New Algorithms for Adaptive Antennas in DS-CDMA Communication Systems

Antônio R. R. de Matos, Adaildo G. D´Assunção, Laércio M. de Mendonça
Universidade Federal do Rio Grande do Norte, Natal RN, Brazil

Abstract — **In this paper two new adaptive algorithms are presented: Multipath Least-Squares Despread Respread Multitarget Array (MLS-DRMTA) and Multipath Recursive Least-Squares (MRLS) algorithms, in order to improve the performance of adaptive antenna arrays in the presence of multipaths. It is shown from simulation that the diagrams radiation formed with the new algorithms developed points beams toward the directions of the entire desired signal arriving multipaths, while that one formed with LS-DRMTA and RLS points only a main beam in the direction of the multipath which is synchronized with the receiver. Thus the new algorithms are indicated to perform coherent combination of multipaths. In the simulations carried through in this work, the generated results are gotten through the use of adaptive antenna arrays situated in Stations of Radio Base (ERB) and destined to the reception of the signal of the users in DS-CDMA communication systems.**

I. INTRODUCTION

In an environment of mobile communications, the existence of multipaths (unbalanced rejoinders of one exactly signal) is responsible for a known undesirable phenomenon as fading. This phenomenon is resulted of the constructive, however destructive interferences however of the existing multipaths, and is responsible for brusque variations of intensity of signal in the sinks. To attenuation this phenomenon, several equalization techniques and diversity have been proposals. In special, if they have become of sufficient interest the methods that isolate the multipaths and carry through its addition to scale, providing a reinforcement of the received signal. The majority of the algorithms considered for use in adaptive antennas, does not take in consideration the existence of multipaths. It is necessary, of this form, that if conceives a way to execute characteristic the space filtering of the adaptive antennas at the same time where if it carries through the addition to scale of the some multipaths of the interest signal.

In DS-CDMA systems several users occupy the same frequency band. An adaptive array employed in such an environment must be able to separate and extract each user's signal simultaneously. LS-DRMTA is a blind adaptive algorithm [1], [2] which utilizes information of CDMA spreading codes to update the weights of adaptive antennas. By the other side, RLS is a non-blind adaptive algorithm [3],[4] which utilizes training sequences to obtain the weights. In this paper we propose modifications in LS-DRMTA and RLS in a way that the weights generated by the new algorithms (MLS-DRMTA and MRLS) can produce a radiation pattern with beams directed toward the several desired signal multipaths, using only one adaptation process. That's the main benefit of this work. It represents the possibility of emphasizing the desired signal through the utilization of its multipaths, and cancellation of interferences with only one adaptation process employed with the adaptive array. This represents the state-of-art when talking about adaptive antennas.

The paper is organized as follows. In Section II, System Modeling, the signal model and adaptive algorithms will be described. Simulations Results will be given in Section III. In Section IV, will be given the Conclusions and Proposals of Future Works.

II. SYSTEM MODELING

A. SIGNAL MODEL

This work considers the adaptation of a antenna array and assuming with there are q users in a DS-CDMA system using the same band frequency. In a typical mobile environment, many replicas of each signal (multipaths) impinge at the receiver with distinct directions of arrival (DOA), amplitudes, complex phases and time delays, causing the well-known fading effect. The received signal by a single isotropic antenna, after baseband conversion, due to the pth multipath of the ith user can be expressed [3] as:

$$s_{ip}(t) = \sqrt{2P_{ip}}\, b_i(t-\tau_{ip}) c_i(t-\tau_{ip}) \exp(-j\phi_{ip}) \qquad (1)$$
$$i = 1, 2, \ldots, q \qquad m = 1, 2, \ldots, L_i$$

This work was supported in part by CAPES and CNPq.

Antônio R. R. de Matos, renede@telemar-ce.com.br, Adaildo G. D´Assunção, adaildo@ct.ufrn.br, Laércio M. de Mendonça, laercio@ct.ufrn.br,, UFRN-CT-DEE,CEP: 59072-970, Natal, RN, Brazil.

where L_i is the number of multipaths of the ith user's signal, P_{ip}, τ_{ip} and ϕ_{ip} are the power, the time delay and the random phase of the pth multipath of ith user, and $b_i(t)$ and $c_i(t)$ are the ith user's data signal and spreading code given by:

$$b_i(t) = \sum_{n=-\infty}^{n=\infty} b_{in} f_{T_b}(t - nT_b) \qquad (2)$$

$$c_i(t) = \sum_{m=-\infty}^{+\infty} c_{im} f_{T_c}(t - mT_c) \qquad (3)$$

where $b_{in} \in \{-1,+1\}$ is the nth data bit of the ith user, $c_{im} \in \{-1,+1\}$ is the mth chip of the ith user's spreading code, and f_{T_b} and f_{T_c} are unit rectangular pulses of duration T_b and T_c, which are the widths of one data bit and one chip respectively. Thus, the total signal received by the same single antenna is:

$$s(t) = \sum_{i=1}^{q} \sum_{p=1}^{L_i} s_{ip}(t) + n(t) \qquad (4)$$

where $n(t)$ is a complex additive white Gaussian noise (AWGN) contribution. The relation $N=T_b/T_c$ is called processing gain. The input data vector of a multitarget adaptive array with M elements and Q outputs, immersed in the environment just described may be modeled as:

$$\mathbf{x}(t) = \sum_{i=1}^{q} \mathbf{A}_i \mathbf{s}_i(t) + \mathbf{n} \qquad (5)$$

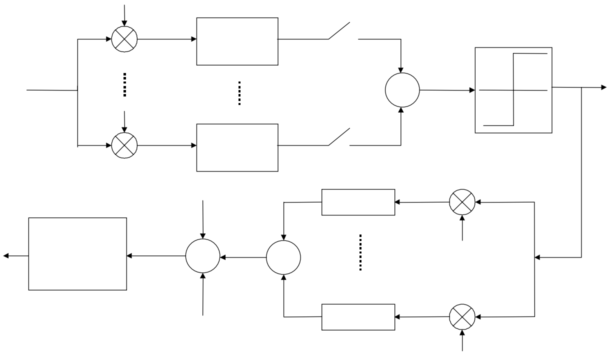
with $\mathbf{x}(t) = [x_1(t)\ x_2(t) ... x_M(t)]^T$, $\mathbf{s}_i(t) = [s_{i1}(t)\ s_{i2}(t)\ ...\ s_{iLi}(t)]^T$, $\mathbf{n}(t) = [n_1(t)\ n_2(t)\ ...\ n_M(t)]^T$ and $\mathbf{A}_i = [\mathbf{a}(\theta_{i1})\ \mathbf{a}(\theta_{i2}) ... \mathbf{a}(\theta_{iLi})]$, where $\mathbf{a}(\theta_{ip})$ is the steering vector of the pth multipath of the ith user's signal, which arrives with a direction of arrival given by θ_{ip} measured clockwise from the broadside of the array. The output signal of the ith port is given [4] by $y_i(t) = \mathbf{w}_i \cdot \mathbf{x}(t)$, where $\mathbf{w}_i = [w_{i1}\ w_{i2} ...\ w_{iM}]^T$ is the weigth vector obtained to extract the ith user signal from $\mathbf{x}(t)$. Sampling $\mathbf{x}(t)$ and $y_i(t)$ at $t_1, t_2, ..., t_k$ and replacing the time index t_i with i, we can define $\mathbf{X} = [\mathbf{x}(1), ..., \mathbf{x}(K)]$, $\mathbf{y}_i = [y_i(1)\ y_i(2)\ ...\ y_i(K)]^T$ and rewrite expression (5) in discrete form as:

$$\mathbf{X} = \sum_{i=1}^{q} \mathbf{A}_i \mathbf{S}_i + \mathbf{N} \qquad (6)$$

where $\mathbf{S}_i = [\mathbf{s}_i(1), ..., \mathbf{s}_i(K)]$ and $\mathbf{N} = [\mathbf{n}(1), ..., \mathbf{n}(K)]$.

B. ADAPTIVE ALGORITHMS

The new algorithms here proposal there are two distinct stages. The first one, consists essentially of the adaptive process, whose main function is to make with that the employed array of antennas captures one not only, but all the significant multipaths of the desired sign. This means to say, that the generated diagram of irradiation must point lobes in the directions of the multipaths and locate null in the directions of the interferences. Soon, the output of the array is a vector addition of the multipaths of the desired signal increased of a parcel due to the noise, what, it provokes the known effect of fading. The output of the array is, then, submitted to the second stage of the algorithm, whose objective is to isolate and to add in phase the multipaths of the desired signal. Of this form, it is obtained with the two stages, to filter the interferences and to make use of the loaded information for all the significant multipaths of the interest signal to improve the detention process.



B1. Multipath Least Squares Despread Respread Multitarget Array (MLS-DRMTA) Algorithm

The MLS-DRMTA algorithm is obtained by applying the extension of *Gauss's method* [6], [7] to the following cost function:

$$F(\mathbf{w_i}) = \sum_{k=1}^{K} \left| y_i(k) - r_i(k) \right|^2 = \sum_{k=1}^{K} \left| \mathbf{w}_i^H \mathbf{x}(k) - r_i(k) \right|^2 \qquad (7)$$

where K is the data block size corresponding to a time interval needed to receive the current ith user's data bit through all multipaths, and $r_i(t)$ is the reference signal generated by respreading the current, posterior and anterior estimated data bits. Data bit estimation is performed by correlating the received signal with several delayed versions of ith user's spreading code and checking the results sum. We assume knowledge of desired signal multipaths' amplitudes and delays [4]. Fig. 1 shows the scheme of MLS-DRMTA. We can summarize the algorithm as:

$$\begin{aligned} \mathbf{y}_i(l) &= [\mathbf{w}_i^H(l)\mathbf{X}(l)]^T \\ &= [y_i(1+lK_1), y_i(2+lK_1), \cdots, y_i(K+lK_1)]^T \end{aligned} \qquad (8)$$

$$\hat{b}_{il} = \mathrm{sgn}\left\{ \mathrm{Re}\left(\sum_{j=1}^{L_i} \sum_{k=1+lK_1}^{(1+l)K_1} y_i(k+k_{ij}) c_i(k-k_{\tau_i}) \right) \right\} \qquad (9)$$

$$\hat{b}_{il_a} = \operatorname{sgn}\left\{\operatorname{Re}\left(\sum_{j=1}^{L_i}\sum_{k=1+lK_1}^{k_{ij}+lK_1} y_i(k)c_i(k+N-k_{ij}-k_{\tau_i})\right)\right\} \quad (10)$$

$$\hat{b}_{il_p} = \operatorname{sgn}\left\{\operatorname{Re}\left(\sum_{j=1}^{L_i}\sum_{k=1+lK_1}^{K+(l-1)K_1-k_{ij}} y_i(k+K_1+k_{ij})c_i(k-k_{\tau_i})\right)\right\} \quad (11)$$

$$\begin{aligned} r_{ij}(l) = \Big[&\hat{b}_{ila}c_i(1+N-k_{ij}+lK_1-k_{\tau_i}),\cdots,\hat{b}_{ila}c_i(N+lK_1-k_{\tau_i}),\\ &\hat{b}_{il}c_i(1+lK_1-k_{\tau_i}),\cdots,\hat{b}_{il}c_i((l+1)K_1-k_{\tau_i}),\\ &\hat{b}_{ilp}c_i(1+lK_1-k_{\tau_i}),\cdots,\hat{b}_{ilp}c_i(K-K1-k_{ij}+lK_1-k_{\tau_i})\Big] \end{aligned} \quad (12)$$

$$\mathbf{r}_i(l) = \sum_{p=1}^{L_i} a_{ij}\mathbf{r}_{ij}(l) \quad (13)$$

$$\mathbf{w}_i(l+1) = [\mathbf{X}(l)\mathbf{X}^H(l)]^{-1}\mathbf{X}(l)\mathbf{r}_\mathbf{i}^*(l) \quad (14)$$

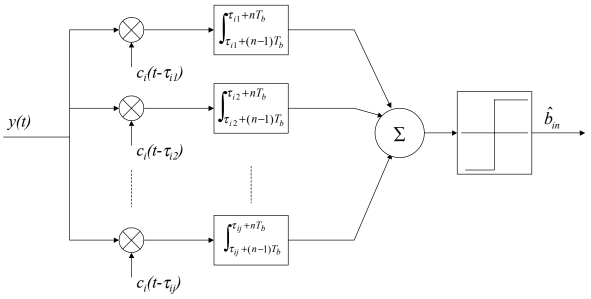
where L_i is the number of multipaths of ith user, K_1, k_{ij}, and k_{τ_i} are respectively the number of samples corresponding to the data bit duration T_b, to the time delay between the jth and early ith-user multipaths and to the propagation delay of the first arriving ith-user multipath, a_{ij} is the amplitude of jth multipath of ith user, and $\hat{b}_{il}, \hat{b}_{il_{-1}}, \hat{b}_{il_{+1}}$ are respectively the estimation of lth, anterior and posterior transmitted data bits.

B2. Multipath Recursive Least-Squares (MRLS)Algorithm

The MRLS algorithm is derived from RLS by changing the manner the reference signal is constructed. While in RLS the reference signal is a copy of a training sequence known in the receiver, in MRLS it is a sum of several versions of the training sequence, each one delayed and multiplied respectively by the time delay and amplitude of a particular multipath of the signal of interest. The amplitudes and time delays of the desired signal multipaths are considered to be known [6], [7]. Thus the reference signal for the ith user is:

$$\mathbf{r}_i = \sum_{\mathbf{j=1}}^{L_i} a_{ij}\mathbf{r}_{ij} \quad (15)$$

where $\mathbf{r}_1 = [r_T(1), r_T(2),...,r_T(K)]$ is the training sequence known in the receiver, $\mathbf{r}_j = [0, 0,...,r_T(1), r_T(2), r_T(K-k_{ij})]$ is a $K \; x \; 1$ vector, valid for $j \geq 2$. The quantities a_{ij}, L_i, K and k_{ij} are the same as defined before. We can summarize the MRLS algorithm as:



$$\mathbf{P}(k+1) = \frac{1}{\alpha}\left\{\mathbf{P}(k) - \frac{\mathbf{P}(k)\mathbf{x}(k+1)\mathbf{x}^H(k+1)\mathbf{P}(k)}{\alpha+\mathbf{x}^H(k+1)\mathbf{P}(k)\mathbf{x}(k+1)}\right\} \quad (16)$$

$$e_i(k+1) = r_i(k+1) - \mathbf{w}_i^H(k)\mathbf{x}(k+1) \quad (17)$$

$$\mathbf{w}_i(k+1) = \mathbf{w}_i(k) + \frac{\mathbf{P}(k)\mathbf{x}(k+1)e_i^*(k+1)}{\alpha+\mathbf{x}^H(k+1)\mathbf{P}(k)\mathbf{x}(k+1)} \quad (18)$$

As mentioned earlier the MRLS algorithm generates a pattern that captures all relevant desired signal multipaths. This implies that the array output is a fading signal. In order to overcome this trouble, a procedure of scalar sum of multipaths must be performed during the reception of signals. This is done by separating and adding the multipaths, with a structure similar to the *Rake Receiver* [8], which explores the adequate characteristics of the spreading codes. Figure 2 shows the block diagram of such a procedure.

III. SIMULATION RESULTS

In this section diagrams of irradiation and of the Bit Error Rate (BER) are presented using algorithms RLS, MRLS, LS-DRMTA and MLS-DRMTA, for adaptive antenna arrays. The scene is composite for eight signals (a signal of interest and seven interference signals) and two secondary multipaths of the interest signal (user 4). The fact not to have been considered the existence of secondary multipath for the interferences does not compromise the validity of the gotten results, a time that such multipaths alone would function as extra parcels of interference, when analyzed of the point of view of the interest signal. The Angles-Of-Arrival (AOA) of the signals (multipaths of the interest signal and interferences) were randomly distributed between -90º and 90º from the antenna array form a uniform distribution. The amplitude of the secondary multipaths of the interest signal is equal 0.7 and 0,5. The used value for the Eb/N0 relation is of 15 dB. Table I shows the configurations of the Angles-Of-Arrival (AOA) of the interference signals and the multipaths of the desired signal, represented for the user of number 4.

TABLE I

CONFIGURATION OF SIGNALS

USER		Angle-Of-Arrival (AOA)
1		-72°
2		-54°
3		-36°
4	Main	0°
	Second. 1	-18°
	Second. 2	18°
5		36°
6		54°
7		72°
8		90°
E_b / N_0 = 15 dB		

In our simulations we have considered a DS-CDMA system [9] using a BPSK modulation scheme, with processing gain N =15, carrier frequency f_c=2.05 GHz and data bit rate R_b = 128 Kbps. Perfect power control was assumed in the system, and Gold sequences were utilized as the spreading codes. The 8-element array with half wavelength spacing between elements was assumed to be located at the base station to perform spatial filtering in the reverse link. The weight vector was calculated by LS-DRMTA, MLS-DRMTA, RLS and MRLS algorithms. We considered that the radio channel introduces additive white Gaussian noise.

The array's radiation pattern was calculated by:

$$G(\theta) = 20\log\left|\sum_{n=1}^{M} w_{in}^{*} e^{-j\mathbf{k}(\theta).\mathbf{d}_n}\right| \tag{19}$$

where $\mathbf{k}(\theta)$ is the propagation vector in θ direction, $\mathbf{d}_n$ is the position vector of the array's nth element, and w_{in} is the nth element of the weight vector $\mathbf{w}_i$ obtained by the adaptive algorithm to receive the ith user signal. For the simulations with MRLS and RLS algorithms the sampling rate was R_s = $1/T_c$, and for LS-DRMTA and MLS-RMTA algorithms was $R_s = 3/T_c$.

Fig. 3 show the diagram of irradiation for algorithms RLS and MRLS, using a linear adaptive array with spacing between elements given by half of the wave length of the frequency of involved transmission. It is possible to notice that algorithm RLS provides profit in the direction of the main multipath of the interest signal to the pacing that rejects the interferences and the secondary multipaths of the interest signal. In fact, algorithm RLS supplies to a protection of 20 dB the 40 dB of the signal of interest in relation to the excessively using ones.

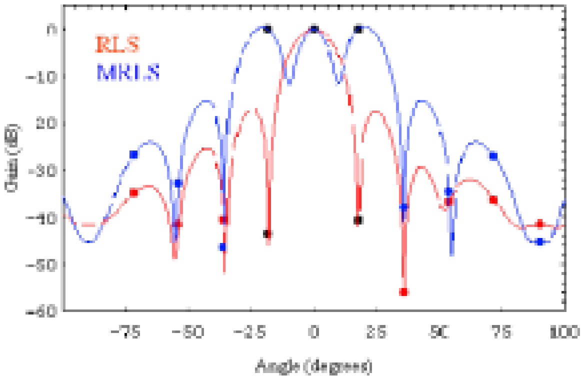


Fig. 3. Diagrams of irradiation generated by a linear array and uniform using algorithms RLS and MRLS (Configuration of the signals: Table I).

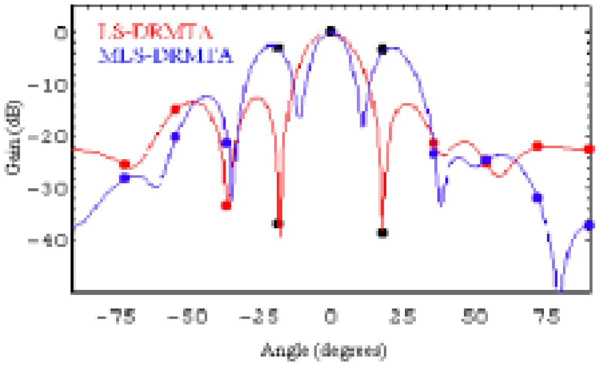


Fig. 3. Diagrams of irradiation generated by a linear array and uniform using algorithms LS-DRMTA and MLS-DRMTA (Configuration of the signals: Table I).

Fig. 4 show the diagram of irradiation generated for algorithm LS-DRMTA with points a lobe in the direction of the main multipath of the interest signal, at the same time where it exactly rejects the secondary interferences and multipaths of this interest signal. The profit of the The profit of the signal desired in relation to the interferences vary of 43 dB the 27 dB. This behavior is similar to presented for algorithm RLS. Already algorithm MLS-DRMTA generates an irradiation diagram that points lobes in the direction of the some multipaths of the desired sign and simultaneously isolates the interferences. This result is analogous to the gotten one with algorithm MRLS.

Finally, the Fig. 5 show the curves that show the Bit Error Rate (BER) in function of the number of users, for algorithms LS-DRMTA, MLS-DRMTA, RLS and MRLS, used in set with a linear adaptive array with 8 spaced elements of λ/2. The environment is composite for a signal of interest with three multipaths, some interferences due the signals of other users and white gaussian noise. The noise level is such that Eb/N0 = 8 dB. The users are made use of such form that the direction of the signals uniformly are distributed between –90° and 90°.

For calculation of the Bit Error Rate (BER), a random sequence of bits was generated that after spread spectrally (multiplied for a code of spread spectral) composed the signal of the interest user. After that, through the same process the signals of the interferences and the multipaths had been generated.