行政院國家科學委員會專題研究計畫　成果報告

用於多用戶偵測之適應性盲蔽平行式干擾消除接收機

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用於多用戶偵測之適應性盲蔽平行式干擾消除接收機
New adaptive blind PIC receivers for multiuser detection

計畫編號：NSC 93-2213-E-009-104
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I.　中文摘要

平行式干擾消除法乃是針對直接序列碼分多重擷取系統一簡單而有效之多用戶偵測器。然而其效能表現可能因前幾階不可靠之干擾消除而降低，因此就有部分平行式干擾消除法的發展，此法乃利用部分消除因子來控制欲消除之干擾量，而提高系統效能。並且此部份平行式干擾消除法可以藉由適應性盲蔽平行式干擾消除法來實現，其最佳部分消除因子可由最小均方差理論求得。在本計劃中吾人針對適應性盲蔽型部分平行式干擾消除法，提出一改善方法，其主要概念在於減低最小均方差理論中所訓練之權重值的數目，並且進行權重值之後續濾波處理，使得最終多餘的均方差能因此減低。吾人也推導改良理論之輸出均方差與位元錯誤率。實驗結果證實所提出之改良理論表現優於傳統部分平行式干擾消除法，而理論分析結果也相當準確。
關鍵詞： 多用戶偵測，平行式干擾消除法，最小均方差理論，效能分析。

Abstract

Parallel interference cancellation (PIC) is considered a simple yet effective multiuser detector for direct-sequence code-division multiple-access (DS-CDMA) systems. However, its performance may deteriorate due to unreliable interference cancellation in the early stages. Thus, a partial PIC detector in which partial cancellation factors (PCFs) are introduced to control the interference cancellation level has been developed as a remedy. In addition, the partial PIC can be implemented adaptively using the adaptive blind partial PIC where the optimal PCFs are trained using the least mean square (LMS) algorithm. In this project we propose an improved adaptive blind partial PIC and analyze its performance. The main idea is to reduce the number of active weights in the LMS algorithm and to perform weight post filtering such that the resultant excess mean square error (MSE) can be reduced. We also derive the output bit error rate for the proposed algorithm. Simulation results verify that the proposed algorithm outperforms the conventional partial PIC approach and analytical results are accurate.
Keyword: multiuser detection, parallel interference cancellation, LMS algorithm, performance analysis.

II.　**計畫緣由與目的**

Multiuser detection (MUD) is a technique for improving the performance of code-division multiple-access (CDMA) systems. The development of MUD algorithms can be dated back to the seminal work of S. Verdu. He proposed a multiuser receiver utilizing the maximum-likelihood criterion [1] and showed a great performance enhancement. However, He also showed that the computational complexity grows exponentially with the user number. The high computational complexity adversely affects its real-world applications. Thus, a variety of low-complexity suboptimum receivers were then proposed [2].

Among the suboptimal receivers, one promising technique is parallel interference cancellation (PIC) [3]. For a particular desired user, the PIC estimates interference from other users, regenerates it, and cancels it from the received signal all at one time. This canceller is usually implemented with a multistage structure. The temporary data decision for a stage is obtained from its previous stage. One problem in the PIC approach is that the interference estimates may not be reliable in early stages. In other words, interference cancellation does not necessarily reduce interference. To alleviate this problem, partial PIC was then developed. Partial cancellation factors (PCFs) ranging from 0 to 1, were introduced to control the signal cancellation level [4]. The optimal PCFs can be obtained in adaptive or non-adaptive ways. The non-adaptive optimal PCFs for specific scenarios can be found in [5-6]. Besides the theoretical solution, the LMS adaptive algorithm was also used to search optimal PCFs for partial PIC [7]. Due to its special architecture, this approach does not need training sequence. We call it adaptive blind partial PIC. It was found that this partial PIC outperforms non-adaptive ones. In this project we propose an improved adaptive blind partial PIC and analyze its performance. The main idea here is to reduce the number of active weights in the LMS algorithm and reduce the adapted weight variance such that the resultant excess mean square error (MSE) can be reduced. We also perform the bit error rate (BER) analysis in the second stage.

III. 研究方法與成果

Consider a synchronous system operated in an AWGN channel. The received signal in a certain bit interval can be expressed as $r(n)=\sum_{k=1}^{K}a_k(n)b_k(n)x_k(n)+v(n)$ where $a_k(n)$ and $b_k(n)$ are the th user's amplitude and data bit, $x_k(n)$ denotes its signature sequence, $v(n)$ is AWGN with variance σ^2, and N is the processing gain. The matched filter output, which is the first stage output, can be represented as $y_k^{(1)}=a_kb_k+\sum_{j\neq k}a_jb_j\rho_{jk}+\gamma_k$ where ρ_{jk} denotes the user correlation and γ_k is the noise term after despreading. From above it can be seen that the output signal is noisy due to the MAI. Thus the adaptive blind partial PIC is introduced to enhance the performance. We first define the error signal as $e^{(i)}(n)=r(n)-\hat{r}^{(i)}(n)$ where $\hat{r}^{(i)}(n)$ is the regenerated received signal and it is expressed as $\hat{r}^{(i)}(n)=\sum_{k=1}^{K}w_k^{(i)}(n)\hat{b}_k^{(i)}x_k(n)$. Here, $w_k^{(i)}(n)$ is the adapted weight for the kth user in the ith stage and serves as the PCF. Consequently, we define the MSE as $J^{(i)}(n)=E\left\{\left(e^{(i)}(n)\right)^2\right\}$. The interference-subtracted signal for the kth user is then $\hat{r}_k^{(i)}(n)=r(n)-\sum_{j\neq k}\hat{b}_j^{(i-1)}x_j(n)w_j^{(i)}(N)$ where the optimal PCFs are obtained using adapted weights at the end of adaptation. We then have the detected bit as $\hat{b}_k^{(i)}=\mathrm{sgn}\left[y_k^{(i)}\right]$ where $y_k^{(i)}$ is the matched filter output in the ith stage and it is given by matching $\hat{r}_k^{(i)}(n)$ with $x_k(n)$. Note that the adaptive blind partial PIC may give different optimal PCFs from that of non-adaptive ones. This is due to different optimization objectives used for the two algorithms. In the non-adaptive type partial PIC, optimal PCFs are determined based on the minimization of the ensemble error average for all transmission bits. In other words, optimal PCFs apply to all received bit signals. On the contrary, the PCF for the adaptive blind partial PIC is obtained by minimizing the ensemble error average within a certain bit interval (given the bit decision in first stage). It can be seen that in the perfect condition, $w_k^{(i)}(N)=\begin{cases} a_k & \hat{b}_k^{(i)}=b_k \\ -a_k & \hat{b}_k^{(i)}\neq b_k \end{cases}$.

Thus, the convergent weights depend on whether the bit decision results in the previous stage are correct or erroneous. The adaptive algorithm allows the weight of each user can attain the desired value symbol by symbol. This is the reason why the adaptive approach performs better than non-adaptive methods. Note that the adaptation period is constrained in one symbol period. This is because the optimal weight for User *k* may be a_k or $-a_k$ depending on the bit decision for each symbol. Although the LMS algorithm is simple, its convergence may slow and the weight may not converge to the desired value in such a short period. In addition, the resultant weight heavily depends on the parameters used in the LMS algorithm so is the cancellation performance. As a matter of fact, it can be seen that the performance of the adapted weights are determined by several factors such as the number of weights, the step size, the number of training data, noise variance, and the weight initials. Note that these factors may interact one another. In this project we will manipulate the first two factors, i.e., the weight numbers and the step size to obtain improved performance. We propose an algorithm that can reduce the number of adapted weight as well as its variance. At the same time, the step size can be increased to accelerate convergence.

It can be easily observed that the MSE of the adaptive blind partial PIC is proportional to the number of weights adapted in the LMS algorithm. One way to improve the system performance is to reduce the weight number trained in the LMS algorithm. This is possible if we know the channel gains. We then propose a procedure to do that. If a user's matched output magnitude exceeds a threshold in the *i*th stage, the corresponding decided bit is deemed reliable and the weight corresponds to this bit is deactivated. In other words, this weight will not be included in the training process. It is shown in Fig. 2(a). Note that there must be some users whose weights are erroneously decided. If this happens, it will increase the noise variance in the LMS algorithm. Thus a proper threshold has to be determined. We call this procedure as the *weight selection* procedure.

It is well known that the convergent weights in the LMS algorithm are random. Thus, if we know the weight distribution, we can perform weight post filtering (estimation). This will enhance the PIC performance furthermore. In this project a piecewise linear decision function is used for weight post filtering. It is shown in Fig. 2(b). We call this the *weight post filtering* procedure.

Note that the weight means for erroneous decision bits will approach the corresponding optimal weights if the processing gain *N* is large. However, in a practical system, *N* is usually not large enough. Thus, we prefer to use a large step size to speed up the weight adaptation for users with erroneous decisions. However, a larger step size will enlarge the weight variance which adversely affects the final performance. The two procedures proposed above can reduce the number of active weights and further filter the convergent weights. As a result, it is possible to use a larger step size without significantly increasing the weight variance. By careful examination, we can find a good compromise among the parameters such that the weights are determined in an optimal way.

The LMS algorithm has been analyzed and developed for over four decades. However, most results cannot be used here. This is because the step size used in this application is large and this will violate many assumptions for conventional analysis. The other reason is that we most concern the transient behavior (due to small sample size) while most works only concern steady-state behavior. In the analysis the derivation for K-user cases are approximated using single-user or two-user cases. The optimal weights are functions of noise. Also the noise is a function of the input code correlation. The derivation is performed by successive conditional expectation such that the conditioned random variables are averaged out in each expectation procedure. Interested users can refer to [8] for details.

In the simulation results partial PIC receivers up to five stages are considered. Various multiuser receivers that include the conventional matched filter, the non-adaptive partial PIC (referred to as PPIC), and the adaptive blind partial PIC (referred to as the APPIC) are compared to the proposed algorithm. The optimized parameters used in each algorithm (such as the optimal PCFs for PPIC, optimal step sizes for APPIC, as well as the step sizes and thresholds in the proposed algorithm) are obtained empirically. In these figures the superior performance enhancement can be observed.

IV. 結論

The adaptive blind partial PIC receiver is a simple yet effective approach for enhancing the link performance of CDMA systems. In this project we propose an improved adaptive blind partial PIC receiver. We propose a weight selection procedure to reduce the number of adapted weights and a weight post filtering scheme to reduce weight variance introduced by the LMS algorithm. Simulation results show that the proposed algorithm outperforms the conventional adaptive approach in all scenarios. We also derive analytical results for the proposed algorithm which include output BER. It has been shown that the analysis results are reasonably accurate.

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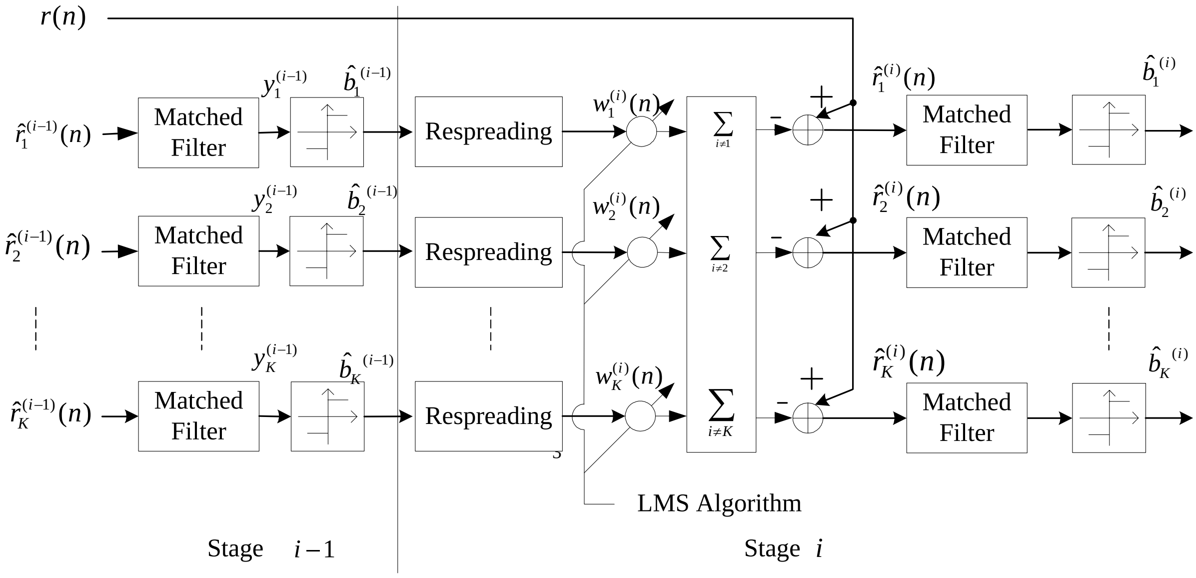

Figure 1. Structure of adaptive blind partial PIC receivers.

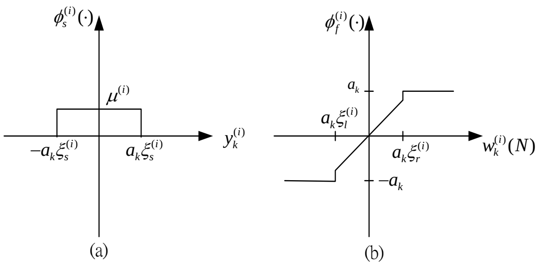

Figure 2. Function used in the proposed algorithm. (a) Weight selection function. (b) Weight post filtering function.

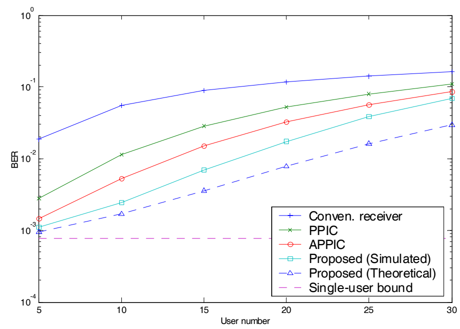

Figure 3. Second stage BER performance comparison.

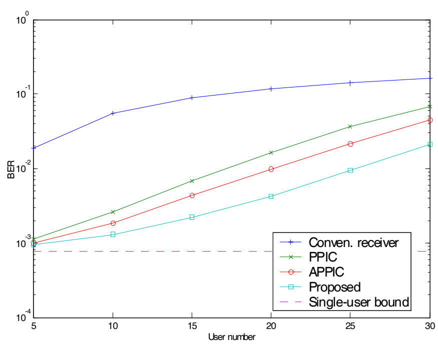

Figure 4. Fifth stage BER performance comparison.

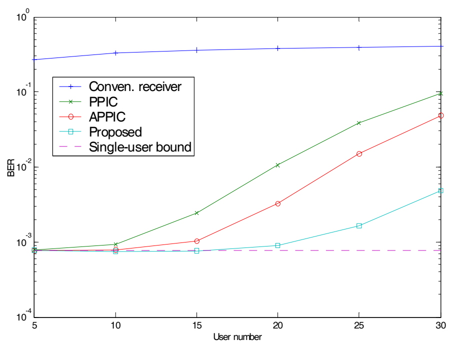

Figure 5. Fifth stage BER performance comparison for the weakest user with power-imbalanced scenario.