THE RESEARCH OF A NEW MULTIUSER DETECTION SCHEME COMBINING DECORRELATING DETECTOR AND PARTIAL PARALLEL INTERFERENCE CANCELLER

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ABSTRACT

The decorrelating detector can afford good data estimates because it does not need to know many parameters of the received signal. However, it shows great performance deprivation when the background noise is high. On the other hand, partial parallel interference canceller(PPIC) has the potential to combat the near-far problem and have much lower computation complexity. But its performance depends on the initial data estimate. An improved PPIC scheme is proposed in this paper to combat the near-far problem. It utilizes the advantages of the two detectors by combining them. The focus of this paper is on the BER performance and the near-far resistance capability of the proposed scheme. Computer simulations demonstrate that the proposed detector has good BER performance and near-far resistance capability.

KEYWORDS

PPIC, Decorrelating Detector, BER, Near-Far Resistance.

Ⅰ INTRODUCTION

The direct-sequence code-division multiple access(DS-CDMA) is the most widely used mobile communication technology in 3G. The capacity and performance of DS-CDMA system is limited by MAI. Especially in the environment when the near-far problem is severe[1~2]. Verdu proposed the optimum detector. Unfortunately, it has exponential computational complexity on the order $O(2^K)$, here K is the number of users. Therefore, some suboptimal multiuser detectors were proposed to mitigate MAI and combat near-far problem[2]. An important example is decorrelating detector[3~5] with an output that is multiuser interference-free and whose bit error rate(BER) is therefore independent of the interfering amplitudes in theory. In addition to this near-far resistance property, the decorrelating detector does not require an estimate of the received signal's amplitudes. But, the decorrelating detector will enhance the system's background noise. Especially when the background noise is high the performance deprivation is severe. However, partial parallel interference canceller(PPIC)[6] deals with the received data with parallel mode whose initial data estimates adopts the output of matched filters. It has advantages such as little time delay and resistance to near-far problem. Especially it has much lower computation complexity compared with other multiuser detection scheme. But its performance depends on the initial data estimates greatly. As the description in the later part of the paper, like parallel interference canceller, in order to improve the performance of PPIC, multistage detection is adopted and the decorrelating detector is used as the initial data estimates in this paper.

In this paper, a new partial parallel interference canceller is proposed, which combines an decorrelating detector with the conventional PPIC to get improved near-far resistance capability. The remainder of the paper is organized as follows: In the Section Ⅱ,the system model to be studied is described. In Section Ⅲ,the structure of the proposed detector is given in detail along with the output data analysis. Some numerical results are given analysed in Section Ⅳ.This paper ends with some concluding remarks in Section Ⅴ.

Ⅱ SYSTEM MODEL

As known to all, DS-CDMA is the most popular among the spread spectrum techniques for multiple access applications. Therefore, in the paper, a system model based on DS-CDMA scheme will be discussed.

Assuming that there are K users in the system which share a channel and the modulation is BPSK, the baseband model of the received signal at the receiver can be written as:

$$r(t)=\sum_{k=1}^{K} s_k(t-t_k)+n(t)=\sum_{k=1}^{K}\sqrt{E_{bk}}\,d_k(t-t_k)\,c_k(t-t_k)\,e^{jj_k}+n(t) \quad (1)$$

where $E_{bk}, d_k(t), c_k(t)$ and j_k are bit energy, information bit, signature waveform and the carrier shift of k^{th} user, respectively. The t_k is the time delays of users at the receiver end. Under synchronous condition, we have $t_1 = t_2 = \cdots = t_K = 0$. The noise $n(t)$ is a complex additive white Gaussian noise(AWGN) with zero mean and two-sided power spectral density(PSD) of $N_0/2$. The d_k and $c_k \in \{-1, 1\}$ with the duration of T_b (bit duration) and T_c (chip duration), respectively, are assumed to be independent identically distributed(i.i.d) random variables. The processing gain is N, here $N = T_b / T_c$. At the receiver end, the arrived signal is passed through a group of correlators in order to recover the information data transmitted by each user. Hence, the output of the k^{th} correlator under synchronous condition would be:

$$\tilde{d}_k^{(0)} = \frac{1}{T_b}\int_0^{T_b} r(t)\, c_k(t)\, dt = \frac{1}{T_b}\int_0^{T_b}\left[\sum_{k'=1}^{K}\sqrt{E_{bk'}}\, d_{k'}(t-\tau_{k'})\, c_{k'}(t-\tau_{k'})\, e^{j\varphi_{k'}} + n(t)\right] c_k(t)\, dt$$

$$= \sum_{k'=1}^{K}\sqrt{E_{bk'}}\, d_{k'}\, r_{k'k}\, e^{j\varphi_{k'}} + n_k \tag{2}$$

where $r_{kk'} = r_{k'k} = \frac{1}{T_b}\int_0^{T_b} c_{k'}(t)\, c_k(t)\, dt = \frac{1}{N}\sum_{i=1}^{N} c_{k'i}.c_{ki}$ and $n_k = \frac{1}{T_b}\int_0^{T_b} n(t).c_k(t)\, dt$ (3)

It is easy to see that n_k is a complex Gaussian random variable with zero mean and variance of N0/2. For the sake of simplicity, hereafter, we will consider the first user as the one of interest.

Ⅲ THE PROPOSED MULTIUSER DETECTION SCHEME AND ITS ANALYSIS

Parallel interference canceller(PIC) subtracts out MAI estimates, therefore it has the potential to combat the near-far problem. As stated in [2], by improving the accuracy of data estimates, especially the initial(first stage of a PIC) data estimates, the PIC can suppress the interferers much more efficiently, i.e. more near-far resistant. Du Lin etc in [7] proposed one multi-user detector which combines PIC and adaptive MMSE. In this scheme, the MMSE is used as the initial data estimates. The scheme has two drawbacks: First, the initial data estimate can be more accurate if other detection method is adopted as the initial data estimate; Second, with the increase of the stages, the depravation of performance will be great. Although the adoption of multistage scheme can enhance the performance of proposed scheme in [7], for a large number of users, when multistage PIC scheme is used, performance improves very slowly as the number of stages goes higher. While the decorrelating detector has simple structure and provides significant performance improvement over conventional matched filter[3]. Furthermore, the decorrelating detector can provide good initial data estimate, because it can completely remove the interfering signals in theory. Divsalar in [6] showed that the cancellation of the entire interferences from each user is not necessarily for PIC. Instead, partial removal of interference enhances the performance drastically. This kind of detector was named partial parallel interference canceller(PPIC) where a small portion of the interference is cancelled in early stages since the decisions are not that reliable. Consequently, as the number of stages increases, the amount of the partial cancellation is increased since it is assumed that more stages result in better quality of data in the sense of BER. In a PPIC detector, the output of the m^{th} stage is based on a weighted sum of the output of the $(m-1)^{th}$ stage's data estimate $\tilde{d}_1^{(m-1)}$ and the interference canceled version of matched filter(MF) output at the $(m-1)^{th}$ stage $\left(\tilde{d}_1^{(0)} - I_1^{(m-1)}\right)$. The idea to use weighted sum originates from the joint observation of $\tilde{d}_1^{(0)}$ and $\tilde{d}_1^{(m-1)}$ [6]. Here, the output of the m^{th} stage of a PPIC detector is[8]:

$$\tilde{d}_1^{m} = l_m \left(\tilde{d}_1^{0} - \hat{I}_1^{m-1} \right) + \left(1 - l_m \right) \tilde{d}_1^{m-1} \tag{4}$$

where $l_m, \tilde{d}_1^{0}, \hat{I}_1^{m}$ and $\tilde{d}_1^{m-1}$ are the partial cancellation coefficient, MF output, interference affecting the first user, and the output of the soft $(m-1)^{th}$ stage of a PPIC detector, respectively. In this paper, we use soft PPIC[6,8] because of its simpler structure .And for the initial data estimates we use decorrelating detector because it need not know the perfect knowledge of the user's parameters[2]. Figure 1 shows the block diagram of a conventional soft PPIC detector.

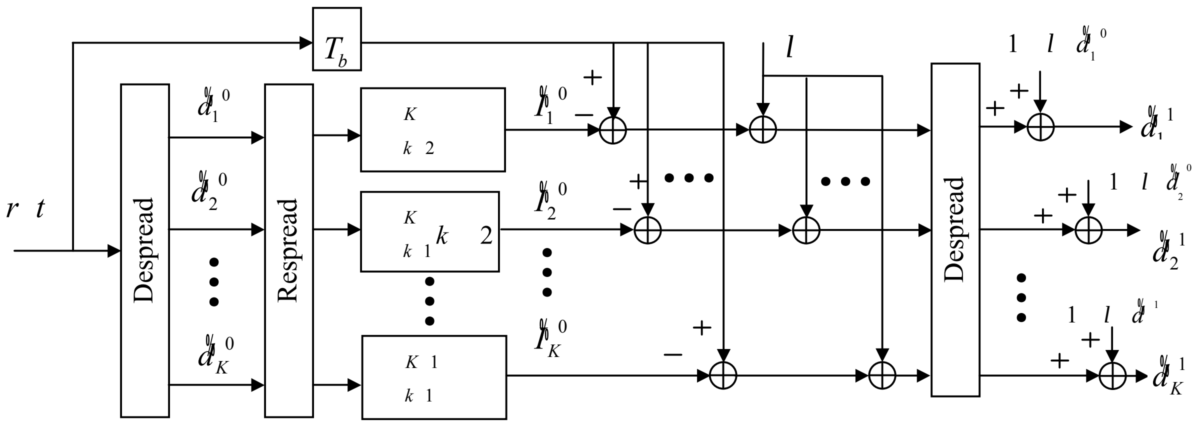

Figure 1 The principal block diagram of one stage of a conventional soft PPIC detector

In our scheme, we use the decorrelating detector as the initial data estimate of a soft PPIC detector. The received signal $r(t)$ is passed on to one decorrelating detector and be demodulated. Then we can get the output signal, we call it $d_{DD}^{0}(t)$ .We can rewrite $d_{DD}^{0}(t)$ as the following form:

$$d_{DD}^{0}(t) = R^{-1}(t) r(t) = Ad(t) + R^{-1}(t) n(t) \tag{5}$$

Here $R^{-1}(t)$, A and $d(t)$ are the cross-correlation, the amplitude and the demodulated information data by the decorrelating detector(in actual communication system, $d(t) \approx d(t)$,where $d(t) = [d_1(t), d_2(t), \ldots, d_k(t), \ldots, d_K(t)]$ is the transmitted information data. $d_{DD}^{0}(t)$ can also be rewritten as the matrix form: $d_{DD}^{0}(t) = [d_{1_{DD}}^{0}(t), d_{2_{DD}}^{0}(t), \ldots, d_{K_{DD}}^{0}(t)]$. $d_{DD}^{0}(t)$ is used as the initial data estimates in a soft PPIC. After being processed by the PPIC, the output data can be expressed as $D(t)$,where $D(t) = [\tilde{d}_1^{m}(t), \tilde{d}_2^{m}(t), \ldots, \tilde{d}_K^{m}(t)]$,here m is the number of stage of a PPIC. The proposed scheme's block diagram is drown as Figure 2.

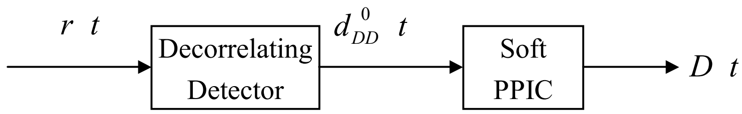

Figure 2 The block diagram of the proposed scheme

In order to derive the data output of the proposed scheme, we give the structure of the i^{th} stage of a soft partial parallel interference canceller. It is drown as Figure 3:

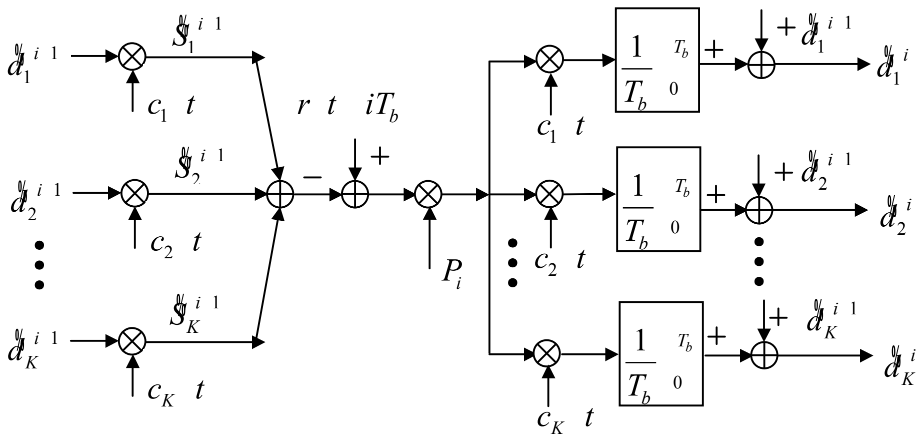

Figure 3 The i^{th} stage of a soft partial parallel interference canceller

According Figure 2, 3 and (4), the output of the i^{th} stage of the proposed detector for the first user(the one of interest) is:

$$\tilde{d}_1^{i}(t) = \frac{1}{T_b}\int_0^{T_b} l_i \left[d_{DD}^{0}(t - iT_b) - \sum_{k=1}^{K} \tilde{S}_k^{i-1}(t) \right] c_1(t)\, dt + \tilde{d}_1^{i-1}(t - T_b) \tag{6}$$

where $\tilde{S}_k^{i-1} = \tilde{d}^{i-1} c_k(t)$ .Since the signals of $\tilde{d}_1^{i}(t)$, $d_{DD}^{0}(t - iT_b)$, $\tilde{S}_k^{i-1}(t)$, $\tilde{d}_1^{i-1}(t - T_b)$ are sampled at $t=iT_b$, the time shifts may be omitted from all signals in order to obtain a simpler notation. After the simplification, we have:

$$\tilde{d}_1^{i} = l_i \frac{1}{T_b}\int_0^{T_b} \left[d_{DD}^{0}(t) - \sum_{k=1}^{K} \tilde{S}_k^{i-1}(t) \right] c_1(t)\, dt + \tilde{d}_1^{i-1}$$

$$= l_i \tilde{d}_1^{0} + (1 - l_i)\, \tilde{d}_1^{i-1} - l_i \sum_{k=2}^{K} \tilde{d}_k^{i-1} r_{k1} \tag{7}$$

Here $$\tilde{d}_1^{0} = l_i \frac{1}{T_b}\int_0^{T_b} d_{DD}^{0}(t)\, c(t)\, dt \tag{8}$$

For a single stage detector(i.e. i=1), we have $\tilde{d}_1^{(1)} = \tilde{d}_1^{(0)} - \lambda_1 \sum_{k=2}^{K} \tilde{d}_k^{(0)} \rho_k$ (9)

Where $\tilde{d}_1^{(0)} = \sqrt{E_{b1}} d_1 e^{j\varphi_1} + \sum_{k=2}^{K} \sqrt{E_{bk}} d_k \rho_{k1} e^{j\varphi_k} + n_1$ (10)

Using (10) and (9), we can get:

$$\tilde{d}_1^{(1)} = \tilde{d}_1^{(0)} - \lambda_1 \left(\tilde{d}_2^{(0)} \rho_{21} + \tilde{d}_3^{(0)} \rho_{31} + \cdots + \tilde{d}_K^{(0)} \rho_{K1} \right)$$

$$= \sqrt{E_{b1}} d_1 \left(1 - \lambda_1 \sum_{k=2}^{K} \rho_{k1}^2 \right) e^{j\varphi_1} + \sum_{k=2}^{K} \sqrt{E_{bk}} d_k \left(\rho_{k1} - \lambda_1 \sum_{k'=2}^{K} \rho_{kk'} \rho_{k'1} \right) e^{j\varphi_k} + \left(n_1 - \lambda_1 \sum_{k=2}^{K} n_k \rho_{k1} \right) \quad (11)$$

where the first, second and the third components of (11) are refered as desired data information, residual interference and the background noise, respectively. For a two-stage detector, we have:

$$\tilde{d}_1^{(2)} = \lambda_2 \tilde{d}_1^{(0)} + (1 - \lambda_2) \tilde{d}_1^{(1)} - \lambda_2 \sum_{k=2}^{K} \tilde{d}_k^{(1)} \rho_{k1} \quad (12)$$

Substituting (9) into (12),we can get:

$$\tilde{d}_1^{(2)} = \tilde{d}_1^{(0)} - (\lambda_1 + \lambda_2 - \lambda_1 \lambda_2) \sum_{k=2}^{K} \tilde{d}_k^{(0)} \rho_{k1} + \lambda_1 \lambda_2 \sum_{k=2}^{K} \sum_{k'=2}^{K} \tilde{d}_{k'}^{(0)} \rho_{k'k} \rho_{k1} \quad (13)$$

Again, applying (10) into (13), yields:

$$\tilde{d}_1^{(2)} = \sqrt{E_{b1}} d_1 \left[1 - (\lambda_1 + \lambda_2 - \lambda_1 \lambda_2) \sum_{k=2}^{K} \rho_{k1}^2 + \lambda_1 \lambda_2 \sum_{k=2}^{K} \sum_{k'=2}^{K} \rho_{kk'} \rho_{k'1} \rho_{k1} \right] e^{j\varphi_1}$$

$$+ \sum_{k=2}^{K} \sqrt{E_{bk}} d_k \left[\rho_{k1} - (\lambda_1 + \lambda_2 - \lambda_1 \lambda_2) \sum_{k'=2}^{K} \rho_{kk'} \rho_{k'1} + \lambda_1 \lambda_2 \sum_{k'=2}^{K} \sum_{k''=2}^{K} \rho_{kk'} \rho_{k'k''} \rho_{k''1} \right] e^{j\varphi_k}$$

$$+ n_1 - (\lambda_1 + \lambda_2 - \lambda_1 \lambda_2) \sum_{k=2}^{K} \rho_{k1} n_k + \lambda_1 \lambda_2 \sum_{k=2}^{K} \sum_{k'=2}^{K} \rho_{kk'} \rho_{k'1} n_k \quad (14)$$

For a two stage of the proposed scheme, (8)~(14) constitute all of the steps of the data detection.In general, for an M-stage soft PPIC detector with the decorrelating detector as the initial data estimate, the output for the first user(assumed to be the desired user) can be expressed as:

$$\tilde{d}_1^{(M)} = \tilde{d}_1^{(0)}$$

$$- \left[A_{11} \sum_{m=1}^{M} \lambda_m - A_{12} \sum^{\binom{M}{2}} \prod \lambda_m + \cdots + (-1)^{M} A_{1(M-1)} \sum^{\binom{M}{M-1}} \prod \lambda_m + (-1)^{M+1} A_{1M} \prod_{m=1}^{M} \lambda_m \right] \sum_{k=2}^{K} \tilde{d}_k^{(0)} \rho_{k1}$$

$$+ \cdots + (-1)^{i} \left[A_{i1} \sum^{\binom{M}{i}} \prod \lambda_m - A_{i2} \sum^{\binom{M}{i+1}} \prod \lambda_m + \cdots + (-1)^{M+1+i} A_{i(M-i)} \sum^{\binom{M}{M-i}} \prod \lambda_m \right.$$

$$+(-1)^{M+2-i} A_{i,M+1-i} \prod_{m=1}^{M} \lambda_m \sum_{k_2 \neq k}^{K} \cdots \sum_{k_{i-1} \neq k_{i-2}}^{K} \tilde{d}^{(0)}_{k_{i-1}} \rho_{k_{i-1}k_{i-2}} \rho_{k_{i-2}k_{i-3}} \cdots \rho_{kk}\rho_{k1}$$

$$+(-1)^{M} \prod_{m=1}^{M} \lambda_m \sum_{k_2 \neq k}^{K} \cdots \sum_{k_{M-1} \neq k_{M-2}}^{K} \tilde{d}^{(0)}_{k_{M-1}} \rho_{k_{M-1}k_{M-2}} \rho_{k_{M-2}k_{M-3}} \cdots \rho_{kk}\rho_{k1} \quad (15)$$

where for convenience, i is used as the index of term of (15) and m is the number of stage. $\prod_{m=1}^{M}{}^{i} \lambda_m$ is defined as the sum of all products of i of λ_m s where $m = 1, 2, \ldots, M$ and

$$A_{ij} = \begin{cases} 1, if\ i = 1 and 1 \le j \le M\ or\ j = 1 and 1 \le i \le M \\ A_{i-1,j} + A_{i,j-1}, otherwise \end{cases} \quad (16)$$

Ⅳ SIMULATION RESULTS AND ITS ANALYSIS

It can be seen that for a large number of interference cancellation stages, the expression for the corresponding output of the proposed scheme becomes very complicated. Therefore, the analysis of the BER performance is very difficult. Instead of the analytical study of multistage detector we will take advantage of computer simulations. We use MATLAB as the simulation software.Figure 4 and 5 shows the BER performance of the proposed scheme. In Figure 4 and 5, the processing gain N=32 and 64 respectively, E_b/N_0 varies from –8 to 0dB. The user number K is 12 and $0 \le \varphi \le 2\pi$. In order to achieve a good confidence level, 100 packets of 10000 bits will be run for each simulation. And we use a two stage of the proposed scheme(i=2). Figure 4 and 5 are given in the following.

In the two figures, CD denotes the conventional detector, DD denotes the decorrelating detector, DD+PPIC denotes the proposed scheme whose initial data estimates adopts decorrelating detector and CD+PPIC denotes the conventional PPIC whose initial data estimates adopts the matched filters. $\lambda_1 = 0.3$ and $\lambda_2 = 0.5$ are used here for the simulation of the proposed scheme. From the two figures, we can see that the BER performance of the proposed scheme are better than CD, DD and CD+PPIC. It can be seen show that the proposed scheme has good BER performance. Because for the application of the mobile receiver, the BER is restricted below 10^{-3}, we can see that, in Figure 4, the processing gain N is 32, here if E_b/N_0 is greater than –2.3dB, then the requirement of the practicable application can be satisfied. Especially, in Figure 5, when the processing gain N=64, if E_b/N_0 is greater than –5dB, then the requirement of the practicable application would be satisfied well. Furthermore, in actual communication system, the processing gain N can be much greater than 64. Now, the BER performance will be much better than what the two figures have shown. Also, we can see that although only two stage(i=2) is adopted, the performance enhancement is obvious. The method overcomes the drawbacks of the PIC whose performance enhance slowly with increase of the stages.

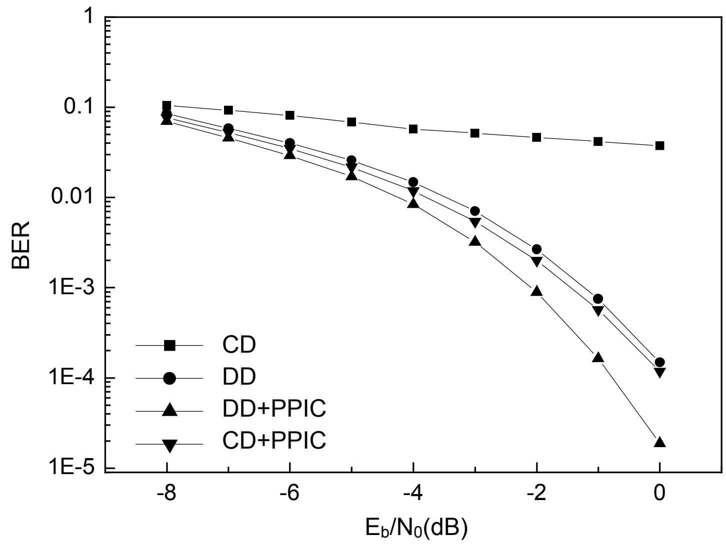

Figure 4 the BER of the proposd scheme(N=32,*K*=12)

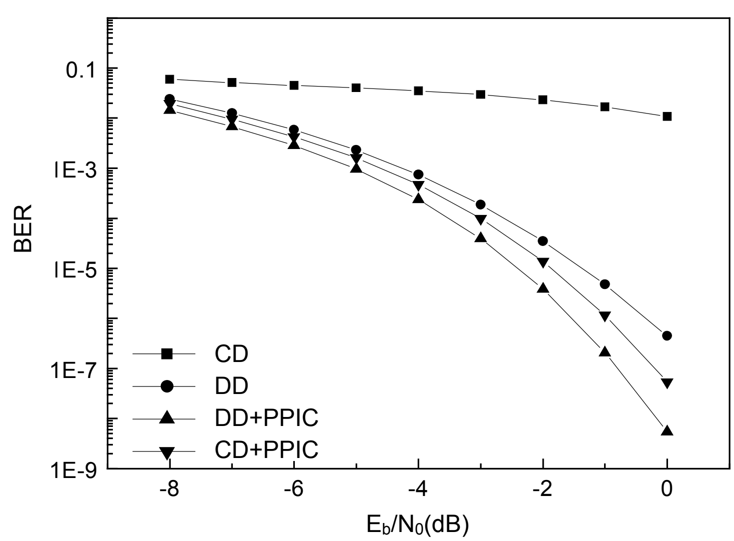

Figure 5 the BER of the proposd scheme(N=64,*K*=12)

In order to demonstrate the near-far resistance capability of the proposed scheme, we use the curves of the BER versus the difference between the $SNR_i \;\; i \;\; 2, \mathbf{L}, K$ of the interfering user and SNR_1 of the desired user. If the BER of one detector is lower, then the near-far resistance capability of one detector of this kind of detector is better. Figure 6 gives the near-far resistance performance of the proposed scheme compared with CD,DD,PPIC. From these curves of Figure 6, we can see the BER variation is almost constant when $SNR_i \;\; SNR_1$ varies from 0~10dB.That is to say the proposed scheme is near-far resistant. And that the near-far resistance of the proposed scheme DD+PPIC is better than CD,DD and CD+PPIC.

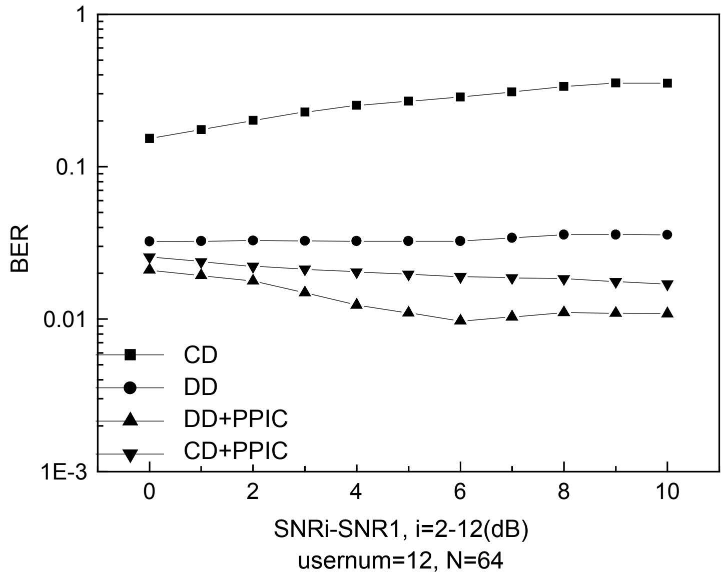

Figure 6 The near-far resistance performance of the proposed scheme (N=64,*K*=12)

Ⅴ CONCLUSION

In this paper, we proposed a new multiuser detector scheme which combines the decorrelating detector and a soft PPIC[6]. Here the output of the decorrelationg detector is adopted as the initial data estimates of PPIC. Computer simulations demonstrate that the proposed scheme has better BER performance than CD, DD and CD+PPIC. Numberical analysis of the BER performance from Figure 4 and Figure 5 and the near-far resistance performance from Figure 6 show that the proposed scheme has better BER performance and are more near-far resistant. Therefore, we can say that the proposed combined multiuser detection scheme is a good scheme for near-far resistance and has actual meanings.

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