A Symbol-by-symbol based Adaptive Interference Canceller for Asynchronous DS/CDMA Systems in Multipath Fading Channels

Jeong Hoon Ko

Electronics and Telecommunications Research Institute, Korea
E-mail: jhk@etri.re.kr

Jung Suk Joo and Yong Hoon Lee

Dept. of Electrical Engineering,
Korea Advanced Institute of Science and Technology, Korea
E-mail : yohlee@eekaist.kaist.ac.kr

Abstract— **We propose a new interference cancellation scheme called the symbol-by-symbol based adaptive interference canceller (SAIC). The SAIC adaptively estimates and removes both multiple access interference (MAI) and intersymbol interference (ISI) at the output of the Rake receiver. It requires neither respreading nor the evaluation of partial cross-correlation. In addition, its complexity is independent of the number of fingers of the Rake receiver. Consequently, the SAIC is considerably simpler to implement than existing techniques. Computer simulation results demonstrate that the SAIC can perform much better than conventional Rake receiver.**

I. Introduction

Although the interference cancellation schemes in [1]-[7] can effectively reduce the multiple access interference in asynchronous DS/CDMA communications, their application to practical systems is rather difficult mainly because of their complexity in implementation. These interference cancellers require either a sophisticated respreading technique or the evaluation of partial cross-correlation, which is computationally expensive. Furthermore, when a Rake receiver is employed under multipath fading environment, use of several interference cancellers—one canceller for each finger of the Rake receiver—is usually required. Therefore, the complexity tends to increase as the number of fingers is increased. A comprehensive tutorial on interference cancellation schemes can be found in [8]-[9].

In this paper, we propose a new interference cancellation scheme that adaptively estimates and removes interference from the output of the Rake receiver on a symbol-by-symbol basis. This scheme, called the symbol-by-symbol based adaptive interference canceller (SAIC), estimates interferences by using a simple least-mean-square (LMS) algorithm and is particularly useful for eliminating interference under slow fading channel environment. The SAIC requires neither respreading nor partial cross-correlation values; and its complexity is independent of the number of fingers, since it is located following the Rake receiver. Therefore, it is considerably simpler to implement than the existing methods. It will be shown through computer simulation that the receiver performance can be significantly improved by employing the SAIC.

II. System Model

We consider BPSK transmission through multipath channel shared by K users employing a direct sequence spread spectrum modulation. Using the notations and the channel model in [2], the communication signals are expressed as follows: The kth user's data signal $b_k(t)$ is given by $b_k(t) = \sum_{i=-\infty}^{\infty} b_k{}^{(i)} P_{T_b}(t - iT_b)$ where $P_{T_b}(t) = 1$ for $0 \leq t < T_b$ and $P_{T_b}(t) = 0$, otherwise; $b_k{}^{(i)} \in \{\pm 1\}$ denotes the ith transmitted bit of the kth user. The kth user's spreading signal is expressed as $a_k(t) = \sum_{i=-\infty}^{\infty} a_k{}^{(i)} P_{T_c}(t - iT_c)$ where $a_k{}^{(i)} \in \{\pm 1\}$ is the spreading sequence of period N and $P_{T_c}(t)$ is the spreading chip waveform with duration $T_c = T_b/N$. The transmitted signal is a carrier modulated version of $b_k(t)a_k(t)$.

The signal received over a multipath fading channel can be written in the form

$$r(t) = \sum_{k=1}^{K} \sum_{\lambda=1}^{L_k} \sqrt{2P_k} g_{k,\lambda} u_k(t - \tau_{k,\lambda}) \cdot cos(w_c t + \phi_{k,\lambda}) + n(t) \qquad (1)$$

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where L_k is the number of paths in the kth user's link; P_k is the transmission power; $g_{k,\lambda}$ is the path amplitude having a Rayleigh distribution; $u_k(t) = b_k(t)a_k(t)$; $\tau_{k,\lambda}$ and $\phi_{k,\lambda}$, respectively, denote the time delay and the phase offset associated with the kth user's λth path; and $n(t)$ is zero-mean white Gaussian noise. It is assumed that $\tau_{k,\lambda}$ and $\phi_{k,\lambda}$ are uniformly distributed over $[0\,,T_b)$ and $[0\,,2\pi)$, respectively.

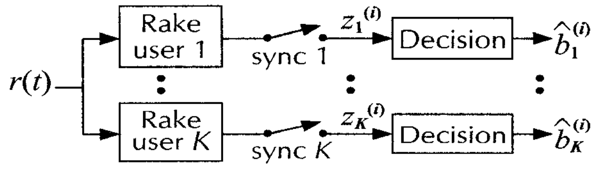

Fig. 1. The conventional detector employing a Rake receiver for each user.

III. Symbol-by-symbol based Adaptive Interference Canceller

Fig. 1 shows the conventional detector employing a Rake receiver for each user. The Rake receiver with F fingers consists of F correlators, that operate with proper delays, followed by a combiner. We assume equal gain combining for the sake of simplicity. Since the time delay $\tau_{k,\lambda} \in [0\,,T_b)$, the ith output of the kth Rake receiver can be written as

$$\begin{aligned} z_k{}^{(i)} &= \alpha_{k,k}^{(i)}(0)b_k{}^{(i)} + \alpha_{k,k}^{(i)}(-1)b_k{}^{(i-1)} + \alpha_{k,k}^{(i)}(1)b_k{}^{(i+1)} \\ &+ \sum_{l\neq k}(\alpha_{k,l}^{(i)}(-1)b_l{}^{(i-1)} + \alpha_{k,l}^{(i)}(0)b_l{}^{(i)} + \alpha_{k,l}^{(i)}(1)b_l{}^{(i+1)}) \\ &+ \sum_{m=1}^{F}\eta_{k,m}^{(i)} \end{aligned} \qquad (2)$$

where $\eta_{k,m}^{(i)}$ is the sampled Gaussian noise associated with each finger and $\alpha_{k,l}^{(i)}(j)$, $j \in \{-1,0,1\}$ represent the amount of interference caused by the lth user's $(i+j)$th data. Specifically, $\alpha_{k,k}^{(i)}(-1)b_k{}^{(i-1)}$ and $\alpha_{k,k}^{(i)}(1)b_k{}^{(i+1)}$ are ISI caused by multipath transmission and $\alpha_{k,l}^{(i)}(j)b_l{}^{(i+j)}$, $l \neq k$, $j \in \{-1,0,1\}$, are MAI terms ($\alpha_{k,l}^{(i)}(j)$ is expressed in terms of the path amplitude and the partial cross-correlations—the expression for $\alpha_{k,l}^{(i)}(j)$ is rather lengthy and thus omitted). Note that the MAI caused by the lth user consists of only three terms corresponding to $b_l{}^{(i-1)}, b_l{}^{(i)}$, and $b_l{}^{(i+1)}$. To simplify notations, (2) is rewritten as

$$z_k{}^{(i)} = \alpha_{k,k}^{(i)}(0)b_k{}^{(i)} + I_k^{(i)} + \sum_{l\neq k} M_{k,l}^{(i)} + \sum_{m=1}^{F}\eta_{k,m}^{(i)} \qquad (3)$$

where

$$\begin{aligned} I_k^{(i)} &= \alpha_{k,k}^{(i)}(-1)b_k{}^{(i-1)} + \alpha_{k,k}^{(i)}(1)b_k{}^{(i+1)} \\ M_{k,l}^{(i)} &= \alpha_{k,l}^{(i)}(-1)b_l{}^{(i-1)} + \alpha_{k,l}^{(i)}(0)b_l{}^{(i)} + \alpha_{k,l}^{(i)}(1)b_l{}^{(i+1)}. \end{aligned}$$

The design of interference cancellation scheme can be formulated as a problem minimizing $E[|(z_k{}^{(i)} - I_k^{(i)} - \sum_{l\neq k} M_{k,l}^{(i)}) - \alpha_{k,k}^{(i)}(0)b_k{}^{(i)}|^2]$ with respect to $\alpha_{k,l}^{(i)}(j)$. When $\alpha_{k,l}^{(i)}(j)$ are slowly varying, this problem may be solved by the LMS algorithm, which results in the following update equations:

$$\begin{aligned} e_k{}^{(i)} &= z_k{}^{(i)} - \hat{I}_k^{(i)} - \sum_{l\neq k}\hat{M}_{k,l}^{(i)} - \hat{\alpha}_{k,k}^{(i)}(0)b_k^{(i)} && (4) \\ \hat{\alpha}_{k,k}^{(i+1)}(0) &= \hat{\alpha}_{k,k}^{(i)}(0) + \mu_1 e_k{}^{(i)}b_k^{(i)} && (5) \\ \hat{\alpha}_{k,l}^{(i+1)}(j) &= \hat{\alpha}_{k,l}^{(i)}(j) + \mu_2 e_k{}^{(i)}b_l^{(i+j)}\ , \ \text{for } (l,j)\neq(k,0) && (6) \end{aligned}$$

where

$$\begin{aligned} \hat{I}_k^{(i)} &= \hat{\alpha}_{k,k}^{(i)}(-1)b_k{}^{(i-1)} + \hat{\alpha}_{k,k}^{(i)}(1)b_k{}^{(i+1)} \\ \hat{M}_{k,l}^{(i)} &= \hat{\alpha}_{k,l}^{(i)}(-1)b_l{}^{(i-1)} + \hat{\alpha}_{k,l}^{(i)}(0)b_l{}^{(i)} + \hat{\alpha}_{k,l}^{(i)}(1)b_l{}^{(i+1)}. \end{aligned}$$

In practice, the symbol values $b_l^{(i+j)}$ in these equations should be replaced with tentative decision values—one may employ a training sequence for $\hat{\alpha}_{k,k}^{(i)}(j)$ but this is not possible for the other cases. As a consequence, the LMS update in (4)-(6) may diverge when the tentative decisions are unreliable. The MAI and ISI can be estimated by multiplying $\hat{\alpha}_{k,l}^{(i)}(j)$ with the tentative decision $\hat{b}_l^{(i+j)}$ which is obtained by hard decision for the output signal of the Rake receiver. The final decisions are obtained by passing the signal in which interferences are eliminated to the hard decision device, i.e., $\tilde{b}_k^{(i)} = sgn(z_k{}^{(i)} - \hat{I}_k^{(i)} - \sum_{l\neq k}\hat{M}_{k,l}^{(i)})$.

The SAIC, illustrated in Fig. 2, is proposed based on the above discussions. The SAIC for each user requires tentative decisions of all K users, and the number of $\hat{\alpha}_{k,l}^{(i)}(j)$ to be updated for each time index i is $3K$. Since the interferences are estimated and eliminated on a symbol-by-symbol basis, the SAIC requires neither respreading nor partial cross-correlation values. In addition, its complexity is independent of the number of fingers of the Rake receiver, because it is located following the Rake receiver. As a consequence, the SAIC is considerably simpler to implement than existing interference cancellation schemes. Its performance, however, may be degraded if the tentative decisions are unreliable due to low SNR, and if $\alpha_{k,l}^{(i)}(j)$ varies rapidly due to fast time-varying fading.

IV. Simulation

The performance of the Rake receiver followed by the proposed SAIC is compared with the conventional Rake receiver by simulating a 10-user ($K = 10$) asynchronous DS/CDMA system. Each user was assigned a unique spreading sequence from a set of Gold codes of length 63, and the data rate $1/T_b$ was 64 kbps. We consider a multipath channel with slowly time-varying Rayleigh fading in which a $900MHz$ carrier frequency and $50km/h$ traveling speed were assumed. The number of multipaths was assumed to be 4 ($L = 4$). The path amplitudes, $g_{k,\lambda}$ were normalized so that the signal power levels at the input and output of the channel are the same, i.e., $\sum_{\lambda=1}^{4} E\{g_{k,\lambda}{}^2\} = 1$, for each k.

The BER values were estimated through 200 simulation runs. For each run, we generated random binary input sequences $b_k{}^{(i)}$ of length 51,000 for $k = 1, ..., 10$. For these input signals, outputs of the SAIC were evaluated. Empirical BER values at each run were obtained by counting the number of errors at the output (the errors occurred in the first 1000 symbol period were ignored, because we consider this as a preamble period). After 200 simulation runs, the resulting BER values for each case were averaged. The coefficients $\alpha_{k,l}^{(i)}(j)$ were estimated without employing any training sequence. For each SNR, several values of μ_1 and μ_2 were tried and the ones exhibiting best performance were selected. This resulted in $\mu_1 \in [0.05, 0.06]$ and $\mu_2 \in [0.005, 0.025]$. Fig. 3 shows the BER values of the SAIC and the conventional receiver in Fig. 1. As expected, the performance of the two receivers is improved as the number of fingers of their Rake receiver approaches the number of multipaths ($L = 4$). The performance of the SAIC is comparable to that of the conventional receiver when E_b/N_0 is less than $10dB$, but the former becomes considerably better than the latter as E_b/N_0 increased. This is because more accurate $\hat{\alpha}_{k,l}^{(i)}(j)$ can be obtained for high E_b/N_0. Fig. 4 shows some $\hat{\alpha}_{k,l}^{(i)}(j)$ values obtained when $E_b/N_0 = 18dB$. It is seen that $\hat{\alpha}_{k,l}^{(i)}(j)$ can take $\alpha_{k,l}^{(i)}(j)$ under time-varying channel environment.

V. Conclusion

A new interference cancellation scheme that can be easily implemented for asynchronous DS/CDMA systems in multipath fading channels was proposed. The performance of this scheme, called the SAIC, is improved as channel becomes slowly time-varying and as the number of resolvable paths is increased. Therefore, the SAIC is particularly useful for future wideband DS/CDMA systems with high data rate.

REFERENCES

[1] M. K. Varanasi and B. Aazhang, "Multistage Detection in Asynchronous Code-Division Multiple-Access Communications," *IEEE Trans. Commun.*, vol. 38, pp. 509-519, April 1990.

[2] Y. C. Yoon, R. Kohno and H. Imai, "A Spread-Spectrum Multi-Access System with Cochannel Interference Cancellation for Multipath Fading Channels," *IEEE Journ. Selected Areas in Commun.*, vol. 11, pp. 1067-1075, Sept. 1993.

[3] M. Kawabe, T. Kato, A. Kawahashi, T. Sato and A. Fukasawa, "Advanced CDMA Scheme Based on Interference Cancellation," *Proc. of VTC'93*, pp.448-451, May 1993.

[4] P. Patel and J. Holtzman, "Analysis of a Simple Successive Interference Cancellation Scheme in a DS/CDMA System," *IEEE Journ. Selected Areas in Commun.*, vol. 12, no. 5, pp. 796-807, June 1994.

[5] A. Johansson and A. Svensson, "Multistage Interference Cancellation in Multirate DS/CDMA on a Mobile Radio Channel," *Proc. VTC'96*, pp. 666-670, 1996.

[6] A. C. K. Soong and W. A. Krzymien, "A Novel CDMA Multiuser Interference Cancellation Receiver with Reference Symbol Aided Estimation of Channel Parameters," *IEEE Journ. Selected Areas in Commun.*, vol. 14, no. 8, pp. 1536-1547, Oct. 1996.

[7] R. M. Bueher and B. D. Woerner, "Analysis of Adaptive Multistage Interference Cancellation for CDMA Using an Improved Gaussian Approximation," *IEEE Trans. Commun.*, vol.44, pp.1308-1321, Oct. 1996.

[8] A. Duel-Hallen, J. Holtzman and Z. Zvonar, "Multiuser Detection for CDMA Systems," *IEEE Personal Communications*, pp.46-58, April 1995.

[9] S. Moshavi, "Multi-user Detection for DS-CDMA Communications," *IEEE Communications Magazine*, pp. 124-136, Oct. 1996.

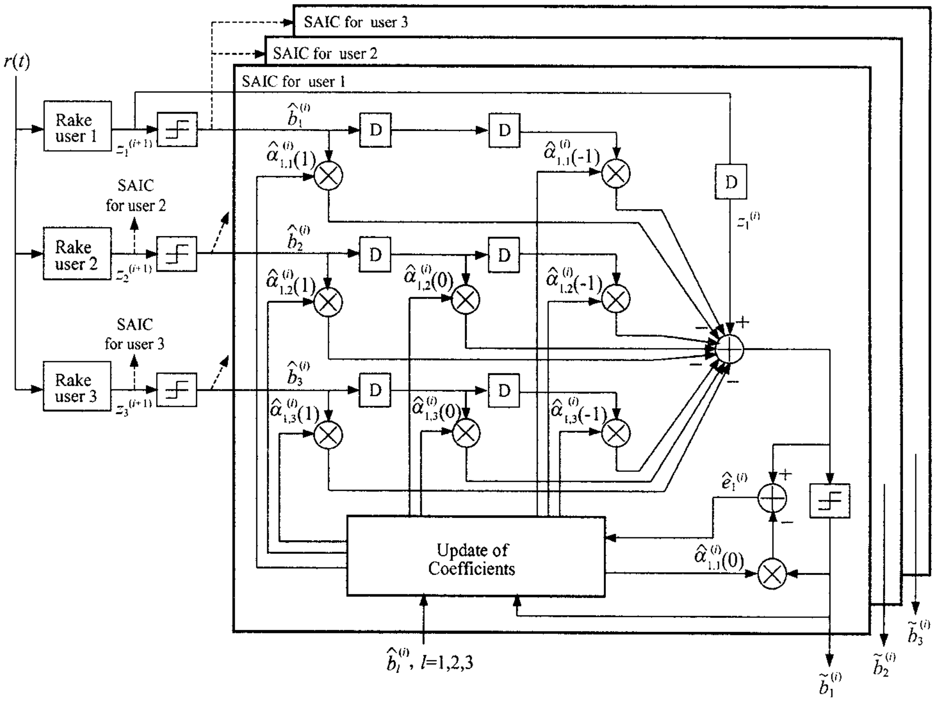

Fig. 2. The structure of the SAIC for user 1 when the number of users $K = 3$. Here D represents the delay by T_b.

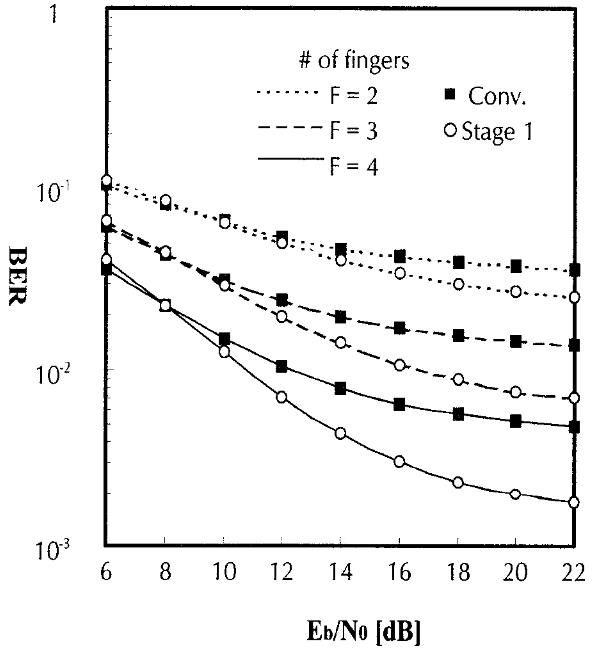

Fig. 3. Comparison of BER values between the conventional receiver in Fig. 1. and the SAIC in multipath Rayleigh fading channel. Here F is the number of fingers.

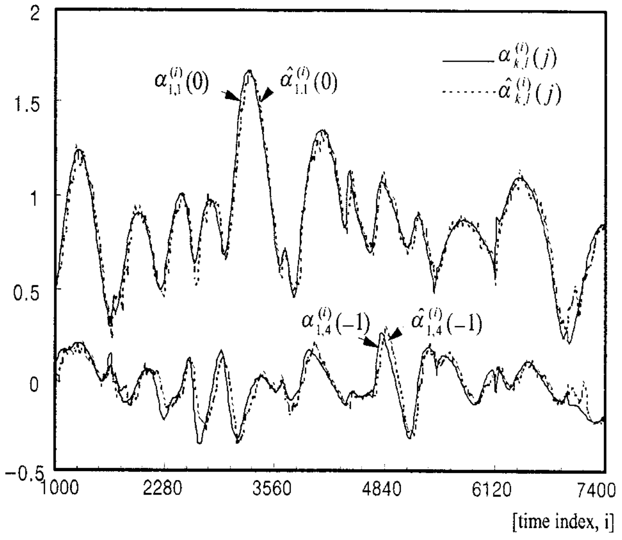

Fig. 4. Some $\hat{\alpha}_{k,l}^{(i)}(j)$ values exhibiting their capacity in tracking $\alpha_{k,l}^{(i)}(j)$. These were obtained when $E_b/N_o = 18dB$.