (7), yet unnecessary in the path metric calculation.
3) The states in the trellis are defined by a sequence of W symbol values, where W is an integer, resulting in M^W states. Since the channel and path metric updates only require the current hypothesized input symbol, it is logical to set W at 1, and if the channel estimate is fixed (time-invariant), the trellis with $W \geq 2$ degenerates into the trellis with $W = 1$. However, when the channel is time-varying and its estimate is updated according to (7), the use of $W \geq 2$ can improve the receiver performance.

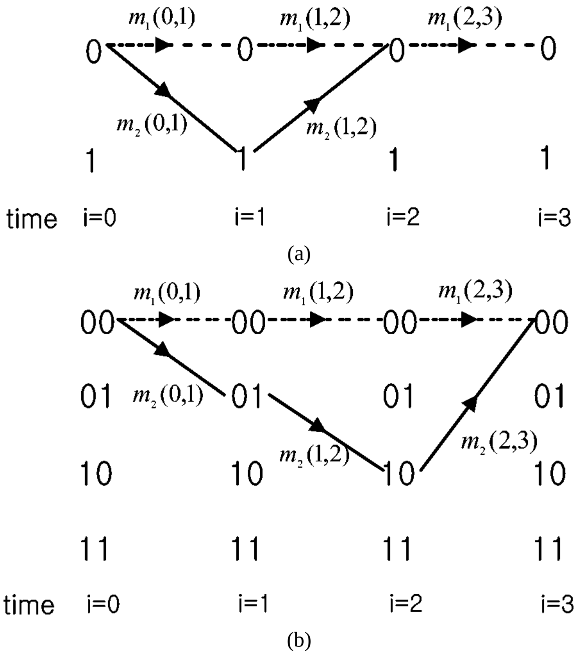

Fig. 2. Trellis diagrams. (a) 2 states ($M = 2$, $W = 1$). (b) 4 states ($M = 2$, $W = 2$).

This is illustrated through the following example. Consider Fig. 2 that shows trellis diagrams with $W = 1$ and 2 ($M = 2$). The input to the trellis is $\{0, 1, 0, 0\}$, plus $m_1(i, i+1)$ and $m_2(i, i+1)$ denote branch metric values associated with incorrect and correct paths, respectively. In general $m_1(i, i+1) > m_2(i, i+1)$, because incorrect paths generate inaccurate channel estimates. The path metric at time n is given by $\sum_{i=0}^{n} m_j(i, i+1)$, for $j = 1, 2$ and $n = 0, 1, 2$. The difference between the path metrics at time n, is denoted by D_n, i.e., $D_n \triangleq \sum_{i=0}^{n}\{m_1(i, i+1) - m_2(i, i+1)\}$. Then D_1 and D_2 for $W = 1$ are the same as those for $W = 2$. When $W = 1$, one of the two paths is selected as the survivor at time $i = 2$: the correct path is chosen if $D_2 > 0$. When $W = 2$, the survivor is selected at time $i = 3$ by calculating D_3. Since $D_3 = D_2 + \{m_1(2, 3) - m_2(2, 3)\}$ and $m_1(2, 3)$ is usually greater than $m_2(2, 3)$, then D_3 can be positive even when $D_2 < 0$. Therefore, the possibility of selecting the correct path when $W = 2$ is generally higher than that associated with $W = 1$. Accordingly, a receiver with $W = 2$ can outperform one with $W = 1$, although the price for using $W \geq 2$ is additional computation. The next section shows that the proposed receiver can outperform the receiver in [1] in exchange for a heavier computational load.

IV. SIMULATION RESULTS

To examine the performance of the proposed receiver, computer simulations were performed for a CDMA system with the following parameters: number of users $K = 5$; binary PSK modulation ($M = 2$); data rate of 9600 bps; scrambling waveform $a_k(t)$ was the PN sequence with period $2^{15} - 1$ [2]; processing gain $N = 128$; pilot and traffic power ratio $G_p^2/G_q^2 = -9$ dB. The signal was transmitted through a four-path ($L = 4$)

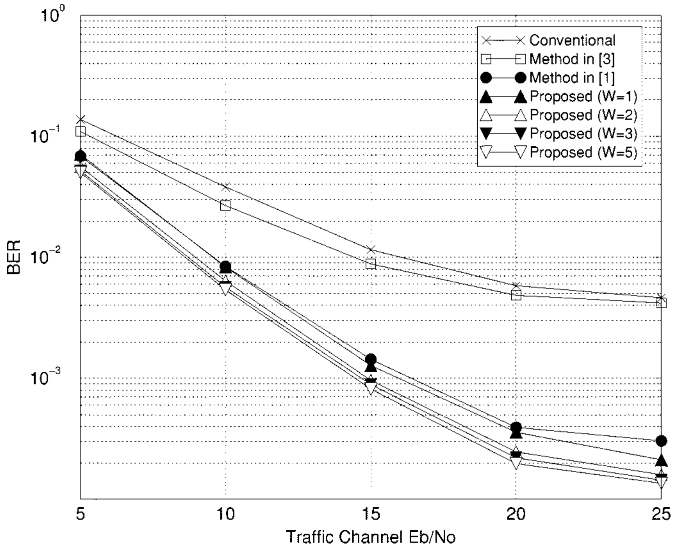

Fig. 3. Comparison of BER performances.

Rayleigh fading channel with an exponential delay power profile $(E[|h_{k,1}|^2] = 0.350, E[|h_{k,2}|^2] = 0.273, E[|h_{k,3}|^2] = 0.212, E[|h_{k,4}|^2] = 0.165)$, and the multipath delays were uniformly distributed in $[0, T)$. The carrier frequency was 1.8 GHz and vehicle speed 100 km/h.

The proposed receiver was compared with a conventional receiver, which only estimates the channel information from the pilot and uses it for symbol detection, and the receivers in [1] and [3]. In the conventional receiver, the channel parameters were obtained by passing the despread pilot $y^{p}_{k,l}(i)$ through a moving average filter with span 10 and the forgetting factor λ for the channel update was set at 0.7, where the filter span and λ were set at those values exhibiting the best performance.

Fig. 3 compares the bit-error rate (BER) performances of the receivers. As expected, the conventional receiver performed the worst. The method in [3] performed somewhat better than the conventional one, however, its performance was considerably worse than those of the proposed and the receiver in [1]. When $W = 1$, the proposed and the receiver in [1] exhibited an almost comparable performance. (Strictly speaking, the former performed slightly better than the latter—this performance gain was achieved by setting $\lambda = 1$ in the proposed method when evaluating the path metric.) With $W \geq 2$, the proposed receiver outperformed the method in [1]: the performance gain was about 2 dB when BER was 10^{-3}. For the proposed receiver, an increased W resulted in better BER performances. However, since most gain was achieved by increasing W from 1 to 2, the use of $W = 2$ is recommended.

V. CONCLUSIONS

A PSP sequence detection receiver which jointly estimates channel parameters and data symbols from pilot and traffic channels was derived by modifying the receiver in [1]. The proposed technique can outperform the receiver in [1] in exchange for additional computation. The advantage of the proposed receiver over existing ones was demonstrated through computer simulation.

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