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A modified multitarget adaptive array algorithm for wireless CDMA system

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Abstract: The paper presents a modified least squares despread respread multitarget constant modulus algorithm (LS-DRMTCMA). The cost function of the original algorithm was modified by the minimum bit error rate (MBER) criterion. The novel algorithm tries to optimize weight vectors by directly minimizing bit error rate (BER) of code division multiple access (CDMA) mobile communication system. In order to achieve adaptive update of weight vectors, a stochastic gradient adaptive algorithm was developed by a kernel density estimator of possibility density function based on samples. Simulation results showed that the modified algorithm remarkably improves the BER performance, capacity and near-far effect resistance of a given CDMA communication system.

Key words: Smart antenna, Code division multiple access (CDMA), Minimum bit error rate (MBER), Near-far effect
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INTRODUCTION

The technology of smart or adaptive antenna which can increase capacity and range, and reduces multipath propagation of mobile radio communication system, has aroused great interest in recent years (Haardt and Spencer, 2003; Bellofiore, 2002; Godara, 1997). Beamforming is a key technology in smart antenna systems (SAS) and many different adaptive beamforming algorithms have been proposed. Code division multiple access (CDMA) system will be applied in most mobile communication systems in the future, so many researchers focus on the adaptive beamforming algorithms in CDMA mobile communication systems. Some algorithms of this kind have been proposed (Agee, 1989; Liberti and Rappaport, 2002). In a CDMA mobile communication system, multiple users occupy the same frequency band at the same time. The beamformer in the base station attempts to form different beams directed to different users. For one desired user, the interference from other directions is reduced or cancelled. Agee (1989) proposed the multitarget least squares constant modulus algorithm (MT-LSCMA) which adopted a Gram-Schmidt Orthogonalization (GSO) procedure so that different weight vectors converged to different beampatterns. However, it does not utilize the information about the pseudo-noise (PN) sequence assigned to each user and is not a computationally efficient algorithm. The algorithm is valid when the number of users in a system is less than that of antenna elements. To solve these problems, Liberti and Rappaport (2002) presented least squares despread respread multitarget algorithm (LS-DRMTA) and least squares despread respread multitarget constant modulus algorithm (LS-DRMTCMA). The two algorithms utilize information on the spreading signal of different users and the reference signal that is the combination of the weighted spreading signal and the weighted complex-limited output of the transmitted signal. They do not process GSO and sorting procedures, but reduce computational complexity and can form beams as many as the number of users in the system that is generally much larger than the number of antenna elements.

In order to update weight vectors, most existing algorithms are based on the classical minimum mean square error (MMSE) criterion or the signal to interference and noise ratio (SINR) criterion. Whereas the design of mobile communication system should be based on the minimum bit error rate (MBER) criterion directly if possible. A research group Chen *et al.*(2001; 2003) developed several algorithms of multiuser detection and beamforming based on MBER, but their researches did not consider such cases as code division multiple access (CDMA) mobile communication system, hostile fading channels, wideband beamforming and dispersive wideband channels that induce intersymbol interference (ISI).

According to LS-DRMTCMA and the idea of MBER criterion as mentioned above, this paper applied the MBER solution to multitarget adaptive array algorithm for wireless CDMA System, modified the cost function of the original algorithm by the MBER criterion. Then a stochastic gradient adaptive algorithm was used to achieve adaptive update of optimal weight vectors. The distinctly better performances of the novel algorithm are reported.

SIGNAL MODEL

Suppose there are M signals impinging on an N-element uniform linear array (ULA) with half wavelength spacing between the elements. The M transmitted signals are denoted as $\boldsymbol{s}_0(t)\ldots\boldsymbol{s}_{m-1}(t)$. The received signals at the base station antenna arrays can be represented as

$$\boldsymbol{X}(t)=[\boldsymbol{x}_0(t)\boldsymbol{x}_1(t)\cdots\boldsymbol{x}_{N-1}(t)]^{\mathrm{T}} \tag{1}$$

$$\boldsymbol{x}_n(t)=\sum_{m=0}^{M-1}\sum_{l=0}^{L_m-1}\boldsymbol{a}(\phi_{ml})\alpha_{ml}\boldsymbol{s}_{ml}(t-\tau_{ml})+\boldsymbol{N}(t) \tag{2}$$

where $\boldsymbol{x}_n(t)$ is the received signal vector by the nth antenna element; L_m is the path number of the mth user; $\boldsymbol{a}(\phi_{ml})$, α_{ml}, $\boldsymbol{s}_m(t-\tau_{ml})$ are the array response vector, complex gain and the transmitted signal envelope respectively; τ_{ml} is the delay time of the lth path component of the mth user; $\boldsymbol{N}(t)$ is the additive white Gaussian thermal noise vector with covariance matrix $\sigma_n^2\boldsymbol{I}$.

Consider a direct sequence code division multiple access (DS-CDMA) system. The lth path component of the mth user, $\boldsymbol{S}_{ml}$, can be written as

$$\boldsymbol{S}_{ml}(t)=\sqrt{2P_{ml}}b_m(t-\tau_{ml})C(t-\tau_{ml})\exp(-j\phi_{ml})$$
$$\text{for } l=0,1,\ldots,L_k-1 \tag{3}$$

where P_{ml}, $b_m(t)$, $C_m(t)$, τ_{ml} and ϕ_{ml} are the power, the transmitted symbol sequence, the signature signal, the time delay and the random phase of the lth path of the mth user respectively. The transmitted symbol sequence can be expressed as

$$b_m(t)=\sum_{n=-\infty}^{+\infty}b_{mk}p(t-kT_b) \tag{4}$$

If we use binary phase shift keying (BPSK) modulation scheme, b_{ml} is in the set of $\{\pm1\}$. $p(t)$ is the pulse shaping filter with duration time T_b. Suppose the time delay between path components is less than the symbol duration time of $\boldsymbol{s}_m(t)$, the signals impinging on the array are sampled and the output vector can be modeled as

$$\boldsymbol{Y}_m(k)=\boldsymbol{W}_m^H(k)\boldsymbol{X}(k) \tag{5}$$

$$\boldsymbol{W}_m(k)=[w_{m1}(k)w_{m2}(k)\cdots w_{mN}(k)]^{\mathrm{T}} \tag{6}$$

where $\boldsymbol{W}_m(k)$ is the weight vector of the mth user.

SOLUTION OF MODIFIED DRMTCMA

For simplicity but without loss of generality, suppose the source #1 is the desired user. LS-DRMTCMA presented by Liberti and Rappaport (2002) uses the despread, decision and the combinational signal of the weighted respread signal and the weighted complex-limited output of the desired user's transmitted signal as the reference signal. It tries to adapt the weight vector to minimize the cost function as follows

$$\boldsymbol{J}(W_1) = \sum_{k=1}^{K} | \boldsymbol{Y}_1(k) - \boldsymbol{R}_1(k) |^2 \tag{7}$$

$$\boldsymbol{Y}_1(k) = \boldsymbol{W}_1^{\mathrm{H}} \boldsymbol{X}_1(k) \tag{8}$$

$\boldsymbol{R}_1(k)$ is reference signal and written as

$$\boldsymbol{R}_1(k) = \alpha_{PN} r_{1PN}(k) + \alpha_{CM} r_{iCM}(k) \tag{9}$$

where

$$\alpha_{pN} + \alpha_{CM} = 1 \tag{10}$$

$$\hat{b}_1(k) = \mathrm{sgn}\{\mathrm{Re}(C_1^{\mathrm{H}}(k) \boldsymbol{y}_1(k))\} \tag{11}$$

$C_1(k)$ is the PN code sequence of the desired user and K is the number of samples in one bit period. The reference signal, $\boldsymbol{R}_1(k)$, is the combined signal of the weighted respread signal and the weighted complex-limited output of the user #1. If α_{CM} is set to zero, LS-DRMTCMA becomes LS-DRMTA. So we only consider modifying LS-DRMTCMA in this paper. The adaptive update solution of weight vector used in LS-DRMTCMA can be given as

$$\underset{W_1}{\mathrm{minimize}}\, \boldsymbol{J}(\boldsymbol{W}_1) \tag{12}$$

Next we discuss the modified DRMTCMA based on MBER criterion. Assuming that P is the number of possible transmitted data bit sequence by M users at the kth snapshot and P is equal to 2^M, then the discrete possibility density function of output from arrays can be modeled as

$$f\left(\boldsymbol{Y}(k)\right) = \sum_{p=1}^{P} \frac{1}{P\sigma} \exp\left(-\left(\frac{\boldsymbol{Y}(k) - \boldsymbol{Y}_p(k)}{\sigma} \right)^2 \right)$$

$$(\sigma = \sigma_n \sqrt{2\pi \boldsymbol{W}_1^{\mathrm{H}} \boldsymbol{W}_1}) \tag{13}$$

$\boldsymbol{Y}_p(k)$ is the array's output which is a function of weight vector when the pth data bit sequence is transmitted by all the M users. The BER of output is given by Eq.(14)

$$\boldsymbol{p}(\boldsymbol{W}_1) = \frac{1}{P} \sum_{p=1}^{P} Q\left(\frac{\hat{b}_{p1} \boldsymbol{R}_p}{\sigma_n \sqrt{\boldsymbol{W}_1^{\mathrm{H}} \boldsymbol{W}_1}} \right) \tag{14}$$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \mathrm{e}^{-t^2/2} \mathrm{d}t (x \geq 0) \tag{15}$$

$\boldsymbol{R}_p$ is the estimated transmitted signal waveform when the pth data bit sequence is transmitted by M users. $\hat{b}_{p1}$ is the estimated transmitted data bit of the desired user. It is detected after array's output signal is despreaded by the desired user's signature signal. $Q(\cdot)$ is the Q function defined by Eq.(15). According to the BER criterion, the target weight vector of the modified algorithm is $\boldsymbol{W}_1$ when $\boldsymbol{p}(\boldsymbol{W}_1)$ in Eq.(14) reaches its minimum. The solution of the adaptive weight vector update used in the modified DRMTCMA can be given by

$$\underset{\boldsymbol{W}_1}{\mathrm{minimize}}\, \boldsymbol{p}(\boldsymbol{W}_1) \tag{16}$$

ADAPTIVE PROCEDURE

In this section, an adaptive procedure is presented to compute the desired user's weight vector. It is based on the minimization of Eq.(14). Classically, the target weight vector is obtained iteratively as follows

$$\boldsymbol{W}_1(n+1) = \boldsymbol{W}_1(n) - \frac{1}{2} \mu \nabla \boldsymbol{p}(\boldsymbol{W}_1) \tag{17}$$

where, n the number of iterations; μ the adaptive gain which is determined by the convergence of the adaptive procedure; ∇ the gradient vector of the functional $\boldsymbol{p}(\boldsymbol{W}_1)$ with respect to $\boldsymbol{W}_1$.

In order to implement the iterative process, the gradient vector $\nabla \boldsymbol{p}(\boldsymbol{W}_1)$ in Eq.(17) must be computed. But unfortunately, it cannot be obtained directly by using Eq.(13) or Eq.(14). To resolve the problem, we utilized a kernel density estimator of possibility density function based on samples (Parzen, 1962). The general form of a kernel estimator is

$$\hat{f}_\lambda(y)=\frac{1}{n\lambda}\sum_{i=1}^{n}K\left(\frac{y-y_i}{\lambda}\right) \tag{18}$$

where $K(\cdot)$ is a kernel function and λ is the bandwidth. Some symmetric probability density functions commonly used as kernel functions are normal, triangular and quadratic. According to Eq.(18), the possibility density function given by Eq.(13) can be estimated based on samples as follows

$$f(\boldsymbol{Y}(k))=\sum_{k=1}^{K}\frac{1}{K\lambda}\exp\left(-\left(\frac{\boldsymbol{Y}(k)-\boldsymbol{Y}_k(k)}{\lambda}\right)^2\right)$$
$$(\lambda=\lambda_n\sqrt{2\pi\boldsymbol{W}_1{}^{\mathrm{H}}\boldsymbol{W}_1}) \tag{19}$$

where K is the data block size or the number of samples during a bit period. For example, if sample rate R_s is N_s times R_c (the chip rate of a CDMA system), K is equal to N_cN_s where N_c is the spread spectrum factor and N_s is a positive integer not less than 2. Accordingly, we can get $\boldsymbol{p}(\boldsymbol{W}_1)$ by K data blocks (assuming the #1 user)

$$\boldsymbol{p}(\boldsymbol{W}_1)=\frac{1}{K}\sum_{k=1}^{K}Q\left(\frac{\hat{b}_{k1}\boldsymbol{R}_k}{\lambda_n\sqrt{\boldsymbol{W}_1{}^{\mathrm{H}}\boldsymbol{W}_1}}\right) \tag{20}$$

where, $\hat{b}_{k1}$ is the desired user's estimated transmitted data bit which is detected after the array's output of the kth transmitted bit is despreaded by the desired user's signature signal; $\boldsymbol{R}_k$ is the estimated transmitted signal waveform of the desired user. It is the respread signal of the estimated transmitted data bit by the signature signal of the desired user; λ_n is the width for a kernel density estimation that is related to σ_n^2; $\boldsymbol{Y}(k)$ is the weighted vector that is the output of the array.

According to Eqs.(19) and (20), the gradient vector of $\boldsymbol{p}(\boldsymbol{W}_1)$ to $\boldsymbol{W}_1$ can be expressed as

$$\nabla\boldsymbol{p}(\boldsymbol{W}_1)=\frac{\partial\boldsymbol{p}(\boldsymbol{W}_1)}{\partial\boldsymbol{W}_1}=\frac{1}{2K\sqrt{2\pi}\lambda_n\sqrt{\boldsymbol{W}_1{}^{\mathrm{H}}\boldsymbol{W}_1}}$$
$$\cdot\sum_{k=1}^{K}\left(\frac{\boldsymbol{Y}_1(k)\boldsymbol{W}_1}{\boldsymbol{W}_1{}^{\mathrm{H}}\boldsymbol{W}_1}-\boldsymbol{R}_1(k)\right)\hat{b}_1(k)\exp\left(-\frac{(\boldsymbol{Y}_1(k))^2}{2\lambda_n^2\boldsymbol{W}_1{}^{\mathrm{H}}\boldsymbol{W}_1}\right) \tag{21}$$

To reduce computational complexity, $\boldsymbol{W}_1$ can be normalized to a unit-length as the operation would not affect the BER performance. So Eq.(21) can be simplified as follows

$$\nabla\boldsymbol{p}(\boldsymbol{W}_1)=\frac{1}{2K\sqrt{2\pi}\lambda_n}\sum_{k=1}^{K}(\boldsymbol{Y}_1(k)\boldsymbol{W}_1-\boldsymbol{R}_1(k))$$
$$\cdot\,\hat{b}_1(k)\exp\left(-\frac{(\boldsymbol{Y}_1(k))^2}{2\lambda_n^2}\right) \tag{22}$$

Putting Eq.(22) into Eq.(17), we can get the updated equation of the weight vector.

The adaptive procedure described above can be summarized as follows:

Step 1: Initial guess of weight vector;

Step 2: Operation is as same as that of LS-DRMTCMA (Liberti and Rappaport, 2002). $\boldsymbol{Y}_1(k)$ can be determined by Eq.(5) and $\hat{b}_1(k)$ and $\boldsymbol{R}_1(k)$ can be updated by Eq.(8) and Eq.(9) respectively;

Step 3: Normalize the weight vector $\boldsymbol{W}_1$;

Step 4: Update the gradient vector $\nabla\boldsymbol{p}(\boldsymbol{W}_1)$ by Eq.(22);

Step 5: Update the weight vector by Eq.(17) until convergence.

SIMULATION RESULTS

This section presents numerical results of various computer simulations implemented by applying the modified DRMTCMA to a smart antenna array operating in a CDMA mobile communication system. To compare performances, results of simulation using three types of beamforming algorithms (LS-DRMTA, LS-DRMTCMA and the novel algorithm) are presented in this paper. The signal environment and some parameters for the computer simulations were as follows unless mentioned otherwise. The array, (linear and half-wavelength spacing), consisted of eight omni-directional antenna elements; the system was assumed to use 31 Gold codes as the spreading signature; the modulation scheme was binary phase shift keying (BPSK); the carrier frequency was about 2 GHz; and the kernel density width λ_n was set to 0.2 that equals $2\sigma_n$. The kernel density width and the step factor μ should be set appropriately to ensure the best combined performance of convergence rate and steady-state BER misadjustment. We only consider the AWGN channel case and the multipath fading was not taken into consideration in this paper. In order to obtain the best performance of the algorithms, 1000 independent Monte-Carlo simulations were implemented for each data point in the simulation.

We first simulated the BER performance of the three beamforming algorithms as a function of user number. The signal-to-noise ratio (SNR) Eb/No of each user was set to 10 dB. As shown in Fig.1, the modified DRMTCMA achieved the best BER performance although the BER performance of LS-DRMTCMA outperformed that of the novel algorithm when the number of users was less than 10. If the required BER was 10^{-3}, the proposed algorithm increased the capacity about 2–3 times as compared with the case of other beamforming algorithms.

Then, let us study the BER performance of the three algorithms as a function of the desired user's Eb/No. Assuming that there are fifteen users in the CDMA system, the signal to noise ratio (SNR) for each user (except the desired user) is set to 10 dB. Fig. 2 shows the different BER performance of the three beamforming algorithms. It is evident that the modified beamforming algorithm has less user SNR in the case of the same BER level, which means the novel algorithm increases the system capacity essentially.

Fig.3 compares the near-far resistance performance of the modified DRMTCMA with that of the LS-DRMTA and LS-DRMTCMA in the considered CDMA communication system. A case of five co-channel users was considered and the #1 user is the desired user and other users are regarded as interfering users. Except for one interfering user, the SNR of the desired user and other interfering users was set to 10 dB. Fig.3 is the observed BER performance when one interfering user's power was varied.

As shown in Fig.3, the BER performance of the proposed algorithm is affected little by the power of the other user. It means that the modified DRMTCMA performance is robust to near-far effect resistance.

This can be explained by the fact that the weight vector is optimized directly by minimizing the bit error rate (BER) of the desired user in the

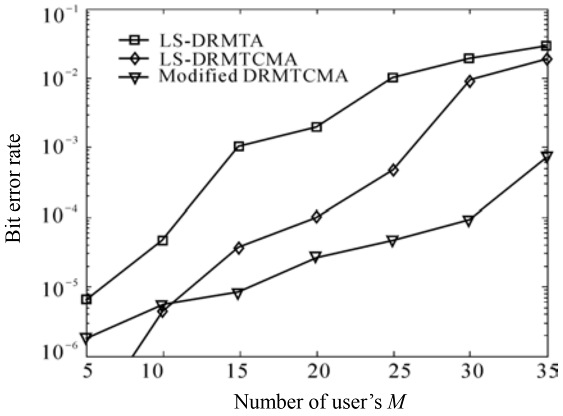

Fig.1 BER performance of the three algorithms as a function of user number
Operating conditions: users' SNR (Eb/No)=10 dB

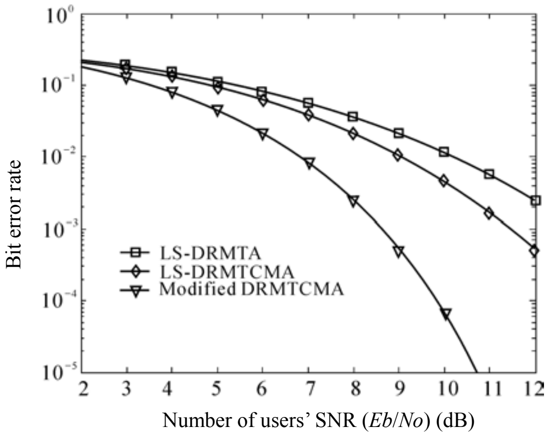

Fig.2 BER performance of the three algorithms as a function of the desired user's SNR (Eb/No)
Operating conditions: the number of users M=15 and other users' SNR (Eb/No)=10 dB

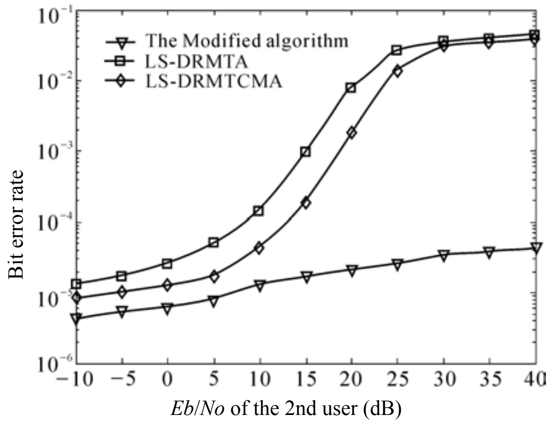

Fig.3 Performance of the three beamforming algorithms on near-far-effect resistance in the case of AWGN channel
Operating conditions: the number of users *M*=5 and other users' SNR (*Eb*/*No*)=10 dB

modified algorithm.

CONCLUSION

In this article, we proposed a modified DRMTCMA and an adaptive beamforming procedure for computing the optimal weight vector with the MBER criterion. The cost function of the original algorithms was modified based on minimum bit error rate criterion. A stochastic gradient adaptive procedure was also presented to obtain adaptive updating of the weight vector. The modified DRMTCMA algorithm can be used in code division multiple access (CDMA) system equipped with smart antennas. Various computer simulations showed that the modified algorithm provides remarkable improvements in the BER performance, capacity and near-far effect resistance of a given CDMA communication system.

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