Performance of Iterative Multiuser Detection with a Partial PIC Detector and Serially Concatenated Codes

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Abstract — An iterative multiuser detection scheme is proposed for DS-CDMA system. An iterative multiuser detection has a partial parallel interference cancellation (PIC) detector and serially concatenated codes. Taking the expectation value of a coded bit the partial PIC detector produces a metric, which becomes an input to the decoders. It is shown that the proposed iterative multiuser detector has near single user performance as MAI is effectively cancelled out and a high coding gain is obtained.

I. INTRODUCTION

Multiple access interference (MAI) is a major factor that degrades the performance of a DS-CDMA system. Various techniques have been studied to solve the problem to increase the system capacity of DS-CDMA system such as channel coding, spatial filtering, code waveform design, and multiuser detection.

As a multiuser detection scheme, multiuser detection with a channel code has been proposed to increase the system capacity. It is known that optimal iterative multiuser detection based on maximum a posteriori probability (MAP) has the complexity proportional to $O(2^K)$ where $K$ is the number of users, which becomes unacceptable for large number of users. To reduce the complexity, sub-optimal iterative multiuser detection schemes have been studied [3].

As a sub-optimal iterative multiuser detection scheme, a parallel interference cancellation (PIC) is used for iterative multiuser detection because it reduces interference from other users while having low complexity. The PIC has a disadvantage that one or more errors occurred at initial iteration degrade the performance of the PIC. To reduce the effect of errors at initial iteration, a partial PIC is used [2].

As a channel coding scheme, turbo codes have been studied to increases their coding gain [7]. Turbo codes achieve BER performance within 0.7 dB of the Shannon Limit. As a turbo code, a serially concatenated convolutional code (SCCC) has a higher coding gain than a parallel concatenate convolutional code (PCCC) for high signal-to-noise ratio (SNR) [9].

In this paper an iterative multiuser detection scheme with a partial PIC detector and a SCCC is proposed for the DS-CDMA system. A partial PIC receiver produces a metric, which becomes an input to the decoders of a SCCC. The performance of the proposed iterative multiuser detection scheme is examined in a channel with an additive white Gaussian noise (AWGN) and Rayleigh fading. In section II the system model of the proposed iterative multiuser detection scheme is described. In section III and IV a partial PIC detector and a SCCC are described, respectively. In section V simulation results are given and in section VI conclusions are drawn.

II. SYSTEM MODEL

Consider a synchronous baseband DS-CDMA system employing BPSK modulation with $K$ users. Fig. 1 shows the block diagram of the transmitter for the proposed iterative multiuser detection scheme. An information bit of each user is encoded by the serially concatenated convolutional code (SCCC) encoder with rate $R$. The constituent encoder of the SCCC encoder is a recursive systematic convolutional (RSC) encoder with memory $m$. Taking the information bit $b_k[i]$ as an input, the outer encoder produces a systematic bit and parity bits. Taking the frames of systematic bits and parity bits, the random interleaver rearranges the order of data bits to reduce correlation between inputs of two constituent encoders. Taking the output of the random interleaver as an input, the inner encoder produces systematic bits and parity bits.
These bits are interleaved by the block interleaver which is used to reduce the deteriorative effect of fading channel.

Suppose that the synchronous baseband DS-CDMA system has the number of frames $N$, a chip duration $T_c$, a bit duration $T_b$, and a processing gain $L$. The signature waveform of the user $k$ is given by

$$s_k(t) = \frac{1}{\sqrt{LT_c}} \sum_{j=0}^{L-1} s_k[j] p_{T_c}(t-jT_c)$$  \hspace{1cm} (1)$$

where $s_k[j] \in \{-1, 1\}$, $j=0, 1, \cdots, L-1$, is the $j$th element of the signature sequence and $p_{T_c}(t)$ is a unit-amplitude rectangular pulse with duration $T_c = T_c R/L$. The baseband signal transmitted by the user $k$ is given by

$$x_k(t) = P_k(t) \sum_{j=0}^{L-1} d_k[j] s_k(t-jT_b)$$  \hspace{1cm} (2)$$

where $P_k(t)$ is the transmitted signal amplitude of the user $k$.

The received baseband signal for the user $k$ is given by

$$r_k(t) = \sum_{j=0}^{L-1} a_k(t) s_k(t-jT_b) + n(t)$$

$$= \sum_{j=0}^{L-1} A_k(t) d_k[j] s_k(t-jT_b) + n(t)$$  \hspace{1cm} (3)$$

where $a_k(t)$ is the channel gain which is an independent, identically distributed Rayleigh random process, $A_k(t) = a_k(t) P_k(t)$ is the received signal amplitude of the user $k$, and $n(t)$ is an AWGN with the power spectral density of $N_0/2$ W/Hz.

Fig. 2 shows the block diagram of the receiver for the proposed iterative multiuser detection scheme. Taking the outputs from the decoders as inputs, the partial PIC detector produces its output, which is referred to as a metric. The metric is obtained from the extrinsic log-likelihood ratios (LLRs) of each decoder. Taking the metric and the output from the outer decoder as the input, the inner decoder computes the extrinsic LLR. Taking the output from the inner decoder as the input, an outer decoder computes extrinsic LLR which is used as a decision variable.

**III PARTIAL PIC DETECTOR**

In the PIC detector, initial metric is obtained by the MF bank and fed into the decoder. For the user $k$ in the 1st iteration, the metric for the $i$th bit is given by

$$y_k^{(i)}[i] = \int_{-LT_c}^{(i+1)LT_c} r(t) s_k(t - iLT_c) dt$$  \hspace{1cm} (4)$$

Suppose that the bit estimates $d_k^{(i-1)}[i]$ are obtained for the $(p-1)$th iteration. Then, in the $p$th iteration, the bit estimates for the user $k$ are multiplied by the signal amplitude $A_k(t)$ and respread by the signature sequence $s_k(t)$ to produce an estimate for the received signal $\hat{r}_k^{(p)}(t)$. In the $p$th iteration, the estimate for the received signal of the user $k$ is given by

$$\hat{r}_k^{(p)}(t) = A_k(t) \sum_{j=0}^{L-1} (d_k^{(p-1)}[i] s_k(t - LT_c)) \times p_{LT_c}(t - iLT_c)$$  \hspace{1cm} (5)$$

For the user $k$ the received signal after subtracting MAI is given by

$$r_k^{(p)}(t) = r(t) - \sum_{k' \neq k} \hat{r}_{k'}^{(p)}(t).$$  \hspace{1cm} (6)$$

In the $p$th iteration, the metric for the $i$th bit is given by

$$y_k^{(p)}[i] = \int_{-LT_c}^{(i+1)LT_c} r_k^{(p)}(t) s_k(t - iLT_c) dt.$$  \hspace{1cm} (7)$$

In the PIC detector, the $i$th bit estimate for the user $k$ is given by

$$d_k^{(p)}[i] = \text{sgn} \left( L(d_k^{(p-1)}[i]) \right)$$  \hspace{1cm} (8)$$

where $L(d_k^{(p-1)}[i])$ is the LLR which is obtained from the decoder of the user $k$.

The PIC detector causes a bias in LLR at the output of the decoder. The bias makes detrimental effect on bit decision in the first iteration of interference cancellation. The effect of the bias diminishes in the later iterations of cancellation. However, when the bias causes incorrect bit decision in the first iteration, its detrimental effect is
shown in later iterations. To mitigate the effect of the bias, the partial PIC receiver with partial cancellation factor is used. The MAI estimate is multiplied by the partial cancellation factor between 0 and 1, and then subtracted from the received signal in each iteration of the receiver. For the user $k$ in the $p$th iteration, the received signal after subtracting MAI is given by

$$r_k^{(p)}(i) = r(i) - C^{(p)} \sum_{j \neq k} \hat{r}_j^{(p)}(i).$$

(9)

where $C^{(p)}$ denotes the partial cancellation factor for the $p$th iteration. The factor increases as iterations proceed.

By using the outputs of the inner and outer decoders, the estimates for the user $k$ and the partial cancellation factor are computed. The output of the decoders about user $k$ is given by

$$L_{\hat{d}_k^{(p)}(i)} = \ln \frac{p[d_k^{(p)}(i) = 1]}{p[d_k^{(p)}(i) = -1]}.$$

(10)

The expectation of a coded bit is obtained as

$$E[d_k^{(p)}(i)] = 1 \times p(d_k^{(p)}(i) = 1) + (-1) \times p(d_k^{(p)}(i) = -1)$$

$$= 1 \times \frac{\exp[L_{\hat{d}_k^{(p)}(i)}]}{\exp[L_{\hat{d}_k^{(p)}(i)}] + 1} + (-1) \times \frac{1}{\exp[L_{\hat{d}_k^{(p)}(i)}] + 1}$$

$$= \tanh \left( L_{\hat{d}_k^{(p)}(i)} / 2 \right).$$

(11)

The magnitude and sign of the expectation correspond to a partial cancellation factor and bit estimate, respectively. From (5) and (9), the estimate for the received signal of the user $k$ is given by

$$\hat{y}_k^{(p)}(i) = A_k(i) \sum_{\tau=0}^{N-1} E[d_k^{(p-1)}(i)] s_k(t - LT_c)$$

$$\times p_{LT_c}(t - iLT_c).$$

(12)

The output of the partial PIC detector for the user $k$ signal is given by

$$y_k^{(p)}(i) = A_k(i) d_k^{(p)}(i) + \sum_{j \neq k} S_{k,j} A_j(i)$$

$$\times (d_j^{(p)} - E(d_j^{(p)}(i))) + \eta[i].$$

(13)

where $S_{k,j}$ is the cross-correlation between signature sequences of $k$th user and $j$th user and $\eta[i]$ is the noise spreaded by the signature sequence of the user $k$. In each iteration, a partial PIC detector computes update probability, which is referred to as soft cancellation value. Soft cancellation value is given by

$$- \sum_{j \neq k} S_{k,j} A_j(i) \left( \frac{\tanh(L_{\hat{d}_j^{(p)}(i)}/2)}{- \tanh(L_{\hat{d}_j^{(p)}(i)}/2)} \right)$$

(14)

The partial cancellation factor for the iterative multiuser detector is smaller than that for the PIC detector, since the magnitude of an expectation is smaller than 1. The magnitude of the partial cancellation factor increases as the iteration proceeds.

IV. SERIALLY CONCATENATED CONVOLUTIONAL CODES (SCCC)

A SCCC has a lower error floor than a parallel concatenated convolutional code (PCCC) in high SNR because the SCCC computes the LLR of outer code, computing the LLRs of coded bits. But a conventional SCCC doesn't computes the LLR of parity bits which are produced by an inner encoder. The proposed SCCC scheme computes the LLR of parity bits of the inner code to deliver LLR to a partial PIC detector.

By using the output of the partial PIC detector, the LLR is given by

$$L(d_k^{(p)}(i)) = \frac{\ln p(d_k^{(p)}(i) = 1)}{\ln p(d_k^{(p)}(i) = -1)}.$$

(15)

The extrinsic LLR is given by

$$L_{\hat{d}_k^{(p)}(i)} = L(d_k^{(p)}(i)) - L_{\hat{d}_k^{(p)}(i)}.$$

(16)

where $L_{\hat{d}_k^{(p)}(i)}$ is a priori LLR which is obtained by other decoder.

V. SIMULATION RESULTS
Consider an synchronous DS-CDMA system having iterative multiuser detection. Suppose that BPSK is used as a modulation scheme and the Gold code of length 31 is used as a signature sequence for each user. Assume that the channel for each user has independent identically distributed frequency-flat Rayleigh fading with normalized Doppler frequency of $f_D T = 0.01$ and $0.001$. Also assume that the receiver knows the signature sequence of all users and has perfect channel estimation for each user and perfect power control for fading. Assume that the serially concatenated convolutional code with rate 1/3, memory 2, and frame length 1024 has max-log-MAP algorithm.

Fig. 3 shows the BER of the proposed iterative multiuser detection scheme with 1, 10, and 20 user in an AWGN channel. I and H represent the numbers of iteration and hard decision, respectively. It is shown that the $E_b/N_0$ required to achieve BER of $10^{-5}$ is reduced by 2.5 dB when single user is considered at the 4th iteration instead of the 1st iteration in proposed iterative multiuser detection scheme. It is also shown that the $E_b/N_0$ required to achieve BER of $10^{-5}$ is reduced by 0.8 dB when the 4th iteration is considered in the proposed iterative multiuser detection scheme with a single user instead of 20 users. Also it is shown that the $E_b/N_0$ required to achieve BER of $10^{-5}$ is reduced by 0.3 dB when 10 users are considered at the 4th iteration in the proposed iterative multiuser detection scheme using soft cancellation value which is calculated from the expectation of a coded bit instead of hard decision.

Fig. 4 shows the BER of the proposed iterative multiuser detection scheme in a Rayleigh fading channel. Fig. 4(a) shows the BER of the proposed iterative multiuser detection scheme in a fast fading channel with a normalized fade rate of 0.01. It is shown that the $E_b/N_0$ required to achieve BER of $10^{-5}$ is increased by 3.5 dB when a single user is considered at the 4th iteration in a fast fading channel instead of an AWGN channel. Fig. 4(b) shows the BER of the proposed iterative multiuser detection scheme in a slow fading channel with a normalized fade rate of 0.001. It is shown that the $E_b/N_0$ required to achieve BER of $10^{-5}$ is increased by 4 dB when a single user is considered at the 4th iteration in a slow fading channel instead of a fast fading channel.

VI. CONCLUSIONS

In this paper a iterative multiuser detection with the partial PIC detector and serially concatenated codes is proposed in synchronous DS-CDMA system over a Rayleigh fading channel. The partial PIC detector using expectation and the modified SCCC are employed in the proposed iterative multiuser detection scheme. It is shown that proposed iterative multiuser detection scheme with expectation of a coded bit have performance improvement over the iterative multiuser detection scheme with hard decision. It is also shown that proposed iterative multiuser detection scheme over a fast Rayleigh fading channel achieves smaller BER than over a slow Rayleigh fading channel.

REFERENCES


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Fig. 1. Block diagram of the transmitter for the proposed iterative multiuser detection scheme.

Fig. 2. Block diagram of the receiver for the proposed iterative multiuser detection scheme.

Fig. 3. BER of the proposed iterative multiuser detection scheme in an AWGN channel.

(a) $f_d T = 0.01$

(b) $f_d T = 0.001$

Fig. 4. BER of the proposed iterative multiuser detection scheme in a Rayleigh fading channel.