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ANTENNA ARRAY CONFIGURATION EFFECTS ON THE RADIATION PATTERN AND BER OF THE MODIFIED ADAPTIVE CMA IN CDMA BASED SYSTEMS[*]

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Abstract– A time-varying multipath channel model for wireless systems as an extended form of Gaussian Wide Sense Stationary Uncorrelated Scattering (GWSSUS) model and a modified adaptive Constant Modulus Algorithm (CMA) for use in a CDMA system environment are presented. The large angular spread of the signal sources is considered. The post-correlation model (PCM) of data structure is used in CMA, too. The modified adaptive CMA algorithm has faster convergence and causes better radiation patterns in different array geometries to track signal sources. Comparing the signal to noise ratio at the output of the algorithm for uniform linear and circular arrays with theoretical results proves the efficiency of the presented algorithm. BER performance of the algorithm for different element numbers of uniform linear and circular array antennas with DBPSK modulation is also studied.

Keywords– Adaptive array antennas, GWSSUS, beamforming, CDMA, vector channel, CMA

1. INTRODUCTION

Generally, most digital communication signals pose some kinds of properties such as the constant modulus property or the spectral self-coherence property. Due to the interference, noise, and the time-varying channel in a communication system, these properties may be corrupted when the signal is received at the receiver. The adaptive array in the receiver tries to restore these properties using a property-restoral-based algorithm, and thus hopes that the output of the array is a reconstructed version of the transmitted signal. The Constant Modulus Algorithm (CMA) is an algorithm for the mentioned purpose.

CMA was first used by Gooch and Lundell [1] in the beamforming problem. Afterwards, many CMA-type algorithms were proposed for use in adaptive arrays. Some communication signs such as phase-shift keying (PSK), frequency-shift keying (FSK), and analog (FM) signals have a constant envelope. This constant envelope may be distorted when the signal is transmitted through the channel. The CMA [2-4] adjusts the weight vector of the adaptive array to minimize the variation of the envelope at the output of the array. After the algorithm converges, the array can steer a beam in the direction of the signal of interest (SOI), and nulls in the directions of the interference.

We encounter two problems in using traditional CMA. When the received signal is affected by fading, the array will lose the wanted signal and will follow another signal with higher power, therefore the array pattern will resonate immediately and will change its direction in a short time. Also, having coherent signals on antenna arrays is very important.

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In this paper, we introduce a signal model for the CDMA-based communication system environment where the Doppler shift is considered at the base station due to mobile unit velocity, and the geometry of the array is arbitrary. Due to the large spread angle and position of each source, received signal fading is noncoherent across the elements of the antenna array. A modified CMA algorithm is proposed to prevent source fading by using a different cost function. In continuation, we assume signal processing after de-spreading and then the convergence of the algorithm is discussed and radiation patterns are presented. To evaluate the performance of the algorithm, the BER at the output has been calculated.

2. SIGNAL MODEL

We assume a Gaussian Wide Sense Stationary Uncorrelated Scattering (GWSSUS) vector channel with objects grouped into uncorrelated clusters. Each cluster is a region containing a number of scatterers such that the signals components from scatterers are confined within a narrow time delay interval and have their own amplitudes and phases. The delays of the signals from each cluster are very close to each other, thus we assume these delays to be equal. Clusters are known by the direction of arrival (DOA) signals and a spread angle that determines the view angle or beam width (BW) of the cluster. We consider a cellular CDMA system where each base station is equipped with a receiving antenna of *n* elements (sensors).

We assume the general case where the number of paths is denoted by *P*, and *i* is the number of users. In the channel model, the total signal received at sensor *n* is given by [5]

$$s_{in}(t,x_n,y_n)=\sum_{p=1}^{P_i}\sum_{l=1}^{L_{ip}}a_{ipl}\ e^{j\dot{\varphi}_{ipl}}\ e^{j\frac{2\pi V}{\lambda}t\cos(\beta_{ipl})}\ e^{j\omega\tau_{ip}}.e^{j(k_x x_n\cos(\phi_p+\nu_{ipl})+k_y y_n\sin(\phi_p+\nu_{ipl}))} \tag{1}$$

where P_i is the number of resolvable paths, τ_{ip} is propagation time-delay along the *p* paths, L_{ip} is number of sub paths, a_{ipl} ,$\dot{\varphi}_{ipl}$ are amplitude and phase of the received signal, β_{ipl} is angle between the mobile unit and *l*th scatterer from *p*th bunch, k_x, k_y are wave numbers in *x* and *y* direction, ν_{ipl} is initial phase in *l*th sub path of *p*th bunch with respect to the average direction of arrival ϕ_p and *V* is the mobile unit velocity. If we rewrite Eq. (1) for a user then we have

$$s_n(t,x_n,y_n)=\sum_{p=1}^{P}\breve{g}_{n,p} \tag{2}$$

where $\breve{g}_{n,p}$ is the received signal from cluster *p*, at the antenna element *n*. By using $\mathbf{g}_p=(\sqrt{N}\big/\|\breve{\mathbf{g}}_p\|)\breve{\mathbf{g}}_p$, $\breve{\mathbf{g}}_p=[\breve{g}_{1,p},\breve{g}_{2,p},\dots,\breve{g}_{n,p}]^T$ is a propagation vector with norm $\sqrt{N}$. Then, at time *t*, the observation vector received by the antenna array can be written as follows:

$$\mathbf{s}(t)=\psi(t)\sum_{p=1}^{P}\mathbf{g}_p(t)\varepsilon_p(t)b(t-\tau_p(t))c(t-\tau_p(t))+\mathbf{n}(t) \tag{3}$$

$\mathbf{n}(t)$ denotes the noise vector term due to thermal noise and interference from other users. $\varepsilon_p^2(t)=\|\breve{\mathbf{g}}_p\|^2\big/\sum_{p=1}^{P}\|\breve{\mathbf{g}}_p\|^2$ is the fraction of the total power

$$\psi^2(t)=\sum_{p=1}^{P}\|\breve{\mathbf{g}}_p\|^2\big/N \tag{4}$$

received from the desired user. The bit sequence $b(t)$ is then spread by a periodic personal code $c(t)$ at rate $L=1/T_c$. We assume the multipath delays to be constant in time (i.e. $\tau_p(t)=\tau_p$). The post correlated observation vector on the despreaded data at the discrete time indexes $k=0,1,2,\dots$ is calculated by the Post Correlation Method (PCM) [6]

$$\mathbf{z}_p(k) = \frac{1}{T}\int_0^T \mathbf{s}(t + \tau_p + kT)\, c(t)\, dt \tag{5}$$

where $\mathbf{s}(t + \tau_p + kT)\, c(t)$ is known as despreaded data in CDMA systems. Here we consider a continuous stream of the data after despreading and segment it into frames of bit duration *T*. If we rewrite (5) in matrix form, then we have

$$\mathbf{z}_p(k) = \psi(k)\mathbf{g}_p(k)\varepsilon_p(k)b(k) + \mathbf{n}_p(k) \quad or \quad \mathbf{Z}(k) = b(k)\psi(k)\mathbf{G}(k)\boldsymbol{\gamma}(k) + \mathbf{N}(k) \tag{6}$$

$\mathbf{G}(k) \in ¢^{N\times P}$ is the steering matrix, $\boldsymbol{\gamma}(k) \in ¢^{P\times P}$ is a diagonal of power ratios (i.e. ε_p) summing to 1 over all paths (i.e. $\sum_{p=1}^{P} \varepsilon_p^2(t) = 1$).

We can rewrite (6) as follows:

$$\mathbf{Z}(k) = \mathbf{J}(k)s(k) + \mathbf{N}(k) \tag{7}$$

where $\mathbf{J}(k) = \mathbf{G}(k)\boldsymbol{\gamma}(k)$, $s(k) = b(k)\psi(k)$, $s(k)$ is the input signal component.

3. PROPOSED CMA

We can use a multistage CMA to extract several signals simultaneously [7-8]. It is assumed that after having the estimation of a signal from each stage, it will be subtracted from the signal of the previous stage. The original CMA tries to minimize the following cost function

$$J(k) = E\left[\left|\left|y(k)\right|^p - 1\right|^q\right] \tag{8}$$

where *y(k)* is the output of the CMA.

Convergence of the algorithm depends on the coefficients *p* and *q* in Eq. (8). Usually, the cost function $J(k)$ with *p=1, q=2*, or *p=2, q=2* is used. The output of the algorithm in the *m*th stage is

$$\tilde{y}_m(k) = \mathbf{w}_m^H(k)\mathbf{e}_m(k) \tag{9}$$

where

$$\mathbf{w}_m(k) = \left[w_{m,1}(k), w_{m,2}(k), \ldots, w_{m,N}(k)\right]^T \tag{10}$$

is the weight vector and for the first stage $\mathbf{e}_1(k) = \underline{\mathbf{J}}(k)$ ($\underline{\mathbf{J}}(k)$ is the columnwised version of $\mathbf{J}(k)$). The output of the (*m+1*)th stage is related to the *m*th stage by the following transfer function.

$$\mathbf{e}_{m+1}(k) = \mathbf{e}_m(k) - \mathbf{u}_m(k)y_m(k) = \mathbf{T}_m(k)\mathbf{e}_m(k) \tag{11}$$

where $\mathbf{u}_m(k)$ is the canceller weight vector and $\mathbf{T}_m(k)$ matrix is defined as

$$\mathbf{T}_m(k) = \mathbf{I} - \mathbf{u}_m(k)\mathbf{w}_m^H(k) \tag{12}$$

Therefore we will have

$$\mathbf{e}_m(k) = \mathbf{T}_{m-1}(k) \ldots \mathbf{T}_1(k)\mathbf{e}_1(k) \tag{13}$$

Then, weights in any stage are calculated with the following equation

$$\mathbf{w}_m(k+1) = \mathbf{w}_m(k) + \mu_{CMA}\, \mathbf{e}_m(k)\varepsilon_m^*(k) \tag{14}$$

where

$$\varepsilon(k) = \tilde{y}(k)\left(1/\left|\tilde{y}_m(k)\right| - 1\right) \tag{15}$$

is the CMA error that forces the array output to unity and $\mu_{CMA} > 0$ is the step size

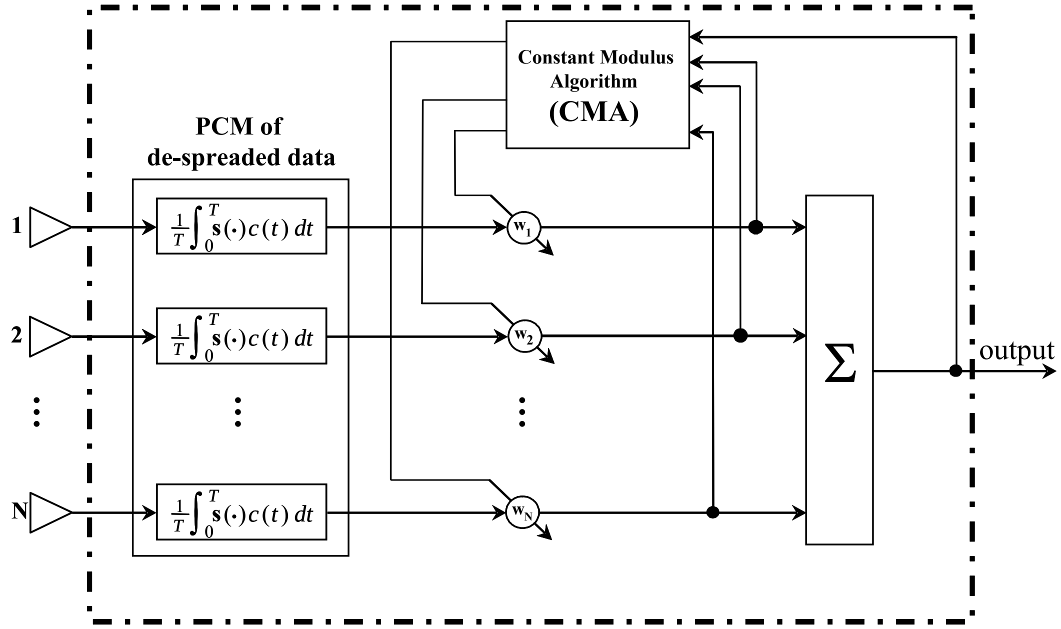


Fig. 1. Block diagram of the receiver with proposed CMA algorithm to extract CDMA signals

In most of the proposed algorithms for CDMA based mobile communication, signal processing before de-spreading is required. Therefore, large sidelobes and low convergence speed are problems that occur in these CMAs. The structure of the receiver with the proposed CMA algorithm to extract the CDMA signal is shown in Fig. 1. Here, we applied the algorithm after de-spreading. The output feedback shows the multistage CMA.

Since the received signal in mobile communication is affected by fading, the extracted weights require some improvement to source tracking. Therefore, a new cost function is used that yields a time-varying step size that slows down the adaptation process during a signal fade, while maintaining the constant modulus property of the original CMA algorithm. We can use the following cost function to calculate array antenna weights to prevent problems in faded source tracking [9].

$$J_q(k) = |y_m(k)|^q \left(|y_m(k)| - 1\right)^2 \tag{16}$$

where, $q \geq 0$ is a parameter to determine the step size.
If we use the cost function in Eq. (16), then the array antenna weight coefficients are

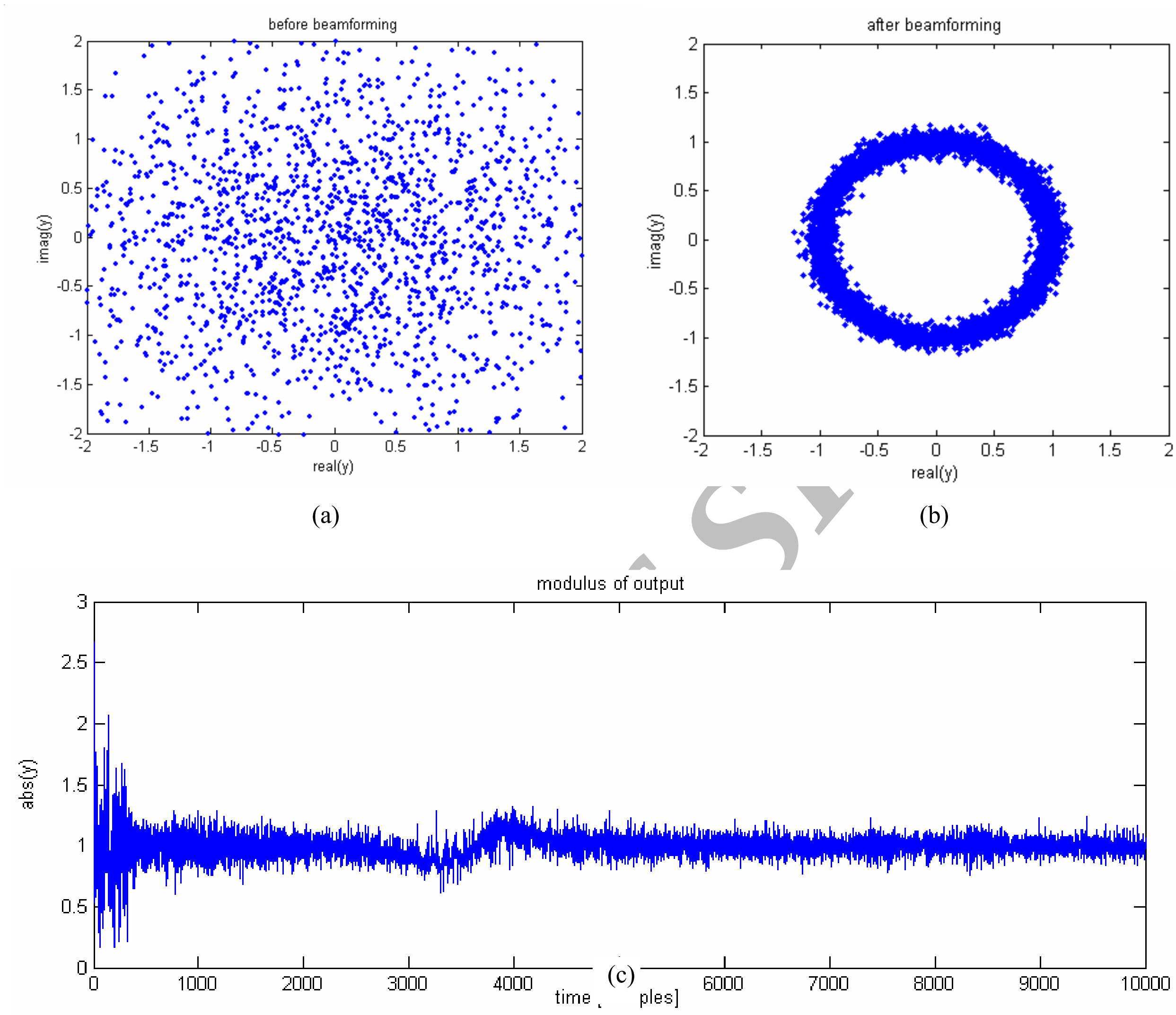
$$\begin{matrix} \mathbf{w}(k), \quad |\tilde{y}_m(k)| < q/(q+2) \\ \mathbf{w}(k) + \mu_{cma}|\tilde{y}_m(k)|^{q-1}.\left[(q+2)|\tilde{y}_m(k)| - q\right]\mathbf{e}_m(k)\varepsilon_m^*(k), \quad |\tilde{y}_m(k)| > q/(q+2) \end{matrix} \tag{17}$$

where $\mathbf{e}_m(k)$ is the input signal in *m*th stage and $\varepsilon_m(k)$ is the *m*th stage error. Variable Step-size CMA (VS-CMA) and CMA have the same complexity in calculations [5], but we will show that VS-CMA is more effective in the CDMA-based wireless communication environment.

4. SIMULATION AND RESULTS

a) Beamformer algorithm convergence

To evaluate the CMA beamformer behavior in the CDMA-based mobile communication environment, we assume a linear array structure. In Fig. 2, $\tilde{y}_m(k)$ as an output for eight element uniform linear array with inter-element spacing $d = \lambda/2$, is shown before and after beamforming. Since the received signal has fading, the CMA algorithm can track the signal with convergence in weights.



(a) (b)

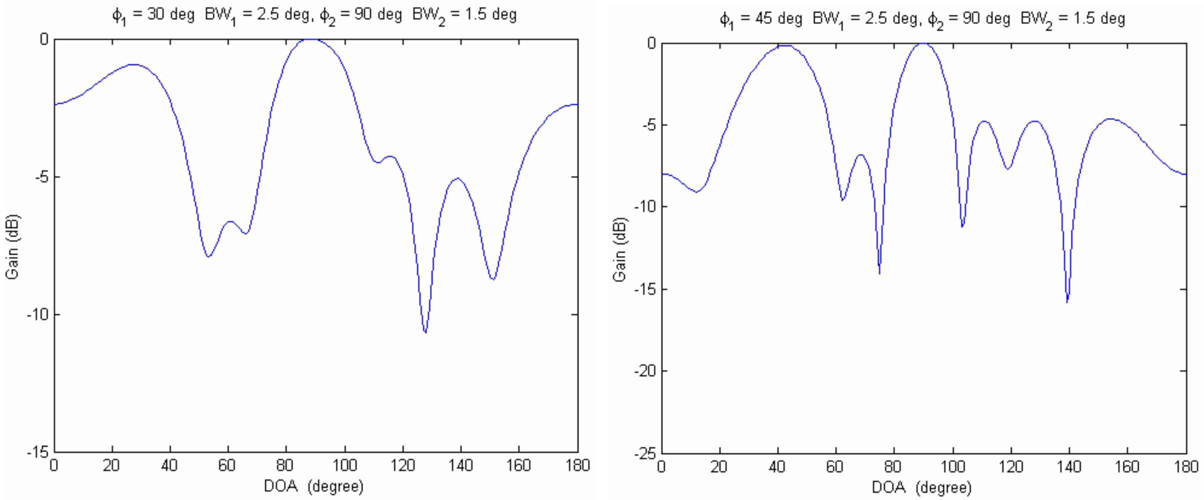
(c)

Fig. 2. a and b) effect of beam forming, c) convergence of VS-CMA

Convergence performance is also shown in Fig. 2. In simulation, we have found that $q=2$ yields good convergence and tracking results [5]. As we observe from Fig. 2, the convergence speed is much better than traditional CMA ($n_{convergence\_VS\text{-}CMA} = 4000$ vs. $n_{convergence\_CMA} = 12000$) [10]-[11].

b) Beam pattern

To assess the tracking performance of VS-CMA, the proposed CMA behavior behind an eight element array in the CDMA-based mobile communication is simulated. At first, when we have uniform linear array (ULA) with inter-element spacing of $\lambda/2$ and two spread bunches placed at 45° and 90° with spread angles of 2.5° and 1.5° respectively, the resultant beam pattern in the output of the algorithm is shown in Fig. 3a. We can see that array adjusts its pattern toward two bunches. In another simulation, for uniform circular array (UCA) with element spacing $\lambda/2$, when bunches have been placed at 30° and 90° with 2.5° and 1.5° spread angles, the resultant beam pattern is shown in Fig. 3b.



(a) (b)

Fig. 3. Beam patterns of 4 element uniform linear and circular array antennas where there are two bunches at (a) 45° and 90° for uniform linear array and (b) at 30° and 90° for uniform circular array

c) Array gain

When we have a mobile unit in a communication environment, the received signal is calculated by Eq. (1). In this case, the covariance matrix of the received signal is obtained by [5]

$$\begin{aligned}\mathbf{R}_{Z(k)} &= E[\underline{\mathbf{Z}}^H(k)\underline{\mathbf{Z}}(k)] \\ &= \sigma_s^2\underline{\mathbf{J}}^H(k)\underline{\mathbf{J}}(k) + \sigma_n^2\mathbf{I} \\ &= \mathbf{R}_s + \mathbf{R}_n\end{aligned} \tag{18}$$

where $\sigma_s^2 = s(k)s^*(k)$ and the $\underline{\mathbf{Z}}(k)$ vector is obtained by concatenation of the $\mathbf{Z}_k$ columns. If we assume $\mathbf{w}$ as the weight vector of antenna elements, then the output signal and related power will be

$$y(k) = \mathbf{w}^H\underline{\mathbf{Z}}(k) \tag{19}$$

$$\begin{aligned}P_{out} &= |y(k)|^2 = \mathbf{w}^H E[\underline{\mathbf{Z}}^H(k)\underline{\mathbf{Z}}(k)]\mathbf{w} \\ &= \sigma_s^2\mathbf{w}^H\mathbf{R}_s(k)\mathbf{w} + \sigma_n^2\mathbf{w}^H\mathbf{w}\end{aligned} \tag{20}$$

The first term of (20) is signal power and the second term is the noise power. So, the signal to noise ratio in the output of the antenna array is

$$SNR_{out} = \frac{\sigma_s^2\mathbf{w}^H\mathbf{R}_s(k)\mathbf{w}}{\sigma_n^2\mathbf{w}^H\mathbf{w}} = SNR_{in} \times AG \tag{21}$$

where AG is the array gain given by

$$AG = \frac{\mathbf{w}^H\mathbf{R}_s(k)\mathbf{w}}{\mathbf{w}^H\mathbf{w}} \tag{22}$$

To calculate the AG in the output of the algorithm we used the proposed channel model, which has Rayleigh fading, for the received signal and AWGN noise for the mentioned environment to generate the propagation data. In our simulation we consider the case of a code length $L=32$, number of elements $N=8$ and number of paths $P=2$ with a uniform power delay profile [5]. The velocity of the mobile unit is assumed *20m/s* and the signal is transmitted with DBPSK modulation with a data bit rate of *9.6 kbits/s* at the carrier frequency of *2GHz*. Simulations were repeated for the linear and circular arrays for different input signal to noise plus interference ratios ($SNIR_{in}$). Theoretically, the array gain (*AG*) obeys *10log (N)*, where *N* is number of elements of array antennas (*N* fold). Table 1 shows *AG*s in ULA and UCA cases obtained for *SNIR=-2, 2, 6, 10 dB*. The simulation results are based on 100 independent trials with a 5000 bit duration for each trial. We can see good performance of the proposed algorithm, because the obtained values in the output of the algorithm are very close to those of the theoretical results.

Table 1. AG for ULA and UCA with SNIR$_{in}$=-2, 2, 6, 10 dB

N=8	SNIR$_{in}$=-2 [dB]	SNIR$_{in}$=2 [dB]	SNIR$_{in}$=6 [dB]	SNIR$_{in}$=10 [dB]
$AG_{theoretical}$ [dB]	9.03	9.03	9.03	9.03
AG_{ULA} [dB]	8.45	8.95	8.90	9.10
AG_{UCA} [dB]	7.85	8.26	8.30	8.90

d) BER performance

The behavior and performance of the proposed CMA is examined by using computer simulations. All simulation cases are involved at 2GHz frequency for a CDMA signal with a spreading factor of 32. BER vs. different SNIRs have been calculated in [12] with *N=1*. For the BER performance of the proposed method, we vary the number of antenna array elements with DBPSK modulation versus SNIR for a single user. From Fig. 4 it is observed that the new receiver has outperformed the conventional method in Rayleigh fading channels, especially when the SNIR of the received signal from the user is small. Also, a comparison between the proposed model with a conventional receiver shows a considerable difference in performance between these two approaches, when we use various structures for antenna arrays (i.e. ULA and UCA) and different number of elements (resolution).

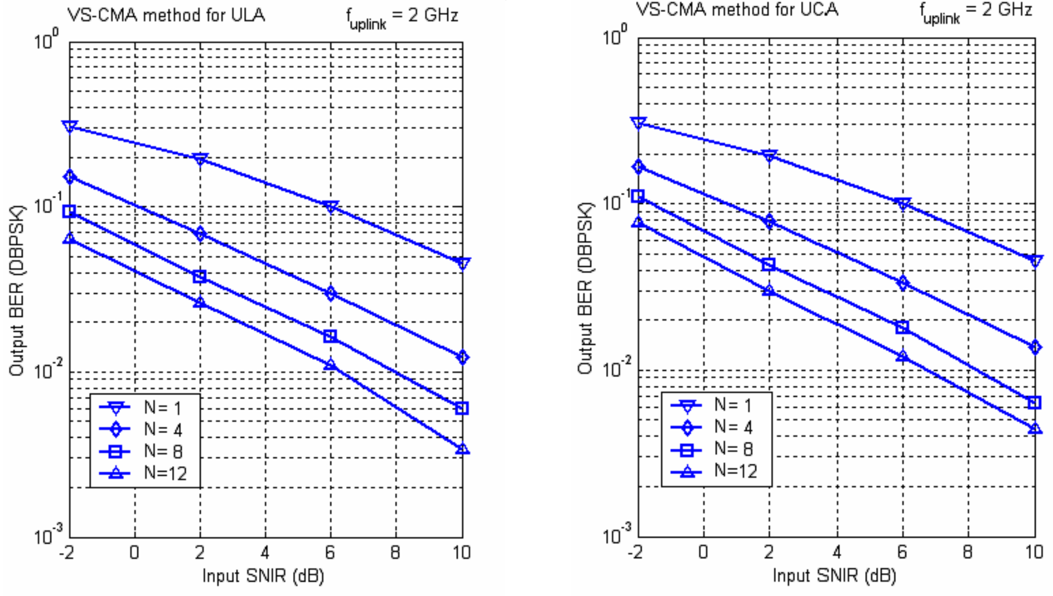


Fig. 4. Bit Error Rates in VS-CMA for a ULA and UCA with different element array numbers of arrays

5. CONCLUSIONS

A new time-varying multi-path vector channel to evaluate the received signal at the base station for CDMA mobile communication systems reveals that the fading of the received signal envelope has

Rayleigh distribution. Thus, if the source captured by the CMA array undergoes a deep fade, the CMA array might release that source in favor of another source. In order to treat the problem of fading, a new cost function is used that yields a time-varying step size.

The idea of exploiting the data structure after despreading is used to propose the modified CMA algorithm which is more suitable in studying the radiation pattern for tracking signal sources in different DOAs and spread bunches for CDMA signals. Comparing the signal to noise ratio and BER performance with DBPSK modulation at the output of the algorithm of uniform linear and circular arrays with that of an ideal case proves the efficiency of the proposed algorithm.

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