Evaluation of the Interference and Noise Suppression Capability of Uniform Linear Array Adaptive Beamforming Antenna

A. C. O. Azubogu, I. I. Nsionu, G. N. Onoh, and V. E. Idigo

Abstract—**This paper evaluates the interference and noise suppression capability of uniform linear array adaptive beamforming antenna, at base stations of WCDMA mobile communication system. The signal-to-interference and noise ratio (SINR) was the performance index used for the evaluation and analysis. SINR was investigated for a conventional narrow band beam former by varying the number of antenna array elements, the inter-element spacing and number of interfering signals or users. The results were compared with that of omni-directional antenna. The graph obtained showed significant improvement in SINR as the number of antenna elements increases in the presence of large interferers for odd numbered array.**

Index Terms—**Adaptive antenna arrays, uniform linear arrays, beamforming, interference suppression and noise reduction capability.**

I. Introduction

There is an increasing demand on mobile wireless operators to provide voice and high speed data services. At the same time, these operators want to support more users per base station, BS to reduce overall network cost and make services available to subscribers. Unfortunately, because the available broadcast spectrum is limited, attempts to increase traffic within a fixed bandwidth create more interference in the system and degrade the signal quality [1].

Therefore, the use of antenna arrays in wireless communication results in the improvement of signal-to-interference and noise ratio (SINR). Before deploying antenna arrays as part of a BS structure of a wireless communication system, it is important to assess the potential of a given array configuration to suppress interference and reduce channel noise. The signal-to-interference and noise reduction capability is therefore an important performance index for an antenna array at a BS of a mobile communication system. The ability of antenna array to give better performance improvement is a function of the array geometry (for example, linear, circular or rectangular), the number of antenna elements, inter-element spacing, number of interfering users and the direction of arrival of the desired user and the interferers. The uniform linear array (ULA) is the most common of all the array geometries employed in cellular and personal communication systems (PCS) [2], and it is the simplest to be used in investigating SINR improvement. In this paper, we provide a detailed presentation of SINR improvement ability of a ULA. In particular, we consider the effect of varying the number of antenna elements, number of interfering users and the inter-element spacing on the SINR improvement with the exclusion of mutual coupling. The performance of omni-directional antenna and adaptive antenna array were compared based on SINR maximization.

The remainder of the paper is organized as follows. Section II presents the cell model of the proposed cellular environment. Section III states the signal model and the cost function for evaluating the SINR. Results and discussions are presented in section IV.

Finally, the conclusions of this work along with some future lines of research are presented in section V.

II. Cell Model

A typical WCDMA mobile environment is shown in figure 1 which consists of seven hexagonal cells covering a large area such as an urban environment like Awka, Nigeria. At each cell is a base station, BS carrying a sectorized antenna dividing the cell into three sectors of 120°. Each BS supports as many users as possible based on installed capacity of a particular cell.

The proposed cell model deploying adaptive antenna array at BS is shown in figure 2 where there is only one BS covering the entire seven hexagonal cells depicted in figure 1, and is situated at the centre cell. The proposed cell is expected to increase capacity, reduce overall cost, minimize specific absorption rate (SAR), and above all suppress interferences.

III. Signal Model

The signal model for investigating the signal-to-interference plus noise ratio (SINR) improvement capabilities of adaptive antenna array is developed by considering the ULA model. Figure 3 shows a simple structure of a narrowband array that can be used for beam forming.

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Authors are with Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka (e-mail: austinazu@yahoo.com; vicugoo@yahoo.com, obynola@yahoo.com).

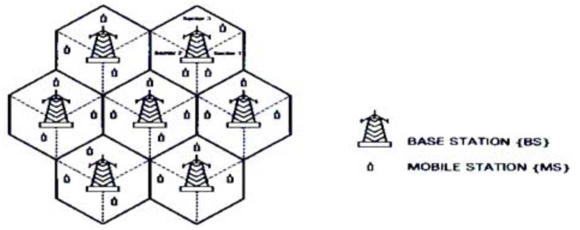


Fig. 1. Typical WCDMA mobile environment with sector antenna at BS

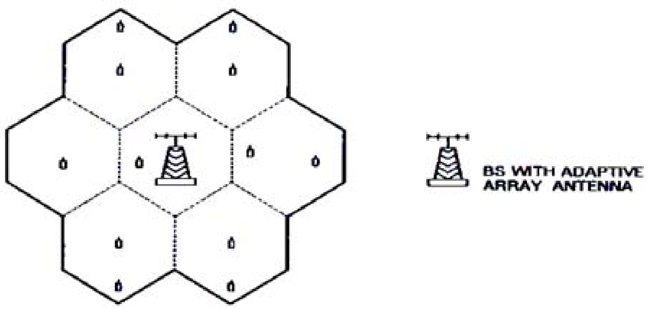


Fig. 2. Proposed WCDMA mobile environmental deploying adaptive array antenna at BS

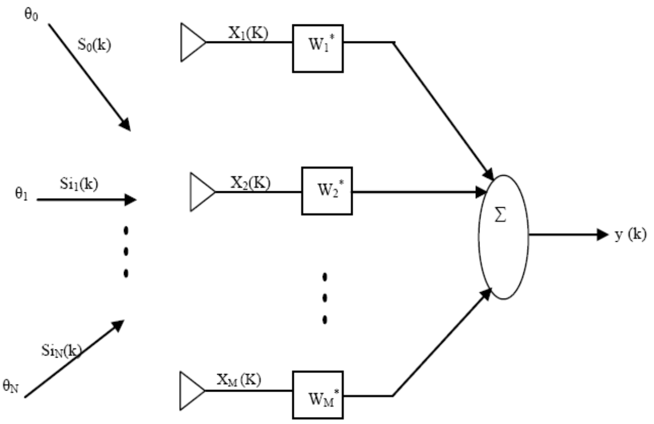


Fig. 3. Conventional narrowband beam forming array

Let ULA be composed of *M* elements and let it receive one desired narrowband signal $S_o[k]$ arriving at angle θ_0 and *N*-narrowband signals $S_i[k]$ from undesired (or interference) users arriving at directions $\theta_1, \theta_2, \cdots \theta_N$. The direction of arrivals (DoA) is known a priori using any of the DoA estimation techniques such as MUSIC and ESPRIT. The input signal at each antenna element is the convolution between the transmitted signal and the channel impulse response. Each received signal at element *m* also includes additive Gaussian noise. Time is represented by the *kth* time sample. The overall received signal vector $\mathbf{X}[k]$ is given by the superposition of desired signal vector $\mathbf{X}_o[k]$, interfering signal vector $\mathbf{X_i}[k]$, and an $M \times 1$ vector $\mathbf{n}[k]$ which represents zero mean Gaussian noise for each channel. Hence, $\mathbf{X}[k]$ can be written as:

$$\mathbf{X}[k] = \mathbf{X}_o[k] + \mathbf{X_i}[k] + \mathbf{n}[k] \tag{1}$$

where

$$\mathbf{X}o[k] = \mathbf{a_0}(\theta_0)\mathbf{S_0}[k] \tag{2}$$

$$\mathbf{X_i}[k] = [\mathbf{a_1}(\theta_1)\mathbf{a_2}(\theta_2)\cdots\mathbf{a_N}(\theta_N)].\begin{bmatrix} S_{i1}[k] \\ S_{i2}[k] \\ \vdots \\ S_{iN}[k] \end{bmatrix} \tag{3}$$

$\mathbf{a_i}(\theta_i), i = 0,1,2\cdots N$ is *M*-element array steering vector for the θ_i direction of arrival defined as:

$$\mathrm{a}(\theta) = \begin{bmatrix} 1 \\ e^{j\beta d\sin\theta} \\ . \\ . \\ . \\ e^{j(M-1)\beta d\sin\theta} \end{bmatrix} = \begin{bmatrix} 1 & e^{j\beta d\sin\theta} \cdots e^{j(M-1)\beta d\sin\theta} \end{bmatrix}^T \tag{4}$$

where $\beta = \frac{2\pi}{\lambda}$ is the wave number and d is the inter-element spacing which is a function of wavelength, λ of arriving signals.

It is assumed that the total number of arriving signals $N+1 \le M$. In a more compact form the overall received signal can be written as

$$\mathbf{X}[k] = \mathbf{X}_o[k] + v[k] \tag{5}$$

where

$v[k] = \mathbf{X_i}[k] + \mathbf{n}[k]$ is the undesired signal.

The arriving signals is time varying and thus our calculations are based upon *K*-time snapshots (or samples). The array correlation matrix associated with vector $\mathbf{X}[k]$ contains information about how signals from each element are correlated with each other and is given by

$$\mathbf{R}_{xx} = \mathbf{E}\{\mathbf{X}[k]\mathbf{X}^H[k]\} \tag{6}$$

The array correlation matrices for both the desired signal $\mathbf{R}_o$ and the undesired signals $\mathbf{R}_v = \mathbf{R_i} + \mathbf{R_n}$ can be approximated by applying temporal averaging over *K*-samples:

$$\mathbf{R}_o = \mathbf{E}\{\mathbf{X}o[k]\mathbf{X}_o^{\mathbf{H}}[k]\} \tag{7}$$

$$\mathbf{R}_{ii} = \mathbf{E}\{\mathbf{X_i}[k]\mathbf{X_i^H}[k]\} \tag{8}$$

$$\mathbf{R_n} = \boldsymbol{\sigma}_\mathbf{n}^2\mathbf{I}, \tag{9}$$

where $\boldsymbol{\sigma}_\mathbf{n}^2$ is the noise variance, and $\mathbf{I}$ is an N×N identity matrix.

IV. Beam Former Output

In the beam former depicted in Figure 3 the array output is given by

$$\mathbf{Y}[k] = \mathbf{W}^H.\mathbf{X}[k] \tag{10}$$

where $\mathbf{W}$ is the weight vector that is applied to the antenna array to produce a beam pattern with its main lobe in the direction of the desired signal. The superscript represents Hermitan transpose.

The weighted array output power for the desired signal is given by

$$\sigma_o^2 = E\{|\mathbf{W^H}.\mathbf{X}_o|^2\} = \mathbf{W^H}.\mathbf{W}.E\{\mathbf{X}_o\mathbf{X}_o{}^{\mathbf{H}}\} \tag{11}$$

$\mathbf{E}\{\mathbf{X}_o\mathbf{X}_o{}^{\mathbf{H}}\} = \mathbf{R}_o$ is the signal correlation matrix that contains information about how signals from each antenna element are related with each other.

The weighted array output power for the undesired signals is given by

$$\sigma_v^2 = \mathbf{E}\{|\mathbf{W^H}.v|^2\} = \mathbf{W^H}.\mathbf{R}_v.\mathbf{W} \tag{12}$$

The signal-to-interference and noise ratio (SINR) is defined as the ratio of the desired signal power to the undesired signal power:

$$SINR = \frac{\sigma_o^2}{\sigma_v^2} = \frac{\mathbf{W^H}.\mathbf{R}_o.\mathbf{W}}{\mathbf{W^H}.\mathbf{R}_v.\mathbf{W}} \tag{13}$$

The weight vector $\mathbf{W}$ is determined by some optimization algorithm to yield optimum SINR or some other objective function [3, 4]. Assuming that maximum SINR beam forming is performed, the SINR can be maximized in equation (13) by taking the derivative w.r.t $\mathbf{W}$ and setting the result equal to zero:

$$\mathbf{R}_o\mathbf{W} = \frac{\mathbf{W^H}.\mathbf{R}_o.\mathbf{W}}{\mathbf{W^H}.\mathbf{R}_v.\mathbf{W}}.\mathbf{R}_v.\mathbf{W} \tag{14}$$

$$\mathbf{R}_o\mathbf{W} = SINR.\mathbf{R}_v.\mathbf{W} \tag{15}$$

or

$$\mathbf{R}_v^{-1}\mathbf{W}\mathbf{R}_o = SINR.\mathbf{W} \tag{16}$$

Equation (15) is an eigenvector equation with *SINR* being the eigenvalues. The maximum *SINR* $(SINR_{\max})$ is equal to the largest eigenvalue. The eigenvector corresponding to this largest eigenvalue is the optimum weight vector, $\mathbf{W}_{opt}$. Thus

$$R_o.W_{opt} = SINR.R_v.W_{opt} \tag{17}$$

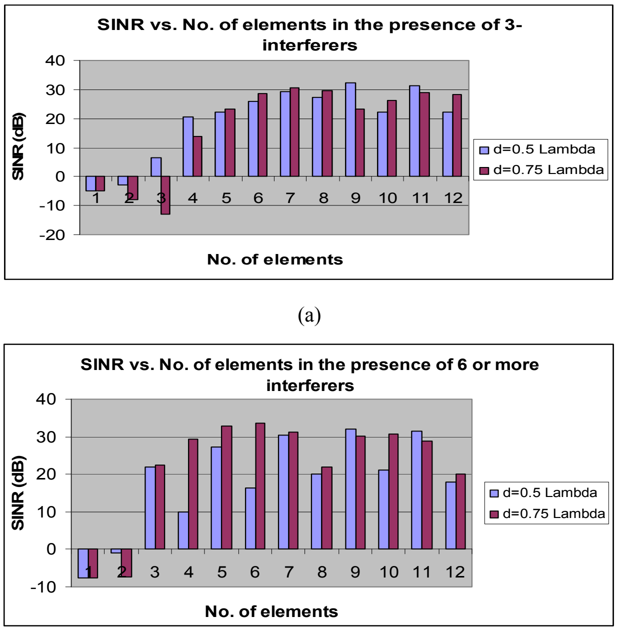
V. Results and Discussions

To investigate the interference and noise suppression capability of an adaptive antenna array, a fixed weight beam former is considered to provide maximum output SINR in the direction of a desired user. In the simulation, we evaluated the maximum SINR for M-ary by varying M between 1 and 12, with inter-element spacing of d=0.5λ and 0.75λ for the ULA model. Seven scenarios were considered with the number of interferers varying between 2 and 12.

In each case, the desired user fixed angle of arrival was set at 30° and noise variance is taken to be 0.001. Both the desired and interfering signals take the form of simple complex-phase modulated signal. Signal amplitude was taken to be 1. The channel model was considered as Rayleigh flat fading and noise as additive white Gaussian (AWGN) with zero mean. Fig. 4 illustrates the effect of varying the inter-element spacing for a ULA and the results show significant improvement as the number of antenna elements increases for odd numbered array while fig.5 shows the result obtained for the 7 scenarios when d= 0.5λ.

Next we compared the omni-directional antenna which was taken as a single element antenna and 2-element array (2-ary) for SINR improvement with

inter-element spacing d=0.5λ. Also, lower-element array (M=3, 4, 5 and6) and medium-element array (M=6, 7, and 8) were compared. Fig. 6 illustrates the comparative analysis of omni directional and adaptive antenna array, while fig.7 shows that for lower-element and medium-element arrays [5].



(a)

(b)

Fig. 4. variation of SINR with number of antenna elements in the presence of (a) 3 interferes and (b) 6 or more interferers.

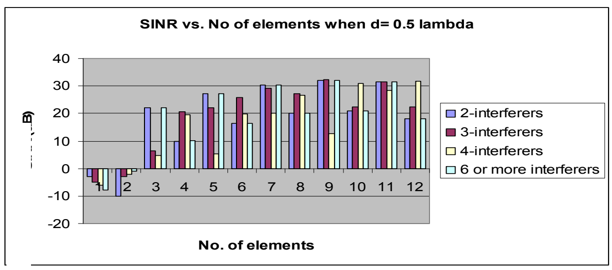


Fig. 5. SINR for the 7 scenarios when d=0.5λ

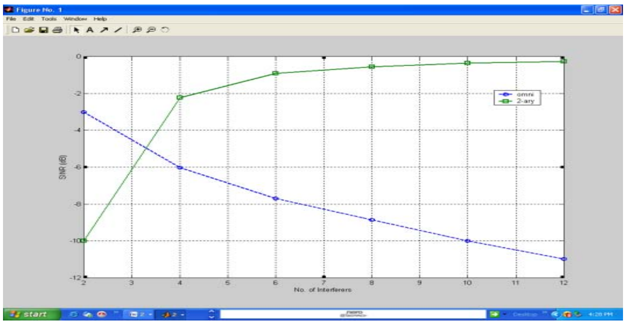


Fig. 6. SINR vs. No. of interferers for omni-directional antenna and 2-element adaptive antenna array

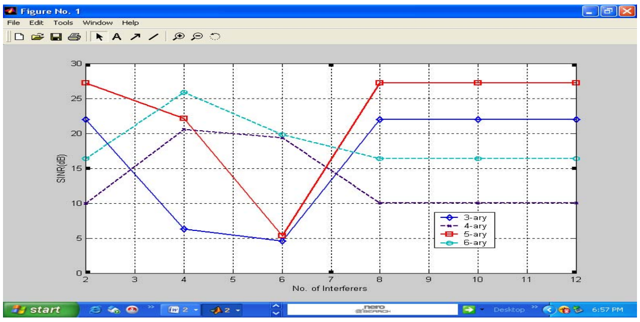


Fig. 7 (a) . comparative analysis of SINR for lower-element array

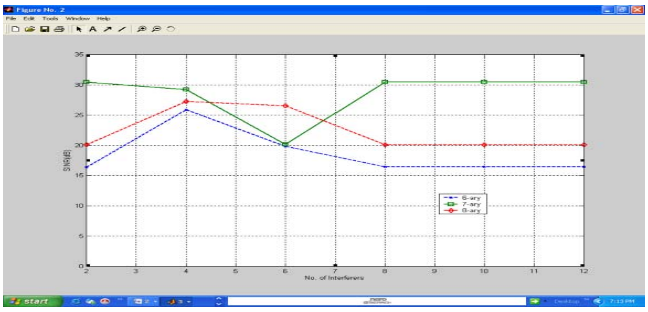


Fig. 7 (b). comparative analysis of SINR for medium-element array

VI. CONCLUSIONS

This paper presented an analysis concerning the SINR improvement for uniform linear arrays employed as part of base station structure of a WCDMA mobile communication system. The results obtained have shown significant improvement as the number of antenna elements increases in the presence of large interferences for odd numbered arrays. From the comparative analysis of lower-element and medium-elements array, 5-element or 7-element arrays will be ideal for BS to avoid system complexity as observed from our results. We have compared analytical results for omni-directional antenna and 2-element array and results showed that 2-ary has SINR improvement of approximately 10 folds that of omni-directional antenna in the presence of large interferers.

Future research will be aimed at dealing with other array geometries and effect of mutual coupling. In addition, a real-time measurement should be carried out at a BS deploying adaptive antenna arrays by adaptively tuning antenna array characteristics and parameters in order to meet antenna array configurations that provide a great interference and noise reduction capability to maximize capacity.

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