PAPER

Adaptive Rake Receiver with Sliding Window Linearly Constrained RLS Algorithm for Multipath Fading DS-SS CDMA System

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SUMMARY An adaptive filtering algorithm based on the sliding window criterion is known to be very attractive for violent changing environments. In this paper, a new sliding window linearly constrained recursive least squares (SW-LC-RLS) algorithm based on the modified minimum mean squared error (MMSE) structure [9] is devised for the RAKE receiver in direct sequence spread spectrum code-division multiple access (DS-SS CDMA) system over multipath fading channels, where the channel estimation scheme is accomplished at the output of adaptive filter. The proposed SW-LC-RLS algorithm has the advantage of having faster convergence property and tracking ability, and can be applied to the environments, where the narrowband interference is joined suddenly to the system, to achieve desired performance. Via computer simulation, we show that the performance, in terms of mean square errors (MSE), signal to interference plus noise ratio (SINR) and bit error rate (BER), is superior to the conventional LC-RLS and orthogonal decomposition-based LMS algorithms based on the MMSE structure [9].

key words: *DS-SS CDMA systems, multipath fading channel, narrowband interference, multiple access interference, sliding window LC-RLS algorithm*

1. Introduction

The code-division multiple access (CDMA) system implemented by the direct sequence spread spectrum (DS-SS) technique is one of the most promising multiplexing technologies for cellular telecommunications services [1]–[4]. The SS communication adopts a technique of using much wider bandwidth necessary to transmit the information over the channel. In the DS-SS CDMA system, due to the inherent structure interference, referred to as the multiple access interference (MAI), the system performance might degrade. To combat MAI, many efficient techniques such as the de-correlating, minimum mean-square error (MMSE), and minimum output energy (MOE) detectors were proposed [5]–[12]. In which, the adaptive multiuser detectors addressed in [9]–[12] are based on the modified MMSE structure. With the modified MMSE structure [9] the adaptive filtering techniques were suggested to compensate the effect due to channel amplitude and phase variation, and hence improving the system performance. Where the channel estimation scheme addressed in [9], [10] is accomplished at the output of the adaptive filter, in which the desired signal to interference plus noise ratio (SINR) should be substantially higher than the input of adaptive filter, and has good capability for wideband interference suppression.

Next, for DS-SS CDMA systems over frequency-selective fading channels, the effect of intersymbol interference (ISI) will exist, such that a multiuser RAKE receiver has to be employed to combat the ISI as well as MAI. Since, in practical wireless communication environments, there may have several communication systems operated in the same area at the same time. In this paper, we will consider the environment of DS-SS CDMA systems, where the asynchronous narrowband interference (NBI) due to other systems is joined suddenly to the CDMA system [13]–[15]. In general, when a system works in a stable state with adaptive detectors, a suddenly joined NBI signal will cause the system performance to be crash down. Under such circumstance, the existing conventional adaptive RAKE detectors may not be able to track well for the rapidly sudden changing NBI associated with the problems of ISI and MAI.

To circumvent the problem addressed above, in this paper, a new sliding window (SW) linearly constrained (LC) recursive least squares (SW-LC-RLS) algorithm is devised for the RAKE receiver in DS-SS CDMA system over multipath fading channels. In [16], it has been proved that the use of the RLS algorithm with the sliding window (SW) approach could achieve better tracking property over the conventional RLS algorithm. With this approach, the sliding window is used to discard old data to reduce the influence of the past on the estimate. It is noted that the use of linear constraint (LC) is significant due to the fact that, ideally, the adaptive weight vector with constraints could converge to the short (spreading) code sequence of desired user, which is independent of the parameters of forgetting factor and window size. Such that the effect of MAI introduced in the multiuser environments could be alleviated, successfully. On the other hand, the SW-RLS algorithm is very useful for the time-varying environments as addressed in [16] over the conventional RLS algorithm, and the selection of window size depends highly on the environments of time-varying systems.

Based on the discussion addressed above, in this paper, the SW-LC-RLS algorithm is devised based on the modified MMSE receiver structure described in [9] to achieve desired performance for the adaptive multiuser detector to suppress the MAI and NBI, simultaneously. The proposed scheme can be viewed as a linearly constrained version of [16], and is very useful for the environment of DS-SS CDMA system over the multipath-fading channel with NBI, which is joined suddenly to the system. The performance improve-

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ment, in terms of mean square errors (MSE), signal to interference plus noise ratio (SINR) and bit error rate (BER), of the proposed algorithm will be verified via computer simulation. With the same MMSE receiver structure of [9], the performance of the proposed algorithm is compared with the conventional LC-RLS and orthogonal decomposition-based LMS algorithms, when deals with the problems just described.

2. Signal Model Description

Let us consider a baseband synchronous DS-SS CDMA system with K active users over multipath Rayleigh fading channels. For convenience, we assume that the first user is the desired user, and the received signal is given by

$$r(t) = y(t) + v(t) + n(t) \tag{1}$$

with the transmitted signal, $y(t)$, being represented as

$$y(t) = \sum_{i=1}^{K} A_i \sum_{l=1}^{L_i} \alpha_{i,l}(t) e^{j\phi_{i,l}(t)} \sum_{n=1}^{N} b_i(t - \tau_{i,l}) s_i(t - nT_c - \tau_{i,l}) \tag{2}$$

where A_i is the signal amplitude of ith user's, $b_i(t)$ and $s_i(t)$ are the corresponding information bearing waveform and the signature waveform, with the length of the PN codes to be N, respectively, and T_c is the chip period. Also, in (1) $n(t)$ is the additive white Gaussian noise and the narrowband interference signal $v(t)$ is denoted as

$$v(t) = A_I \exp(j(\omega_I t + \theta_I)) \tag{3}$$

A_I, ω_I, and θ_I are designated as the amplitude, the frequency, and the phase of narrowband interference signal, respectively. Moreover, there are L_i fading paths for the ith user, and $\alpha_{i,l}(t)e^{j\phi_{i,l}(t)}$ denote the complex attenuation of the lth path due to Rayleigh fading channel of the ith user, and $\tau_{i,l}$ are the corresponding time delays. The signature waveform of the ith user is defined by

$$s_i(t) = \sum_{m=1}^{N} s_i^m \psi(t - mT_c) \tag{4}$$

where $s_i^m \in \{+1, -1\}$, for $m = 1, 2, \cdots, N$, is the mth element of the spreading sequence, $\psi(t)$ is the chip waveform, and $N = T_b/T_c$ is the processing gain.

3. Adaptive Multiuser Rake Receiver

We assume that after the front-end chip-matched filtering the received signal is sampled at the chip rate, T_c, over a bit interval T_b. From (1) and (3), for the RAKE receiver the equivalent discrete received signal vector of lth branch, $\mathbf{r}_l(m)$, at time $t = mT_b + \tau_{1,l}$ can be expressed as

$$\begin{aligned} \mathbf{r}_l(m) &= b_1(m)\alpha_{1,l}(m)e^{j\phi_{1,l}(m)}\mathbf{s}_1 \\ &\quad + \sum_{i=2}^{K} b_i(m)\alpha_{i,l}(m)e^{j\phi_{i,l}(m)}\mathbf{s}_i \\ &\quad + \sum_{i=1}^{K} \sum_{p=2}^{2(L_i-1)} \overline{b}_{i,p}(m)\overline{\mathbf{s}}_{i,p} + \mathbf{v}_l(m) + \mathbf{n}_l(m) \end{aligned} \tag{5}$$

where $\mathbf{s}_i$, for $1 \le i \le K$, is the spreading code vector of the ith user with unit norm, e.g., $\|\mathbf{s}_1\|^2 = 1$. The third term of (5) including $\overline{b}_{i,p}(m)$ and $\overline{\mathbf{s}}_{i,p}$ represents the part of ISI. Moreover, $\mathbf{v}_l(m)$ is designated as the narrowband interference vector, and $\mathbf{n}_l(m)$ denotes the AWGN vector, with zero mean. In the receiver, for channel estimation, a pilot symbol-aided modulation scheme described in [10] is employed, where each pilot symbol is periodically inserted into data symbol streams at every M data bits. We note that in the receiver of the DS-SS CDMA systems, to improve the system performance interference sources, viz., the wideband interference (MAI and ISI) and the narrowband interference (NBI) introduced by other communication systems, have to be minimized. In [9], [11], [12], the adaptive multiuser detector, with the orthogonal decomposition-based LMS algorithm, based on the modified MMSE criterion is employed. The modified cost function results in separate the adaptive multiuser detectors for each multipath component [9], hence, the adaptive RAKE receiver could be employed, in which each receiver branch is adapted independently to suppress interference. In [9], [11] the cost functions of the modified MMSE criterion for the lth branch of the adaptive RAKE detector is defined as:

$$E[|e_l(i)|^2] = E[|\hat{c}_{1,j}(i)d_l(i) - \mathbf{w}_l^H(i)\mathbf{r}_l(i)|^2] \tag{6}$$

In (6) the desired signal can be viewed as $d_l(i)$ multiplied by the $\hat{c}_{1,l}(i)$ which is the estimate of $c_{1,l}(i) = \alpha_{1,l}(i)e^{j\phi_{1,l}(i)}$ of desired user, where $\alpha_{1,l}(i)$ and $\phi_{1,l}(i)$ are amplitude and phase of the lth channel path coefficient, respectively. Moreover, $\mathbf{w}_l(i)$ is the corresponding tap weight vector, and $(\bullet)^H$ denotes the Hermitian operation. The adaptive Rake receiver based on the modified MMSE cost function of (6) is depicted in Fig. 1 [9], where the outputs of all adaptive receiver branches are maximal-ratio combined to produce decision variable. It is noted that the performance of the receiver based on the modified MMSE criterion depends highly on the accuracy of the estimated channel parameters. The most commonly used way to estimate channel coefficient is the moving average of pilot symbols, using input or output signal of the adaptive filter. However, the channel estimation is performed before the adaptive filtering process, therefore, the estimated channel information is very noisy. In Fig. 1, to estimate channel parameters the output signal of the adaptive filter was employed [9], in which, the estimated lth path of channel, $\hat{c}_{1,l}(i)$, of desired user is obtained as follows:

$$\hat{c}_{1,l}(i) = \frac{1}{N} \sum_{j=1}^{N_p} b_{1p}(i - jM)\mathbf{w}_l^H(i - jM)\mathbf{r}_l(i - jM)$$

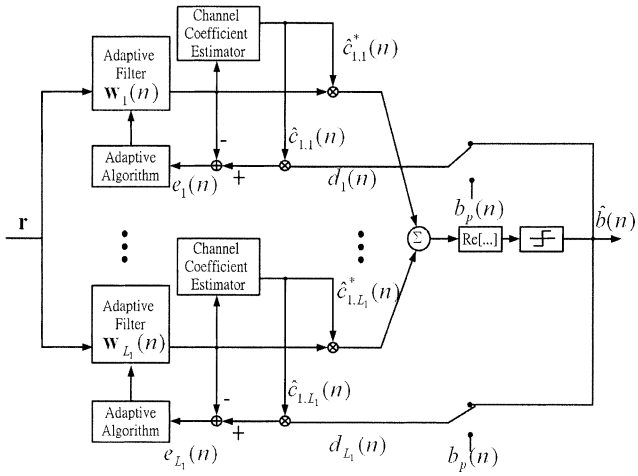


Fig. 1 General block diagram of the adaptive multiuser RAKE detector.

where N_p denotes the number of pilot symbols used for channel estimation and $b_{1p}(i - jM)$ is the sequence of pilot symbol of the desired user, know to the receiver, where M denotes the insertion period of pilot symbols.

4. Sliding Window LC-RLS Algorithm

For notational simplicity, in what follows, the subscript indicating the lth branch of the adaptive receiver is dropping out and ignored. To derive the SW-LC-RLS algorithm for individual branch of adaptive detector for DS-SS CDMA system, the cost function is chosen to be the exponential weighted least square value of the error,

$$e(i|n) = \tilde{d}(i) - \mathbf{w}^H(n)\mathbf{r}(i), \text{ i.e.,}$$

$$\varepsilon(n) = \sum_{i=n-L+1}^{n} \lambda^{n-i}|e(i|n)|^2, \quad (7)$$

and as described earlier $\tilde{d}(i)$ was defined as the $\tilde{d}(i) = \hat{c}_1(i)d(i)$, and $\lambda(0 < \lambda \leq 1)$ is the forgetting factor, which controls the tracking capability, and L denotes the length of sliding window. Cost function (7) is minimized subject to the constraint:

$$\mathbf{w}^H(n)\mathbf{s}_1 = 1 \quad (8)$$

where $\mathbf{s}_1$ is the spreading code vector of the desired user. The tap weight vector that minimizes the cost function (7), subject to the constraint (8), is obtained through the Lagrange multiplier method. Consequently, the constrained optimal least squares (LS) weight vector can be obtained [17]

$$\mathbf{w}(n) = \mathbf{R}^{-1}(n)\theta(n) + \mathbf{R}^{-1}(n)\mathbf{s}_1[\mathbf{s}_1^T\mathbf{R}^{-1}(n)\mathbf{s}_1]^{-1} \cdot [1 - \mathbf{s}_1^T\mathbf{R}^{-1}(n)\theta(n)] \quad (9)$$

where the input signal autocorrelation matrix, $\mathbf{R}(n)$, and the input-desired signal cross-correlation vector, $\theta(n)$, are designated as

$$\mathbf{R}(n) = \sum_{i=n-L+1}^{n} \lambda^{n-i}\mathbf{r}(i)\mathbf{r}^H(i) \quad (10)$$

and

$$\theta(n) = \sum_{i=n-L+1}^{n} \lambda^{n-i}\mathbf{r}(i)\tilde{d}^*(i), \quad (11)$$

respectively. From (10) the recursive equation of obtaining $\mathbf{R}(n)$ from $\mathbf{R}(n-1)$, involved the terms of updating and downdating, is described as follows

$$\mathbf{R}(n) = \lambda\mathbf{R}(n-1) + \mathbf{r}(n)\mathbf{r}^H(n) - \lambda^L\mathbf{r}(n-L)\mathbf{r}^H(n-L) \quad (12)$$

Based on (11) and (12), the SW-LC RLS algorithm can be derived. To do so, first, we recall that in deriving the conventional SW-RLS algorithm, the procedure involves two steps, viz., the updating and downdating. For convenience, we may define the intermediate updating matrix, $\mathbf{R}_m(n)$, which is given by

$$\mathbf{R}_m(n) = \lambda\mathbf{R}(n-1) + \mathbf{r}(n)\mathbf{r}^H(n) \quad (13)$$

Moreover, we note that in (9) the constrained optimal weight vector, $\mathbf{w}(n)$, consist of two terms, the first term is the unconstrained optimal solution

$$\mathbf{w}_{unc}(n) = \mathbf{R}^{-1}(n)\theta(n) \quad (14)$$

and the second term is related to the constraint parameter. For further derivation, we let

$$\mathbf{g}(n) = \mathbf{R}^{-1}(n)\mathbf{s}_1 \quad (15)$$

$$\varphi(n) = \mathbf{s}_1^T\mathbf{R}^{-1}(n)\mathbf{s}_1 \quad (16)$$

With the inversion lemma of matrix, the inverse of the intermediate updating matrix, $\mathbf{R}_m(n)$, of (13) is obtained as follows

$$\mathbf{R}_m^{-1}(n) = \lambda^{-1}\mathbf{R}^{-1}(n-1) + \lambda^{-1}\mathbf{k}_u(n)\mathbf{r}^H(n)\mathbf{R}^{-1}(n-1) \quad (17)$$

where $\mathbf{k}_u$ is the Kalman gain vector of the updating procedure

$$\mathbf{k}_u(n) = \frac{\mathbf{R}^{-1}(n-1)\mathbf{r}(n)}{\lambda + \mathbf{r}^H(n)\mathbf{R}^{-1}(n-1)\mathbf{r}(n)} \quad (18)$$

By right-multiplying both sides of (17) by the constraint vector $\mathbf{s}_1$, it gives

$$\mathbf{g}_m(n) = \mathbf{R}_m^{-1}(n)\mathbf{s}_1 = \lambda^{-1}[\mathbf{g}(n-1) - \mathbf{k}_u(n)\mathbf{r}^H(n)\mathbf{g}(n-1)] \quad (19)$$

Again, by left-multiplying both sides of (19) by the constraint vector $\mathbf{s}_1$, and after some mathematical manipulation, we have

$$\varphi_m(n) = \mathbf{s}_1^T\mathbf{R}_m^{-1}(n)\mathbf{s}_1 = \lambda^{-1}[\varphi(n-1) + \rho(n)\eta(n)] \quad (20)$$

where scale-parameters $\rho(n)$ and $\eta(n)$ are designated as

$$\rho(n) = \mathbf{s}_1^T \mathbf{k}_u(n) \tag{21}$$

and

$$\eta(n) = \mathbf{r}^H(n)\mathbf{g}(n-1) \tag{22}$$

respectively. To apply the classical inverse for (20), $\varphi_m^{-1}(n)$ can be easily obtained

$$\varphi_m^{-1}(n) = \lambda[1 + q(n)\eta^*(n)]\varphi^{-1}(n-1) \tag{23}$$

where $q(n)$ is defined by

$$\begin{aligned} q(n) &= \frac{\varphi^{-1}(n-1)\rho(n)}{1-\eta(n)\varphi^{-1}(n-1)\rho(n)} \\ &= \lambda^{-1}[\varphi_m^{-1}(n)\mathbf{s}_1^T\mathbf{k}_u(n)] \end{aligned} \tag{24}$$

In order to discard the past data out of the data window, downdating procedure has to be performed with (12) and (13). In the downdating procedure, input signal autocorrelation matrix $\mathbf{R}(n)$ can be expressed as

$$\mathbf{R}(n) = \mathbf{R}_m(n) - \lambda^L \mathbf{r}(n-L)\mathbf{r}^H(n-L) \tag{25}$$

With the similar derivation of (17), the inversion of matrix $\mathbf{R}(n)$ can be expressed as

$$\mathbf{R}^{-1}(n) = \mathbf{R}_m^{-1}(n) + \mathbf{k}_d(n)\mathbf{r}^H(n-L)\mathbf{R}_m^{-1}(n) \tag{26}$$

Again, $\mathbf{k}_d$ is the Kalman gain vector of the downdating process; i.e.,

$$\mathbf{k}_d(n) = \frac{\mathbf{R}_m^{-1}(n)\mathbf{r}(n-L)}{\lambda^{-L} - \mathbf{r}^H(n-L)\mathbf{R}_m^{-1}(n)\mathbf{r}(n-L)} \tag{27}$$

Similarly, by right-multiplying both sides of (26) by the constraint vector $\mathbf{s}_1$, yields

$$\mathbf{g}(n) = \mathbf{g}_m(n) + \mathbf{k}_d(n)\mathbf{r}^H(n-L)\mathbf{g}_m(n) \tag{28}$$

Substituting (26) into (16) and with the definition of (19) and (23), it gives

$$\varphi(n) = \varphi_m(n) + \rho_m(n)\eta_m(n) \tag{29}$$

where scale-parameters $\rho_m(n)$ and $\eta_m(n)$ are defined as

$$\rho_m(n) = \mathbf{s}_1^T\mathbf{k}_d(n) \tag{30}$$

and

$$\eta_m(n) = \mathbf{r}^H(n-L)\mathbf{g}_m(n) \tag{31}$$

respectively. The inversion of (29), $\varphi^{-1}(n)$, can be easily obtained

$$\varphi^{-1}(n) = [1 - q_m(n)\eta_m(n)]\varphi_m^{-1}(n) \tag{32}$$

where $q_m(n)$ is defined by

$$q_m(n) = \frac{\varphi_m^{-1}(n)\rho_m(n)}{1+\eta_m(n)\varphi_m^{-1}(n)\rho_m(n)} = \varphi^{-1}(n)\mathbf{s}_1^T\mathbf{k}_d(n)] \tag{33}$$

It should be noted that with the results derived above, (9) can be implemented recursively. First, with the definition of the unconstrained optimal solution defined in (14), (9) can be rewritten as

$$\begin{aligned} \mathbf{w}(n) &= \mathbf{w}_{unc}(n) + \mathbf{R}^{-1}(n)\mathbf{s}_1[\mathbf{s}_1^T\mathbf{R}^{-1}(n)\mathbf{s}_1]^{-1} \\ &\quad \cdot [1 - \mathbf{s}_1^T\mathbf{w}_{unc}(n)] \end{aligned} \tag{34}$$

After some mathematical manipulation, the updated equation of SW-LC LS weight vector can be obtained

$$\begin{aligned} \mathbf{w}(n) &= \mathbf{w}(n-1) + [\mathbf{I} - \mathbf{g}_m(n)\varphi_m^{-1}(n)\mathbf{s}_1^T] \\ &\quad \cdot \mathbf{k}_u(n)e^*(n|n-1) - [\mathbf{I} - \mathbf{g}(n)\varphi^{-1}(n)\mathbf{s}_1^T] \\ &\quad \cdot \mathbf{k}_d(n)e_m^*(n-L|n) \end{aligned} \tag{35}$$

Table 1 Summary of sliding window linearly constrained RLS algorithm.

• Summary of SW-LC-RLS Algorithm
⋙ Initial Condition
$\mathbf{R}^{-1}(0)=\delta^{-1}\,\mathbf{I}$, δ =small constant
$\mathbf{w}(0)=\mathbf{s}_1$
For n=1,2,...,compute
$\mathbf{w}(n) = \mathbf{w}(n-1)$
$+[\mathbf{I}\text{-}\mathbf{g}_m(n)\,\varphi_m{}^{-1}(n)\mathbf{s}_1{}^T]\mathbf{k}_u(n)\mathrm{e}^*(n\|n\text{-}1)$
$\text{-}[\mathbf{I}\text{-}\mathbf{g}(n)\varphi^{-1}(n)\mathbf{s}^T]\mathbf{K}_d(n)\mathrm{e}_m{}^*(n-L\|n)$
■ Updating
$e(n\|n-1)=\tilde{d}(n) - \mathbf{w}^H(n-1)\mathbf{r}(n)$
$\mathbf{k}_u(n)=\frac{\mathbf{R}^{-1}(n-1)\mathbf{r}(n)}{\lambda+\mathbf{r}^H(n)\mathbf{R}^{-1}(n-1)\mathbf{r}(n)}$
$\mathbf{R}_m{}^{-1}(n)=\lambda^{-1}\mathbf{R}^{-1}(n\text{-}1)\text{-}\lambda^{-1}\mathbf{k}_u(n)\mathbf{r}^H(n)\mathbf{R}^{-1}(n\text{-}1)$
$\mathbf{g}_m(n) = \mathbf{R}_m^{-1}(n)\mathbf{s}_1$
$\varphi_m^{-1}(n) = [\mathbf{s}_1^T\mathbf{R}_m^{-1}(n)\mathbf{s}_1]^{-1}$
■ Downdating
$e_m(n-L\|n)=\tilde{d}(n) - \{\mathbf{w}(n-1)$
$+[\mathbf{I} - \mathbf{g}_m(n)\varphi^{-1}(n)\mathbf{s}_1^T]\mathbf{k}_u(n)e^*(n\|n-1)\}^H\mathbf{r}(n-L)$
$\mathbf{k}_d(n)=\frac{\mathbf{R}_m^{-1}(n-1)\mathbf{r}(n-L)}{\lambda^{-L}+\mathbf{r}^H(n-L)\mathbf{R}_m^{-1}(n-1)\mathbf{r}(n-L)}$
$\mathbf{R}^{-1}(n) = \mathbf{R}_m^{-1}(n) + \mathbf{k}_d(n)\mathbf{r}^H(n-L)\mathbf{R}_m^{-1}(n)$
$\mathbf{g}(n) = \mathbf{R}^{-1}(n)\mathbf{s}_1$
$\varphi^{-1}(n) = [\mathbf{s}_1^T\mathbf{R}^{-1}(n)\mathbf{s}_1]^{-1}$

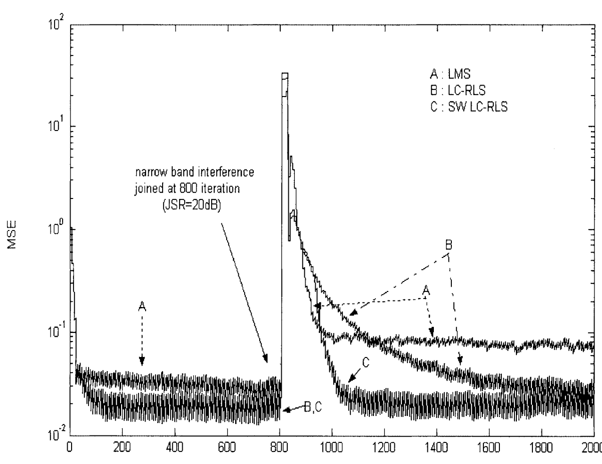
where

$$e(n|n-1) = \tilde{d}(n) - \mathbf{w}^H(n-1)\mathbf{r}(n)$$
$$e_m(n-L|n) = \tilde{d}(n-L) - \{\mathbf{w}(n-1) + [\mathbf{I} - \mathbf{g}_m(n)\varphi_m^{-1}(n)\mathbf{s}_1^T]\mathbf{k}_u(n)e^*(n|n-1)\}^H\mathbf{r}(n-L)$$

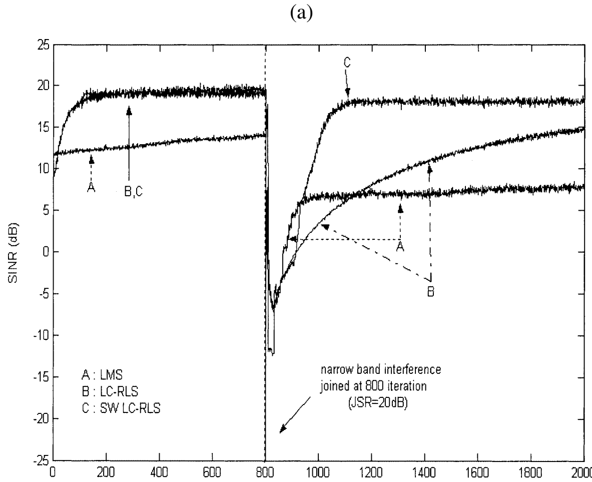
This completes our derivation, for convenience, it is summarized in Table 1 as reference. We note that, basically, the derivation of the SW-LC RLS algorithm is based on the modified MMSE receiver structure described in [9].

5. Computer Simulation Results

In this section, to document the merits of our proposed SW-LC-RLS algorithm, computer simulation results are given. Also, the performance, in terms of MSE, output SINR and BER, is compared with the conventional LC-RLS and the LC-MMSE schemes, under the environment of synchronous pilot symbol-aided BPSK DS-SS CDMA system over multipath fading channels. To do so, the up-link channel is considered and assumed that all active users are experiencing different multipath fading channels. In the computer simulation, the non-orthogonal Gold codes with length N=31 are employed. The channel bandwidth is 3.968 MHz, the carrier frequency is 2.0 GHz (consistent with that given in [9]), and the mobile speed is set as 50 km/h. E_b/N_0 of the desired user is set to be 20 dB, and transmitter powers of all active users are set to be equal. Each pilot symbol is periodically inserted into data symbol streams at every eight data bits, and the number of pilot symbols used for channel estimation is 3 [9]. For each branch of the RAKE receiver all the adaptive detectors, the number of taps in the filter is set to N (Gold code chip length). The tap weight vector for the adaptive filter is initialized as $\mathbf{s}_1$. To verify the improvement of the proposed algorithm, a specific case is examined, in which, an adverse circumstance for a strong NBI, with frequency and phase of $\omega_I = 0.3\pi$, $\theta_I = 0$, respectively, and joined at 800 number of bit iteration. The forgetting factor of SW-LC-RLS and LC-RLS algorithms is chosen to be $\lambda = 1$, while the step size $\mu = 1/\mathit{maximal\ tap\ weight\ power}$ for LMS algorithm is selected.

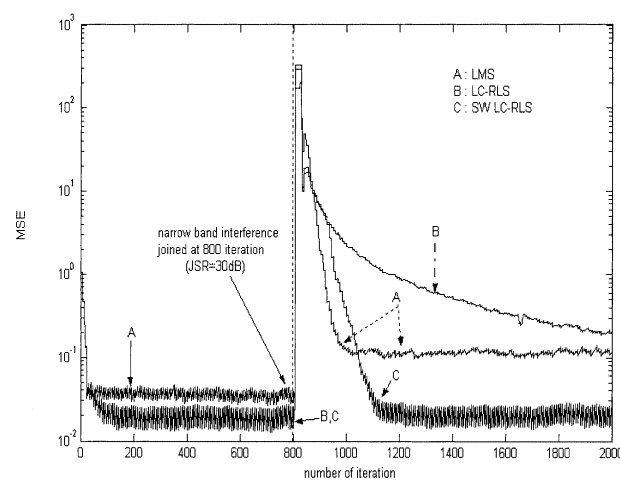


(a)

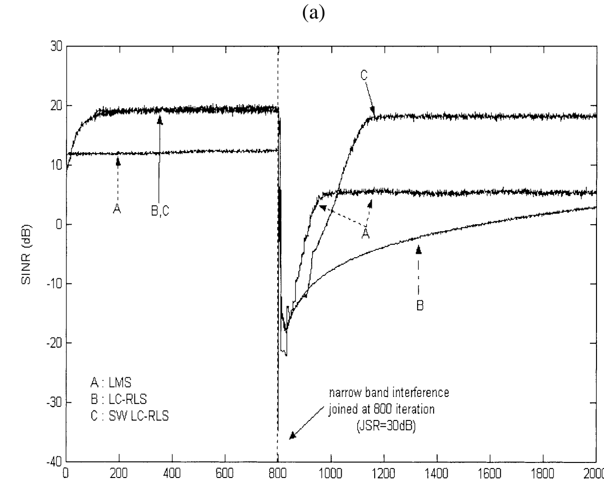


(b)

Fig. 2 Learning curves comparison with different techniques under fading channel with a narrowband interference JSR=20 dB (a) MSE (b) output SINR.



(a)



(b)

Fig. 3 Learning curves comparison with different techniques under fading channel with a joined narrowband interference JSR=30 dB (a) MSE (b) output SINR.

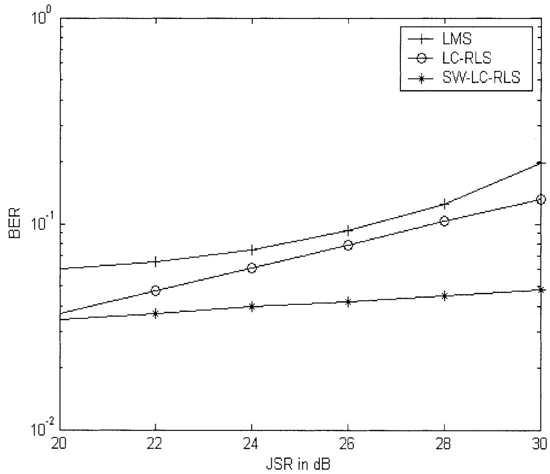


Fig. 4 Performance comparison of BER against joined JSR for RAKE receivers combined with different adaptive multiuser detectors under 3-paths fading channel.

In the first example, a fading channel with single path is considered to investigate the tracking capability with the proposed algorithm, where the performance, in terms of MSE and SINR, is evaluated and compared with the LC-RLS algorithm and the orthogonal decomposition-based LMS algorithm. The results are shown in Fig. 2 and Fig. 3, which are the averaging of 200 independent runs. In Fig. 2, we assume the number of users is 5. In this case, a strong narrowband interference with jammer-to-signal ratio, JSR=20 dB is suddenly joined at 800th iteration. The length of sliding window of SW-LC-RLS algorithm is 100.

As shown in Fig. 2, the learning curve of MSE and the output SINR with the SW-LC-RLS algorithm performs the best. Also, the LC-RLS algorithm is superior to the one with the orthogonal decomposition-based LMS algorithm. Next, with the same parameter as in Fig. 2, except that JSR=30 dB is used to replace. From Fig. 3, we learn that the MSE and SINR improvement are more significant compared with other two algorithms, as shown in Fig. 2. All other two algorithms could not track the suddenly jointed NBI as good as the proposed algorithm. Finally, with the adaptive multiuser RAKE receiver for a downlink multipath-fading channel with 3 paths, and 10 users, the BER is depicted in Fig. 4, for comparison. Here, the BER performance is represented as a function of JSR. In this plot, the case with a suddenly joined NBI is also considered. Again, we observed that the proposed SW-LC RLS algorithm has the superior performance compared with the LC-RLS algorithm and the orthogonal decomposition-based LMS algorithm. We may conclude that the proposed scheme is very useful in practical wireless communication systems, where the MAI, ISI as well as a NBI introduced by other communication systems could be solved simultaneously.

6. Conclusions

In this paper, a new sliding window linearly constrained RLS algorithm has been devised for the DS-SS CDMA system over multipath fading. With the proposed algorithm associated with the modified MMSE receiver structure [9], the effect of the narrowband interference (NBI) due to other system, the MAI as well as ISI of the DS-SS CDMA system over multipath fading channel could be alleviated effectively. It has the advantage of faster convergence and better tracking capability compared with the conventional linearly constrained RLS algorithm as well as the orthogonal decomposition-based LMS algorithm [9], when the NBI was joined suddenly to the DS-SS CDMA system. The performance improvement, in terms of the mean squared error, output SINR and the BER, has been verified from simulation results. Besides, the proposed algorithm retained the advantage of the sliding window and the direct linearly constrained optimization approaches. We then concluded that the SW-LC-RLS algorithm proposed in this paper is very suitable for multipath fading channels affected by varying strong narrow band interference DS-SS CDMA systems to gain the better convergence.

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