

An Iterative Multiuser Receiver Using Partial Parallel Interference Cancellation for Turbo-Coded DS-CDMA Systems

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Abstract—In this paper, a low-complexity multiuser receiver for turbo-coded DS-CDMA systems is presented to perform jointly iterative multiuser detection and turbo-decoding. The proposed approach consists of a new multistage partial parallel interference cancellation (NPPIC) detector and K single-user turbo decoders, where K is the number of active CDMA users. The NPPIC detector is derived based on the single-user maximum *a posteriori* criterion and has a similar simple structure to the conventional partial parallel interference cancellation scheme presented by Divsalar *et al.* A prominent feature of this detector is that it delivers interference-cancelled soft outputs to the turbo decoders and utilizes the soft information from the turbo-decoders' output. Extensive computer simulations demonstrate that the cooperation between NPPIC and turbo-decoding offers significant performance gain over the traditional non-iterative receivers and performs comparably to some existing iterative schemes of much higher complexity.

I. INTRODUCTION

The capacity of code-division multiple-access (CDMA) systems is greatly limited by multiple access interference (MAI). The poor performance of the conventional single-user detector and the high complexity of the optimal multiuser detector have motivated a lot of researches on sub-optimal approaches with lower complexity. These detectors include the linear decorrelating detectors [1], the linear minimum mean-squared error (MMSE) detectors [2], and the multistage interference cancellation detectors [3]–[7].

Recently, multistage parallel interference cancellation (PIC) has received considerable attention due to its simple structure and less decision delay. However, in some cases, the traditional multistage PIC (the total-PIC) [3] fails to guarantee performance improvements with more stages, due to improper interference estimates in cancellation. Divsalar *et al.* [4] proposed a partial PIC (PPIC) scheme, which alleviates the above-mentioned problem by introducing a weight in each stage to reduce the cost of wrong estimations. Nevertheless, at a heavy system load, the update of user bit estimations still becomes unreliable and may degrade the performance significantly. A linear version of this PPIC with weight optimization can be found in [5]. An example of practical real-time implementation of the PPIC scheme with complexity $O(K)$ per stage (K : number of users) is presented in [6]. In [7], Xue *et al.* suggested an adaptive least-mean-squares PIC (LMS-PIC) structure, where for each stage the weights are obtained by minimizing the mean-squared error between the received signal and its estimate through the LMS algorithm. Their results show a substantial performance improvement over the total-PIC and the conventional PPIC schemes. However, this approach involves much higher complexity of

$O(KGN_s)$ per stage, where G is the processing gain and N_s is the number of samples per chip.

It is believed that multiuser detection can be combined with forward error correction techniques to achieve additional performance enhancement. The optimal solution [8] for joint multiuser detection and decoding requires prohibitive complexity of $O(2^{Kv})$ (v : constraint length of the code). In [9], Reed *et al.* presented an iterative multiuser receiver structure that consists of a multiuser likelihood metric calculator and several single-user turbo decoders. This iterative receiver, though achieves near-single-user performance, still involves high computational complexity for likelihood calculations and metric generations. Gamal *et al.* [10] proposed an iterative scheme based on the MMSE criterion. Despite its excellent performance, the complicated matrix inversion operations involved in this approach still make its practical applications limited. Recently, Hsu *et al.* [11] proposed a low-complexity iterative approach that comprises a modified decorrelating decision-feedback detector (MDDFD) and a bank of single-user turbo decoders. Since this structure performs multiuser detection in a successive manner, performance for each user is highly dependent on the order of signal detections. Normally, user signals detected later will benefit from the results of those detected earlier. As shown in [11], for the case of low cross-correlation in spreading codes, this scheme exhibits an impressive performance for the most significant user (i.e., the last one for detection).

In this paper, we propose a low-complexity iterative multiuser receiver for turbo-coded DS-CDMA systems. The proposed approach consists of a new multistage partial parallel interference cancellation (NPPIC) detector and K single-user turbo decoders. The main idea of NPPIC is derived based on the single-user maximum *a posteriori* (MAP) criterion. A prominent feature of this detector is that it delivers interference-cancelled soft outputs to the turbo decoders and utilizes the soft information from the turbo-decoders' output. Extensive computer simulations demonstrate that the developed integrated receiver based on NPPIC offers significant performance gain over the traditional non-iterative receivers and performs comparably to some existing iterative schemes of much higher complexity.

II. SYSTEM MODEL

Throughout this paper, for simplicity of notations, we consider the uplink of a synchronous CDMA system in which K users are communicating simultaneously over a common additive white Gaussian noise (AWGN) channel with binary phase-shift keying (BPSK) modulation. The receiver at the base station is assumed to recover the timing and each user's

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carrier phase perfectly. Therefore, the equivalent baseband received signal can be written as

$$r(t) = \sum_{k=1}^K \sqrt{P_k} m_k(t) PN_k(t) + n(t) \quad (1)$$

where $n(t)$ denotes the ambient AWGN with power σ^2 and, for the k th user, P_k is the received power, $m_k(t) = \sum_{l=1}^L a_k(l) p(t - lT_b)$ represents the data modulation of L turbo-coded bits (L : frame size) with the l th bit $a_k(l)$ taking values on ± 1 equiprobably and unit-power rectangular pulse $p(t)$ of duration T_b , and $PN_k(t)$ is the spreading pseudo-noise (PN) waveform.

For each bit interval, the received signal $r(t)$ is first despreading by a bank of K matched-filters. Without loss of generality, we assume that the first interval is observed. As a result, the output of the k th matched-filter output is given by

$$Y_k = \frac{1}{\sqrt{T_b}} \int_0^{T_b} r(t) PN_k(t) dt = \sqrt{E_{bk}} a_k + \sum_{j=1, j \neq k}^K \sqrt{E_{bj}} a_j \rho_{jk} + n_k \quad (2)$$

where $E_{bk} = P_k T_b$ represents user k 's bit energy,

$$\rho_{jk} = \frac{1}{T_b} \int_0^{T_b} PN_j(t) PN_k(t) dt \quad (3)$$

is the cross-correlation coefficient between users j and k , and

$$n_k = \frac{1}{\sqrt{T_b}} \int_0^{T_b} n(t) PN_k(t) dt \quad (4)$$

is the Gaussian noise component of the k th user.

III. DERIVATION OF THE NEW INTERFERENCE CANCELLATION STRATEGY

In this section, we first have a brief overview on the conventional PPIC method, and then give a derivation of the proposed approach.

A. The Conventional PPIC

The multistage PPIC detector [4] performs the following decision rule for the k th user's bit at the m th stage:

$$\tilde{a}_k^{(m)} = p^{(m)}(Y_k - \hat{I}_k^{(m)}) + (1 - p^{(m)}) \tilde{a}_k^{(m-1)} \quad (5)$$

$$\hat{a}_k^{(m)} = \text{sgn}\{\tilde{a}_k^{(m)}\} \quad (6)$$

where

$$\hat{I}_k^{(m)} = \sum_{j=1, j \neq k}^K \sqrt{E_{bj}} \hat{a}_j^{(m-1)} \rho_{jk} \quad (7)$$

represents the estimated MAI computed from the other users' hard decisions $\{\hat{a}_j^{(m-1)} : j = 1, \dots, K, j \neq k\}$ at stage $m-1$, $p^{(m)}$ denotes the partial cancellation weight, and $\tilde{a}_k^{(m)}$ is defined as the "soft" decision of a_k (at stage m). The use of $p^{(m)}$ at each stage is aimed to reduce the cost of wrong MAI estimations. Furthermore, it is suggested that the weight should be increased for each successive stage since the estimates may become more reliable in later stages when most of the interference is cancelled.

B. The Proposed NPPIC

In this subsection, we derive a new PPIC (NPPIC) algorithm based on an alternative likelihood calculation approach. First, the *a posteriori* probability $p(a_k | Y_k, \hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)})$ for user k at stage m is investigated through the Bayes' rule as follows:

$$\begin{aligned} p(a_k | Y_k, \hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)}) &= \frac{\alpha(a_k) \cdot \beta(a_k)}{\alpha(+1) \cdot \beta(+1) + \alpha(-1) \cdot \beta(-1)} \\ &= \frac{\alpha(a_k) \cdot p(a_k | \hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)}) \cdot p(\hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)})}{\alpha(+1) \cdot \beta(+1) + \alpha(-1) \cdot \beta(-1)} \\ &\approx \frac{\alpha(a_k) \cdot p(a_k | \tilde{a}_k^{(m-1)}) \cdot p(\hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)})}{\alpha(+1) \cdot \beta(+1) + \alpha(-1) \cdot \beta(-1)} \\ &= C_0^{-1} \cdot \alpha(a_k) \cdot \gamma(a_k) \cdot p(a_k) \cdot p(\hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)}) \end{aligned} \quad (8)$$

where

$$\alpha(a_k) = p(Y_k | a_k, \hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)}) \quad (9)$$

$$\beta(a_k) = p(a_k, \hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)}) \quad (10)$$

$$\gamma(a_k) = p(\tilde{a}_k^{(m-1)} | a_k) \quad (11)$$

$$C_0 = \{\alpha(+1) \cdot \beta(+1) + \alpha(-1) \cdot \beta(-1)\} \cdot \{\gamma(+1) \cdot p(a_k = 1) + \gamma(-1) \cdot p(a_k = -1)\} \quad (12)$$

and the approximation follows from the assumption that the K users' symbols are statistically independent. The log-likelihood ratio (LLR) for a_k at the m th stage can then be evaluated as

$$\begin{aligned} \Lambda_k^{(m)} &= \log \frac{p(a_k = +1 | Y_k, \hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)})}{p(a_k = -1 | Y_k, \hat{I}_k^{(m)}, \tilde{a}_k^{(m-1)})} \\ &= \log \underbrace{\frac{p(a_k = +1)}{p(a_k = -1)}}_{\Lambda_{k,\text{in}}^{(m)}} + \log \underbrace{\frac{\alpha(+1) \cdot \gamma(+1)}{\alpha(-1) \cdot \gamma(-1)}}_{\Lambda_{k,\text{ex}}^{(m)}}. \end{aligned} \quad (13)$$

The first term $\Lambda_{k,\text{in}}^{(m)}$ represents the *a priori* (intrinsic) information that is available at stage m . The second term $\Lambda_{k,\text{ex}}^{(m)}$, which is known as the extrinsic information, is generated by the m th stage of interference cancellation. This information, together with other information produced from other parts of the receiver (e.g. the channel decoder), will be fed into the next stage as the *a priori* information $\Lambda_{k,\text{in}}^{(m+1)}$. The hard decision result of a_k at the m th stage is simply given by $\hat{a}_k^{(m)} = \text{sgn}\{\Lambda_k^{(m)}\}$ and will then be used to generate the interference estimates $\{\hat{I}_j^{(m+1)} : j = 1, \dots, K, j \neq k\}$.

By considering the Gaussian approximation of the residual noise after interference cancellation and that of $\tilde{a}_k^{(m-1)}$ as assumed in [4], the extrinsic information in (13) can be rewritten as

$$\begin{aligned} \Lambda_{k,\text{ex}}^{(m)} &\approx (Y_k - \hat{I}_k^{(m)}) \cdot 2\sqrt{E_{bk}} / \sigma_{k,m}^2 + \tilde{a}_k^{(m-1)} \cdot 2\sqrt{E_{bk}} / \tilde{\sigma}_{k,(m-1)}^2 \\ &\approx \tilde{a}_k^{(m)} \cdot 2\sqrt{E_{bk}} / (\sigma_{k,m}^2 + \tilde{\sigma}_{k,(m-1)}^2) \end{aligned} \quad (14)$$

where

$$\tilde{a}_k^{(m)} = p^{(m)}(Y_k - \hat{I}_k^{(m)}) + (1 - p^{(m)}) \tilde{a}_k^{(m-1)} \quad (15)$$

denotes the soft decision of a_k at the m th stage, $\sigma_{k,m}^2$ is the power of the residual noise, $\tilde{\sigma}_{k,(m-1)}^2$ represents the variance of $\tilde{a}_k^{(m-1)}$, and $p_k^{(m)} = \tilde{\sigma}_{k,(m-1)}^2 / (\sigma_{k,m}^2 + \tilde{\sigma}_{k,(m-1)}^2)$.

As a counterpart to [4], a reduced-complexity sub-optimal approach can be attained if the cancellation weight $p_k^{(m)}$ in (15)

are pre-assigned rather than computed exactly. Moreover, the computation of $\Lambda_{k,\text{ex}}^{(m)}$ involves the evaluation of $\sigma_{k,m}^2$, which can be obtained through various estimation methods with additional complexity cost [12]. In order to maintain a simple structure of the proposed approach, the power of the residual noise is approximated to that of ambient AWGN while (14) is calculated. Consequently, for the k th user, the procedure of the NPPIC scheme at stage m can be addressed as follows

$$\tilde{a}_k^{(m)} = p^{(m)}(Y_k - \hat{I}_k^{(m)}) + (1 - p^{(m)})\tilde{a}_k^{(m-1)} \quad (16)$$

$$\Lambda_{k,\text{in}}^{(m)} = \Lambda_{k,\text{ex}}^{(m-1)} + \Lambda_{k,\text{other}} \quad (17)$$

$$\Lambda_{k,\text{ex}}^{(m)} = \tilde{a}_k^{(m)} \cdot 2\sqrt{E_{bk}} / (\sigma^2 p^{(m)}) = \tilde{a}_k^{(m)} \chi_k^{(m)} \quad (18)$$

$$\hat{a}_k^{(m)} = \text{sgn}\{\Lambda_k^{(m)}\} = \text{sgn}\{\Lambda_{k,\text{in}}^{(m)} + \Lambda_{k,\text{ex}}^{(m)}\} \quad (19)$$

where $\Lambda_{k,\text{other}}$ denotes the soft reliability information of a_k generated from other parts of the receiver, $\hat{I}_k^{(m)}$ is as defined in (7) and a unified weighting factor $p^{(m)}$ is assigned for all users. The principle for choosing $p^{(m)}$, as stated previously, should be increased as the fidelity of $\{\hat{a}_j^{(m-1)} : j = 1 \dots K, j \neq k\}$ improves which implies a larger $p^{(m)}$ in the later stages. Indeed, this perception is supported by the numerical results to be presented later. Furthermore, at the initial stage, we set $\tilde{a}_k^{(0)} = Y_k$, $\hat{a}_k^{(0)} = \text{sgn}\{Y_k\}$, and $\Lambda_{k,\text{ex}}^{(0)} = 0$.

The NPPIC scheme is applicable in both coded and uncoded systems. Specifically, for the uncoded case and $\Lambda_{k,\text{other}} = 0$, the evaluation of (18) is reduced to

$$\Lambda_{k,\text{ex}}^{(m)} = (1/p^{(m)}) \cdot \tilde{a}_k^{(m)}, \quad (20)$$

as long as the user bit energy E_{bk} and the noise power σ^2 are held constant over all stages.

Comparing the new algorithm (16)-(19) with the conventional PPIC in [4], the determination of $\hat{a}_k^{(m)}$ is no longer simply $\text{sgn}\{\tilde{a}_k^{(m)}\}$ but does involve the *a priori* likelihood information $\Lambda_{k,\text{in}}^{(m)}$. This coincides the powerful turbo-processing concept and in turn aids to the accuracy of the estimate $\hat{a}_k^{(m)}$. Beyond the likelihood-iterating feature, this new algorithm has a similar structure to the conventional PPIC scheme [4] and accordingly can be implemented through the same method [6] with complexity of $O(K)$ per stage. The block diagram of one stage of the proposed NPPIC scheme is depicted in Fig. 1.

IV. AN ITERATIVE MULTIUSER RECEIVER

Based on the developed multistage NPPIC detector, we further propose an iterative multiuser receiver for turbo-coded DS-CDMA systems. Fig. 2 depicts the structure of this iterative receiver, which comprises a M -stage NPPIC detector and K single-user turbo decoders. We consider a turbo code that consists of two recursive systematic convolutional (RSC) codes linked by an interleaver and assume that the BCJR algorithm [13] is used for decoding turbo codes. In the beginning of the first receiver iteration, reliability information of data bits from the turbo-decoders' output is not available;

consequently, $\Lambda_{k,\text{other}}(l) = 0$ ($k = 1, \dots, K$ and $l = 1, \dots, L$) and initialization of the NPPIC detector is set the same as described in section III-B. The NPPIC detector delivers soft interference-cancelled outputs $\{\tilde{a}_k^{(M)}(l) : k = 1, \dots, K, l = 1, \dots, L\}$ to the input of turbo decoders. After N turbo-decoder iterations, the LLR's $\{L_k(l) : k = 1, \dots, K\}$ of data bits at the turbo-decoders' output are fed back to the input of the NPPIC detector as the soft reliability information $\{\Lambda_{k,\text{other}}(l) : k = 1, \dots, K\}$ for the next receiver iteration, i.e., $\Lambda_{k,\text{other}}(l) = L_k(l)$. Since the proposed NPPIC scheme requires the soft reliability information for both the systematic (uncoded) bits and the redundant (coded) bits, the turbo decoders are modified to produce the LLR's for these bits. The corresponding modification can be found in [14]. Therefore, in the new receiver iteration, we have

$$\begin{aligned} \hat{a}_k^{(0)}(l) &= E\{a_k(l)\} = \sum_{a_k(l) \in \{+1, -1\}} a_k(l) \cdot p(a_k(l)) \\ &= \sum_{a_k(l) \in \{+1, -1\}} \frac{a_k(l) \cdot \exp(a_k(l) \cdot L_k(l))}{1 + \exp(a_k(l) \cdot L_k(l))} \\ &= \tanh(L_k(l)/2), \end{aligned} \quad (21)$$

$\tilde{a}_k^{(0)}(l) = \sqrt{E_{bk}} \tanh(L_k(l)/2)$, and $\Lambda_{k,\text{ex}}^{(0)}(l) = 0$ for the initial stage of the proposed NPPIC detector, where $k = 1, \dots, K$.

V. SIMULATION RESULTS

In order to verify the effectiveness of the proposed interference cancellation algorithm, the bit error rate (BER) performance of the multistage NPPIC detector is first investigated for uncoded CDMA systems and is then followed by the simulation results of the integrated receiver for turbo-coded systems.

A. Performance Evaluation for Uncoded Systems

For performance comparison of the proposed NPPIC approach to other schemes, computer simulations were also run for various PIC detectors, such as the total-PIC [3], the conventional PPIC [4], the linear PPIC [5], and the LMS-PIC [7] approaches. In the simulated example, we adopted a set of randomly generated short codes with processing gain $G = 64$ for signal spreading/despreading and considered a zero-mean AWGN with double-sided spectral density $N_0/2$. The cancellation weights for both the NPPIC and the conventional PPIC schemes were set to be 0.7 in the first stage, 0.9 in the last stage and unified to 0.8 in the intermediate stages, while those for the linear PPIC detector were optimized based on the steepest descent method as presented in [5]. The step sizes for the LMS-PIC scheme were set to be 0.1 in the first stage, 0.05 in the second stage, and 0.02 in the following stages. Furthermore, fractionally spaced sampling at a rate of $N_s = 2$ samples per chip was performed for the LMS-PIC scheme to guarantee convergence. The number of cancellation stages employed for each scheme is 4 and the number of CDMA users is set to be 45, i.e., a 70% system load is assumed.

Fig. 3 shows BER versus the signal-to-noise ratio ($\text{SNR} = E_b/N_0$) for a power-balanced CDMA system, where the energy of each user's bit is equal to E_b . In this case, the total-PIC has the worst performance due to its severe error

propagation problem. The conventional and linear PPIC approaches behave well at low-to-moderate SNRs. However, both schemes suffer BER saturation as SNR increases. On the other hand, the NPPIC detector performs comparably to the LMS-PIC scheme when SNR is below medium and provides the best performance when SNR gets higher. In particular, to achieve the BER of 10^{-2} , the LMS-PIC, the linear PPIC, and the conventional PPIC schemes require respectively an extra 0.5 dB, 3.3 dB, and 4.3 dB SNR relative to the proposed NPPIC detector.

B. Performance Evaluation for Turbo-Coded Systems

The BER performance of the proposed iterative receiver was also investigated. We further assume that the receiver knows the ambient noise variance exactly. A rate $R=1/2$ turbo code with two 4-state (constraint length $\nu=3$; octal generator 7, 5) RSC codes and a helical block interleaver of length $L=210$ bits were used for simulations. Besides, the BCJR algorithm [13] was employed for decoding turbo codes. In the simulations, we considered a power-balanced 4-user ($K=4$) system with equal cross-correlation $\rho_{jk}=0.5$ ($1 \leq j, k \leq 4$). Three receiver iterations were executed, and for each receiver iteration two stages of the proposed NPPIC (i.e., $M=2$) and two turbo-decoder iterations (i.e., $N=2$) were performed. The cancellation weight set $[p^{(1)} \ p^{(2)}]$ for NPPIC was set to $[0.5 \ 0.55]$ for the first iteration, $[0.6 \ 0.65]$ for the second iteration, and $[0.7 \ 0.75]$ for the final iteration. The use of a set of higher cancellation weights in each successive receiver iteration is due to the increased signal fidelity out of the turbo decoders. For comparison purpose, simulations were also run for three non-iterative receivers and three iterative ones. Among the three non-iterative schemes, the first one comprises a LMS-PIC detector with $3 \times M = 6$ stages followed by turbo decoders with $3 \times N = 6$ decoding iterations, the second and the third receivers are obtained by replacing the LMS-PIC detector in the first example with conventional and linear PPIC detectors (with the same number of stages), respectively. This yields to comparable complexity for each of the non-iterative receivers to the proposed approach. An identical set of 6 weights employed in the proposed approach was also applied to the conventional PPIC scheme, while the cancellation weights or the step sizes related to the rest two non-iterative receivers was set the same manner as in section V-A. Moreover, the iterative receivers presented in [9]-[11] were also included for performance comparison, where the number of receiver iterations and the number of turbo-decoder iterations for each receiver iteration were set the same as that of the proposed scheme. For all the receivers compared, the numbers of total turbo-decoder iterations are all equal to six.

The performance comparison for various receivers is depicted in Fig. 4, where we have denoted the proposed scheme and the three approaches in [9], [10], and [11] as "Iterative NPPIC", "Iterative MUD", "Iterative MMSE", and "Iterative MDDFD", respectively. One can observe that "Iterative NPPIC" has an impressive performance improvement over all the non-iterative schemes as well as "Iterative MDDFD" and performs comparably to "Iterative MMSE" and "Iterative MUD". Note that even with only one receiver iteration (the non-iterative case), "Iterative NPPIC" still outperforms each non-iterative scheme. This means the

proposed receiver is superior to the non-iterative schemes in terms of both performance and complexity. Specifically, for a coded BER of 10^{-3} , the proposed receiver has nearly the same excellent performance as "Iterative MUD" and "Iterative MMSE" and offers an extra 0.5 dB performance gain over "Iterative MDDFD" (user #4). Moreover, at a higher SNR (e.g. 3.5 dB), the detrimental effects of MAI can almost be overcome by the proposed approach.

In each iteration, "Iterative MUD" and "Iterative MMSE" involve respectively $O(2^K)$ and $O(K^4)$ computational operations in executing multiuser detection. However, the complexity involved by "Iterative NPPIC" is only of $O(KM)$. This reveals the efficiency of the proposed receiver in attaining a given quality of service for turbo-coded systems.

VI. CONCLUSIONS

In this paper, we have presented an iterative multiuser receiver for turbo-coded DS-CDMA systems. This receiver is based on the cooperation between the developed new partial parallel interference cancellation (NPPIC) and turbo-decoding in an iterative manner. The main idea of NPPIC is derived on the basis of the single-user MAP criterion. It can process the reliability information generated from the previous cancellation stage as well as that from the turbo-decoders' output and produce the extrinsic information for use in the next stage. This leads to a more reliable likelihood iterating and hence improves the estimation of user data bits. In addition, the NPPIC detector delivers interference-cancelled soft outputs to the turbo decoders. The complexity of the NPPIC detector is of $O(K)$ per stage, which is the same as that of the conventional PPIC scheme [4] and is much lower than that of the LMS-PIC method [7].

For an uncoded CDMA system, computer simulations have shown that the performance gain of the proposed NPPIC approach is substantial over other existing PIC schemes. For a turbo-coded system, performance of the integrated receiver based on NPPIC is further compared to a variety of approaches. Simulation results have revealed that this receiver can provide a significant performance improvement over the non-iterative schemes as well as the approach in [11]. Besides, it can achieve nearly the same performance as other well-known iterative schemes [9]-[10] of much higher complexity. The high-performance and low-complexity features make the proposed receiver attractive for use in practical applications.

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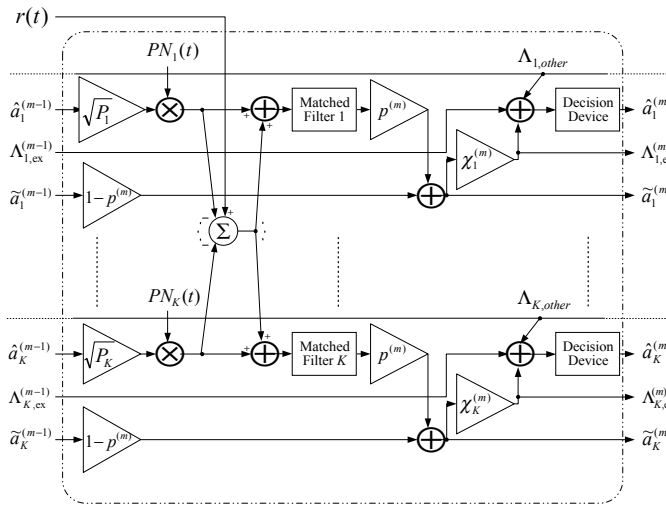


Fig. 1. m th stage of the NPPIC detector.

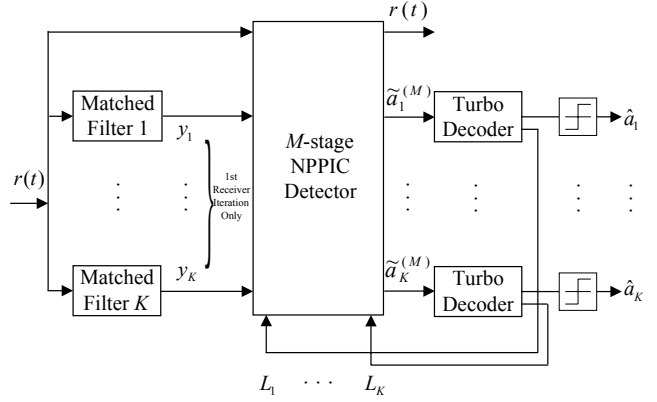


Fig. 2. The proposed iterative multiuser receiver based on NPPIC for turbo-coded DS-CDMA systems.

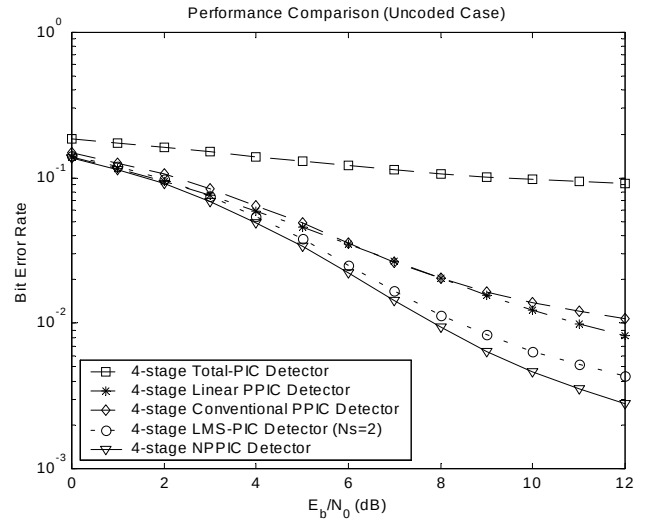


Fig. 3. Performance comparison of various multiuser detection schemes in a power-balanced uncoded DS-CDMA system.

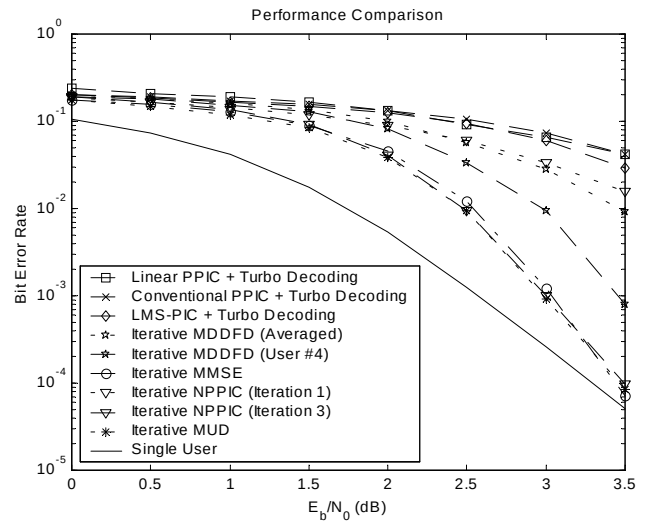


Fig. 4. Performance comparison of various multiuser receivers in a power-balanced turbo-coded DS-CDMA system.