行政院國家科學委員會專題研究計畫　成果報告

碼域多重進接之最佳部分平行干擾消除器

計畫類別：個別型計畫
計畫編號：NSC91-2213-E-009-141-
執行期間：91 年 08 月 01 日至 92 年 10 月 31 日
執行單位：國立交通大學電信工程學系

計畫主持人：吳文榕

報告類型：精簡報告
報告附件：出席國際會議研究心得報告及發表論文
處理方式：本計畫可公開查詢

中　華　民　國 92 年 10 月 20 日

行政院國家科學委員會專題研究計畫成果報告

碼域多重進接系統之二階式最佳部份平行式干擾消除器

An Optimum Two-stage Partial Parallel Interference Canceller for CDMA Systems

計畫編號：NSC 91-2213-E-009-141

執行期限： 91 年 8 月 1 日至 92 年 7 月 31 日

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I. 中文摘要

在直接序列碼域多重進接系統中，平行式干擾消除法是一有效且簡單的多用戶偵測器，然而在前幾階中，其系統效能可能由於不可靠的干擾估測值而受到影響，因此部份消除因子被用來控制干擾消除量，而產生了部份平行式干擾消除法。在本計劃中，我們提出一個二階式部份平行式干擾消除器，並求得其最佳部份消除因子之運算式，我們的理論結果適用於功率控制下或無功率控制下之系統，也適用於同步與非同步系統。實驗結果顯示，理論最佳值與實驗值非常接近，我們所推導之最佳二階式部份平行式干擾消除法也比三階全平行式干擾消除法表現優良。

關鍵詞： 碼域多重進接系統，平行式干擾消除法，部分消除因子。

Abstract

Parallel interference cancellation (PIC) is considered as an effective yet simple detector for multiuser communications in direct-sequence code division multiple access (DS-CDMA) systems. However, the system performance may be deteriorated due to unreliable interference estimate in early canceling stages. Thus the partial cancellation factor (PCF) is introduced to control the interference canceling level resulting in the partial PIC approach. In this project, we propose a method deriving a closed-form solution for the optimum PCF in a two-stage partial PIC receiver. Our results apply to either power balanced or unbalanced, synchronous or asynchronous systems. Simulation results show that our theoretical optimal PCF values are close to the empirical ones. Also, the optimal two-stage partial PIC even outperforms a three-stage full PIC.

Keyword: parallel interference cancellation, partial cancellation factor, CDMA.

II. 計畫緣由與目的

Direct-sequence code-division multiple

-access (DS-CDMA) is considered as a promising technique in cellular and personal communications. Conventional receivers utilizing a bank of matched filters suffers from the multiple access interference (MAI) according to other users and the near-far effect due to imperfect power control. To mitigate these problems a maximum-likelihood detector was proposed. In order to reduce the computational complexity, some suboptimum multiuser receivers were then proposed. Among the suboptimum detectors, parallel interference cancellation (PIC)[1,2,3] is regarded as a simple and useful method. PIC cancels all MAI from other users simultaneously in one stage. The computational complexity is low and the processing delay is small.

Conventional PIC receivers admit the full cancellation of MAI in each stage. However, the MAI estimate may not be reliable in earlier canceling stages. As a consequence the *partial* PIC detector was proposed [4],[5] in which the partial cancellation factors (PCFs) are introduced to control the interference cancellation level. The optimum PCF can be either adaptively trained or theoretically calculated. Although the adaptive method is simple, it requires a period of time for training. In [6], a method is proposed to calculate the optimum PCF in synchronous systems. The drawback of the result is that it only applies to a perferct power control scenario. In this project we propose a method to theoretically calculate the optimal PCF in a two-stage partial PIC receiver. Our results can be applied to synchronous or asynchronous, power balanced or unbalanced systems. Simulations show that our theoretical optimal PCFs match with the empirical ones.

III. 研究方法與成果

Consider an asynchronous CDMA transmission system accommodating K users. The equivalent baseband received signal can be obtained as

$$r(t) = \sum_{k=1}^{K} s_k(t-\tau_k) + n(t)$$
$$= \sum_{k=1}^{K} \sqrt{P_k}\, a_k(t-\tau_k) b_k(t-\tau_k) + n(t),$$

where $s_k(t)$ denotes the k th user's transmitted signal, and $a_k(t)$, $b_k(t)$ represent the signature and data waveforms, both are rectangular pulse trains with chip and bit duration. Also, P_k is the signal power, τ_k the transmission delay, and $n(t)$ the additive white Gaussian noise with two-sided power spectral density $N_0/2$. The first stage decision statistic of user k (assumed as the desired user) at the i th bit can be obtained by correlating the received signal with the corresponding spreading waveform. For a particular user, the partial PIC receiver regenerates and subtracts the interference from other users as

$$\hat{r}_k(t, C_k) = r(t) - C_k \sum_{j \neq k} \hat{s}_j(t-\tau_j).$$

Note that the interference estimate is

$$\hat{s}_k(t) = \frac{1}{T} a_k(t) \sum_{i=-\infty}^{\infty} Y_{k,i}\; q(t-iT) \qquad (8)$$

where $Y_{\mathrm{k,i}}$ denotes the matched filter output and $q(t)$ is as rectangular pulse with bit duration T . In addition, C_k is the partial cancellation factor (PCF) for the k th user. Thus, the decision output in the second stage can be represented as

$$Z_{k,i}(C_k) = \int_{iT+\tau_k}^{(i+1)T+\tau_k} \hat{r}_k(t) a_k(t-\tau_k) dt.$$

We denote the bit error rate (BER) for the user k as $P(e_k)$. We assume that the probabilities for $b_k(i) = 1$ and $b_k(i) = -1$ are equal. If we treat bits from other users as identical and independent random variables, the BER can be found as

$$P(e_k) = Q(C_k \mid b_k(i) = 1)$$
$$= Q\left(\sqrt{\frac{M\{Z_{k,i}(C_k)\}}{V\{Z_{k,i}(C_k)\}}} \right)$$

where $Q(.)$ is the Q-function and

$$M\{Z_{k,i}(C_k)\} = E\{Z_{k,i}(C_k)\}^2$$

$$V\{Z_{k,i}(C_k)\}=E\{Z_{k,i}^2(C_k)\}-E\{Z_{k,i}(C_k)\}^2.$$

The squared mean is found to be

$$M\{Z_{k,i}(C_k)\}=P_k\left(T-\frac{C_k}{T}\sum_{m\neq k}R_{m,k}^2+\hat{R}_{m,k}^2\right)^2$$

$$\triangleq P_k\left(T-\frac{C_k}{T}\Lambda_1\right)^2$$

where Λ_1 is defined implicitly. The correlation functions are defined as

$$R_{j,k}(\tau_{j,k})\triangleq\int_0^{\tau}a_j(t-\tau)a_k(t)dt$$

$$\hat{R}_{j,k}(\tau_{j,k})\triangleq\int_{\tau}^{T}a_j(t-\tau)a_k(t)dt.$$

Similarly, the variance can be obtained as

$$V\{Z_{k,i}(C_k)\}=\Delta_1C_k^2-2\Delta_2C_k+\Delta_3$$

where $\Delta_i, 1\leq i\leq 3$ are represented as

$$\Delta_1=P_k\cdot\frac{1}{T^2}\sum_{m\neq k}2R_{m,k}^2\hat{R}_{m,k}^2+\sum_{m\neq k}P_m(\phi_m^2+\psi_m^2)$$

$$+\frac{1}{T^2}\left(\sum_{m\neq k}\sum_{j\neq m,k}^{\tau_j\leq\tau_m}\sqrt{P_m}R_{m,j}R_{j,k}\right)^2$$

$$+\frac{1}{T^2}\left(\sum_{m\neq k}\sum_{j\neq m,k}^{\tau_j>\tau_m}\sqrt{P_m}\hat{R}_{m,j}\hat{R}_{j,k}\right)^2$$

$$+\frac{1}{T}\frac{N_0}{2}\sum_{m\neq k}(R_{m,k}^2+\hat{R}_{m,k}^2)$$

$$+\frac{1}{T^2}\cdot\frac{N_0}{2}\left(\sum_{m\neq k}\sum_{j\neq m,k}^{\tau_j\leq\tau_m}2\hat{R}_{m,j}R_{m,k}R_{j,k}\right.$$

$$+2\hat{R}_{m,j}\hat{R}_{m,k}\hat{R}_{j,k}+2R_{m,j}R_{m,k}\hat{R}_{j,k}$$

$$\left.-\sum_{m\neq k}\sum_{j\neq m,k}^{\tau_j=\tau_m}\hat{R}_{m,j}R_{m,k}R_{j,k}+\hat{R}_{m,j}\hat{R}_{m,k}\hat{R}_{j,k}\right)$$

$$\Delta_2=\sum_{m\neq k}P_m(R_{m,k}\phi_m+\hat{R}_{m,k}\psi_m)$$

$$+\frac{N_0}{2T}\sum_{m\neq k}R_{m,k}^2+\hat{R}_{m,k}^2$$

$$\Delta_3=\sum_{m\neq k}P_m(R_{m,k}^2+\hat{R}_{m,k}^2)+\frac{N_0}{2}T,$$

and ϕ_m and ψ_m are defined as

$$\phi_m\triangleq R_{m,k}+1/T\sum_{j\neq m,k}^{\tau_j>\tau_m}R_{m,j}R_{j,k}$$

$$+1/T\sum_{j\neq m,k}^{\tau_j\leq\tau_m}(\hat{R}_{m,j}R_{j,k}+R_{m,j}\hat{R}_{j,k})$$

$$\psi_m\triangleq\hat{R}_{m,k}+1/T\sum_{j\neq m,k}^{\tau_j\leq\tau_m}\hat{R}_{m,j}\hat{R}_{j,k}$$

$$+1/T\sum_{j\neq m,k}^{\tau_j>\tau_m}(\hat{R}_{m,j}R_{j,k}+R_{m,j}\hat{R}_{j,k}).$$

Consequently, we can obtain C_k as

$$C_{k,opt}=\left\{C_k:V\frac{dM}{dC_k}-M\frac{dV}{dC_k}=0\right\}.$$

Thus the solution to the optimum PCF is then

$$C_{k,opt}=\frac{\Delta_2T^2-\Delta_3\Lambda_1}{\Delta_1T^2-\Delta_2\Lambda_1}.$$

IV. 結論

For multiuser detection in DS-CDMA systems, the PIC receiver is considered an effective and easy solution. It is known that the performance and the stability of the full PIC can be further improved. This is achieved using the idea of partial cancellation and the receiver of this type is called partial PIC. In this project, we have derived the optimum PCF for a two-stage partial PIC receiver which can reach the minimum BER in the asynchronous system. Experimental results have been validated and demonstrates the good matching between our theoretical and empirical results. The optimal two-stage partial PIC is shown to perform better than the two-stage and even three stage full PIC receivers. Note that the synchronous system can be considered as a special case of asynchronous one. It is straightforward to simplify our results for synchronous systems.

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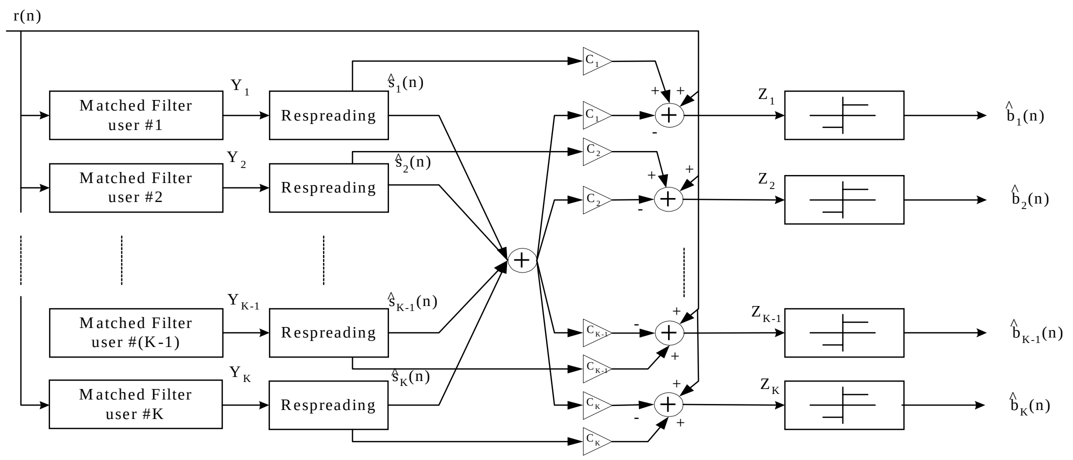
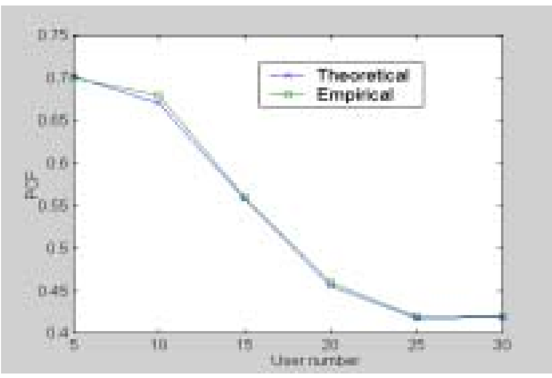


Figure 1. Structure of the partial PIC receiver.



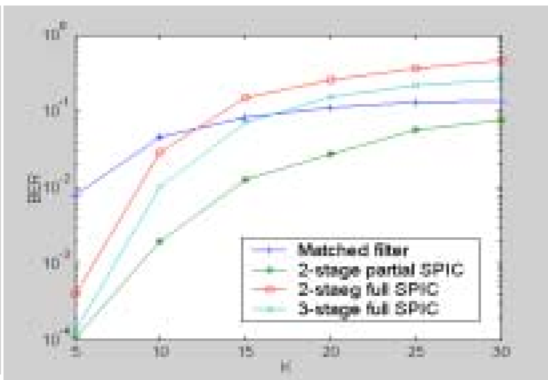


Figure2. Comparison of the theoretical and empirical optimum PCF under different user numbers with Gold codes of length 31 and SNR=8 dB.

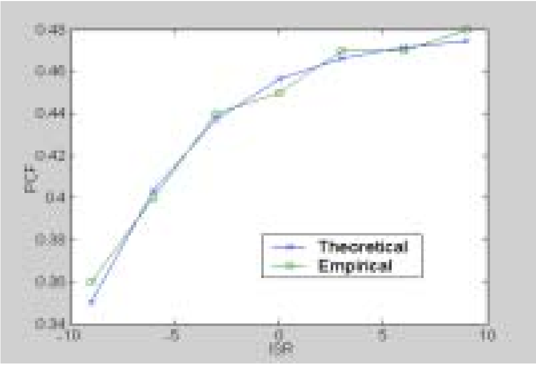


Figure 3. Comparison of the theoretical empirical optimum PCF under different interference-to-signal ratios with K=20 and SNR=8 dB.

Figure 4. Performance comparison under different user number with perfect power control. SNR=10 dB.

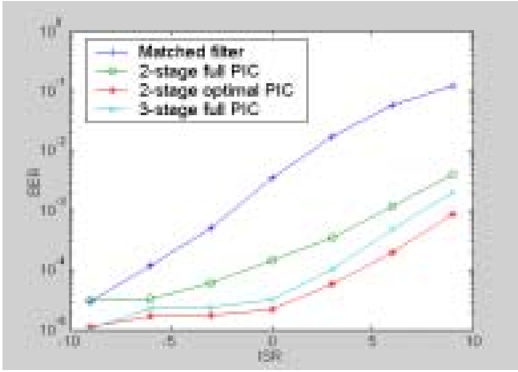


Figure 5. Performance comparison under different interference-to-signal ratios with K=4 dB and SNR=10.