RESEARCH ARTICLE OPEN ACCESS

Analysis of Base Station Adaptive Antenna Array Performance in CDMA20001X Mobile Radio Network

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ABSTRACT

Over the last few years, wireless cellular communications has experienced rapid growth in the demand for provision of high data rate wireless multimedia services. This fact motivates the need to find ways to improve the spectrum efficiency of wireless communication systems. Smart or adaptive antennas have emerged as a promising technology to enhance the spectrum efficiency of present and future wireless communications systems by exploiting the spatial domain. This paper presents the analysis of base station adaptive antenna array performance in CDMA20001X mobile radio network. The results for the performance of CDMA20001x in the presence and absence of adaptive antenna array were simulated in Matlab. The simulation results show a significant reduction in the BER in the presence of adaptive antenna unlike in the absence of adaptive antenna array. Thus, using adaptive antenna array is an effective solution in reducing the effect of interference and increasing channel capacity in CDMA20001x. CDMA20001x is chosen as the platform for this paper since it has been adopted as the air-interface technology by the Third Generation (3G) wireless communication systems.

Keywords:- Adaptive antenna array,CDMA20001x,beamforming,rake receiver.

I. INTRODUCTION

Wireless cellular communication systems have evolved considerably since the development of the First generation (1G) systems in the 70's and 80's, which relied exclusively on Frequency Division Multiple Access/Frequency Division Duplex (FDMA/FDD) and analog Frequency Modulation (FM) [1]. The second generation (2G) wireless communication systems, which make up most of today's cellular networks, use digital modulation formats and Time Division Multiple Access/Frequency Division Duplex (TDMA/FDD) and Code Division Multiple Access/Frequency Division Duplex techniques [2]. Examples of 2G systems include Interim Standard-95 Code Division Multiple Access (IS-95 CDMA) which is used in American, Asian and Pacific countries including USA, South Korea and Australia [3] and Global System for Mobile communications (GSM) which is widely used in European and Asian countries including China and Australia [4]. The 2G systems have been designed for both indoor and vehicular environments with an emphasis on voice communication. While great effort in current 2G wireless communication systems has been directed towards the development of modulation, coding and protocols, antenna related technology has received significantly less attention up to now [5]. However, it has to be noted that the manner in which radio energy is distributed into and collected from space has a profound influence on the efficient use of spectrum [6].

Over the last few years, wireless cellular communication has experienced rapid growth in the demand for wireless multimedia services such as internet access, multimedia data transfer and video conferencing. Thus, the third generation (3G) wireless communications systems must provide a variety of new services with different data rate requirements under different traffic conditions, while maintaining compatibility with 2G systems. Examples of 3G standards include CDMA2000 [7] which has been commercially launched in countries including USA and South Korea and Wideband-CDMA (W-CDMA) [8] which has been launched in Europe, Japan and Australia [9]. This increasing demand for high data rate mobile communication services, without a corresponding increase in radio frequency spectrum allocation, motivates the need for new techniques to improve spectrum efficiency. Adaptive antenna arrays have emerged as one of the most promising technologies for increasing the spectral efficiency and improving the performance of present and future wireless communication systems [10].

II. ADAPTIVE ANTENNA SYSTEM

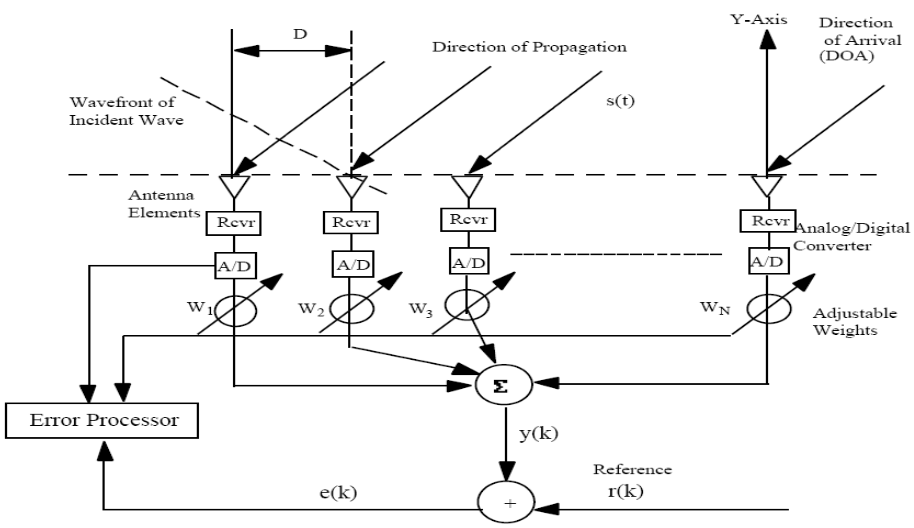

Fig 1. Adaptive antenna array system

This is an array of antennas which is capable of changing its antenna pattern dynamically to adjust to noise, interference and multipath. They are used to enhance received signals and may also be used to form beams for transmission.

In an adaptive array, signals received by each antenna are weighted and combined using complex weights (magnitude and phase) in order to maximize a particular performance criterion e.g. the Signal to Interference plus Noise Ratio (SINR) or the Signal to Noise Ratio (SNR). Fully adaptive system use advanced signal processing algorithms to locate and track the desired and interfering signals to dynamically minimize interference and maximize intended signal reception[11].

Unlike conventional antennas, they confine the broadcast energy to a narrow beam. It optimizes the way the signals are distributed on a real time basis by focusing the signal to the desired user and 'steering' it away from the other users occupying the same channel in the same cell and adjacent or distant cell [12]. The beam forming is done digitally, and a main lobe is generated in the direction of the strongest signal component. In addition, side lobes are generated in the direction of multi path components and nulls in the direction of interferers. This technique will maximize the signal to interference and noise ratio (SINR). Continuously steering a beam onto the wanted signal, rather than picking the best of a number of fixed beams, improves the system's ability to optimize the wanted SNR. This is the main advantage of adaptive antenna array system over switched beam system. This is achieved through an algorithm that generates a set of complex antenna element weights to construct the required beam. This algorithm is called the ADAPTIVE ALGORITHM also known as the adaptive beamforming algorithm [13].The adaptive array architecture is based on the Least Mean Square(LMS)algorithm.

2.1 LEAST MEAN SQUARE (LMS) ALGORITHM

This algorithm varies the weights of the antenna array based on the received data in order to maximize the signal strength of the signal of interest(SOI) and crucial in steering the main beam of the antenna array. Figure 1 shows the plane waves arriving at the antenna elements. The signals are then down converted to an Intermediate Frequency and sampled by an Analog to Digital (A/D) converter. The A/D converter converts the electrical signal from analog to digital form. Then, this input signal is multiplied with a variable weight and all the symbols are summed to produce an output, y(k).The reference signal r(k) is generated with local oscillator whose carrier frequency exhibits high correlation with the SOI. The error signal e(k) is the difference between the summed output ,y(k) and the reference signal, r(k). The error, as indicated in Figure 1 can be written as[14]:

$$e(k) = d(k) - y(k) \quad (1)$$

Where $y(k) = w^H x(k)$

Therefore, $e(k) = d(k) - w^H x(k)$ (2)

Squaring the error gives

$$|e(k)|^2 = |d(k) - w^H x(k)|^2 \quad (3)$$

Expanding the squared error gives us

$$|e(k)|^2 = |d(k)|^2 - 2d(k)\, w^H x(k) + w^H x(k)\, x^H(k)\, w \quad (4)$$

Simplifying the equation gives

$$\mathrm{E}[|e(k)|^2] = \mathrm{E}[|d(k)|^2] + w^H(k) R_{xx} w(k) - 2w^H(k) r \quad (5)$$

Writing it in terms of the cost function becomes

$$J(w) = D - 2w^H r + w^H R_{xx} w \quad (6)$$

Where $D = E[|d(k)|^2]$

Employing the gradient method to locate the minimum of, gives

$$\nabla w(J(w)) = 2 R_{xx} w - 2r \quad (7)$$

The minimum occurs when the gradient is zero. Thus, the solution for the weights which is the optimum Wiener solution (w or w_{opt}) is given by:

$$0 = 2 R_{xx} w - 2r$$

$$w = w_{opt} = R_{xx}^{-1} r \quad (8)$$

The solution in (8) is predicated on our knowledge of all signal statistics and thus in our calculation of the correlation matrix. In general, we do not know the signal statistics and thus must resort to estimating the array correlation matrix ($\overline{R}_{xx}$) and the signal correlation vector ($\bar{r}$) over a range of snapshots or for each instant in time. The instantaneous estimates of these values are given as:

$$\overline{R}_{xx}(k) \approx x(k)x^H(k) \tag{9}$$

and

$$\bar{r} \approx d^*(k)x(k) \tag{10}$$

The LMS algorithm can also employ an iterative technique called the method of *steepest descent* to approximate the gradient of the cost function. The direction of steepest descent is in the opposite direction as the gradient vector. This method recursively computes and updates the sensor array weights vector w. It is intuitively reasonable that successive corrections to the weights vector in the direction of the negative of the gradient vector should eventually lead to minimum mean square error, at which point the weights vector assumes its optimum value. The method of steepest descent can be approximated in terms of the weights using the LMS method. The steepest descent iterative approximation is given as:

$$w(k+1) = w(k) - \frac{1}{2}\mu\, \nabla w\, (J(w(k))) \tag{11}$$

where, μ is the step-size parameter and ∇w is the gradient of the performance surface. If we substitute the instantaneous correlation approximations, we have the LMS solution.

$$\begin{aligned} w(k+1) &= w(k) - \mu\, [\overline{R}_{xx}\, w - \bar{r}\,] \\ &= w(k) + \mu\, [\bar{r} - \overline{R}_{xx}\, w] \\ &= w(k) + \mu\, e^*(k)\, x(k) \end{aligned} \tag{12}$$

But, $e(k) = d(k) - w^H(k)x(k)$ = error signal (13)

where, μ is the step-size parameter and ∇w is the gradient of the performance surface.

$d(k)$ is the desired signal at the receiver, equal to the transmitted signal and $w(k+1)$ denotes the weights vector to be computed at iteration $(k+1)$ and μ is the LMS gradient step size (gain constant). LMS gradient step size controls the convergence characteristics of the algorithm, that is how fast and close the estimated weights approach the optimal weights. The smaller the step size the longer it takes the LMS algorithm to converge. This means that a longer reference or training sequence is needed, which would reduce the payload and, hence, the bandwidth available for transmitting data. Also, if the step-size is too small, the convergence is slow and we will have the overdamped case. If the convergence is slower than the changing angles of arrival, it is possible that the adaptive array cannot acquire the signal of interest fast enough to track the changing signal. If the step-size is too large, the LMS algorithm will overshoot the optimum weights of interest. This is called the *underdamped case*. If attempted convergence is too fast, the weights will oscillate about the optimum weights but will not accurately track the solution desired. It is therefore imperative to choose a step-size in a range that insures convergence. In order to ensure the stability and convergence of the algorithm, the adaptive step size should be chosen within the range specified as:

$$0 < \mu < \frac{1}{2\lambda_{max}} \tag{14}$$

2.2 MODEL OF ADAPTIVE ARRAY SYSTEM

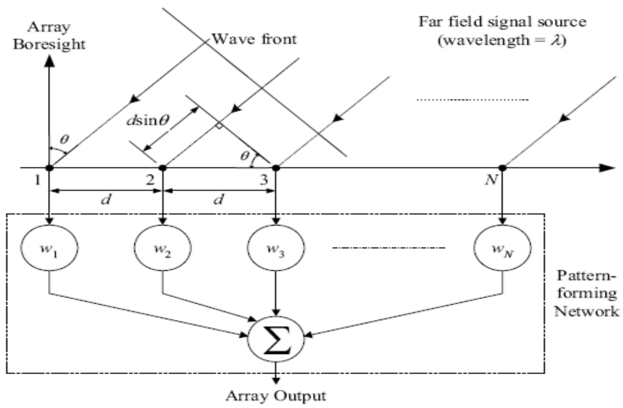

Fig 2:Geometry of Uniform Linear Array

Consider a uniform linear array comprising N sensors, and let it receive M narrowband source signals S_M (t) from desired users arriving at directions $\theta_1, \theta_2, ..., \theta_M$ as shown in Figure 2.

The array also receives I narrowband source signals S_I (t) from undesired (or interference)

users arriving at directions $\theta_1, \theta_2, ..., \theta_I$. At a particular instant of time t = 1, 2,.., k, where k is the total number of snapshots taken, then the desired users signal vector X_M (t) can be defined as:

$$X_M(t) = \sum a(\theta_M)\, S_M(t) \qquad (15)$$

where a(□ $_M$) is the M × 1 array steering vector which represents the array response at direction θ_M and is given by

$$a(□_M) = [\exp\{ j(n-1)S_M \}]^T ; 1 < n < N \qquad (16)$$

where$[(.)]^T$ is the transposition operator, and S_M represents the electrical phase shift from element to element along the array. This can be defined by

$$S_M = \frac{2\pi d}{\lambda} \sin(\theta_M) \qquad (17)$$

where d is the inter-element spacing and □ is the wavelength of the received signal. The desired users signal vector X_M (t) of (15) can be written as:

$$X_M(t) = A_M(t)\, S(t) \qquad (18)$$

where A_M (t) is the M × 1 matrix of the desired users signal direction vectors and is given by

$$A_M(t) = [\, a(\theta_i), a(\theta_2), ..., a(\theta_M)\,]^T \qquad (19)$$

and S (t) is the M × 1 desired user's source waveform vector defined as:

$$S(t) = [\, S_1(t), S_2(t), ..., S_M(t)\,] \qquad (20)$$

We also define the undesired (or interference) users signal vector X_I (t) as:

$$X_I(t) = A_I(t)\, i(t) \qquad (21)$$

where A_I (t) is the $I \times 1$ matrix of the undesired users signal direction vectors and is given by

$$A_I = [a(\theta_i), a(\theta_2), \ldots\ldots, a(\theta_I)]^T \quad (22)$$

and $i(t)$ is the $I \times 1$ undesired (or interference) users source waveform vector defined as:

$$i(t) = [i_1(t), i_2(t), \ldots\ldots, i_I(t)] \quad (23)$$

The overall received signal vector $X(t)$ is given by the superposition of the desired users signal vector X_M (t), undesired (or interference) users signal vector X_I (t)and an N×1 vector n(t) which represents white sensor noise. Hence, $X(t)$ can be written as:

$$X(t) = X_M(t) + n(t) + X_I(t) \quad (24)$$

where $n(t)$ represents white Gaussian noise. The output response of the uniform linear array (in analog form) is given by:

$$y(t) = w^H X(t) \quad (25)$$

$$w = [w_1, w_2, \ldots\ldots, w_M]^T = \text{array weights}$$

where w^H denotes the complex conjugate transpose of the weight vector w .

$$\text{y(t)} = w^H (X_M(t) + n(t) + X_I(t)) \quad (26)$$

The conventional (forward-only) estimate of the covariance matrix of the input vector x for a finite sample size is defined as the maximum likelihood estimation of matrix R and can be calculated as

$$R = E[X(t) X^H(t)] \quad (27)$$

III. RESULTS AND ANALYSIS

Table 1: Simulation Parameters

Propagation environment	**AWGN channel**
Eb/No (in dB)	**0.1-1.0**
Modulation	**QPSK(downlink),BPSK(uplink)**
Chip rate	**3.84MCPs**
Spreading factor	**4.256**
Channel bit rate	**5.76Mbps**
Pulse shaping	**roll off=0.22**
Receiver	**Adaptive antenna**

Table 2:Result for CDMA20001X without Adaptive Antenna

Eb/No (dB)	**BER(without Adaptive)**
0.1	0.5346
0.2	0.5278
0.3	0.5227
0.4	0.5206
0.5	0.5185
0.6	0.5149
0.7	0.5114
0.8	0.5093
0.9	0.5081
1.0	0.5057

Table 3:Results for CDMA20001x with Adaptive antenna array

Eb/No (dB)	**BER(Adaptive)**
0.1	0.489
0.2	0.480
0.3	0.4762
0.4	0.4758
0.5	0.4758
0.6	0.4730
0.7	0.4615
0.8	0.4508
0.9	0.4278
1.0	0.4124

Table 4:Results for CDMA20001x with Rake receiver and Adaptive Antenna

Eb/No (db)	**BER(Adaptive and Rake receiver)**
0.1	0.00184
0.2	0.00183
0.3	0.001673
0.4	0.001673
0.5	0.001673
0.6	0.001673
0.7	0.001673
0.8	0.001673
0.9	0.000418
1.0	0.000410

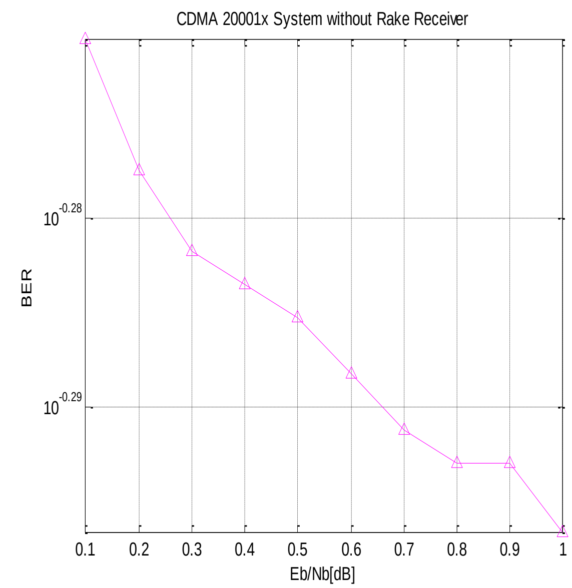

Fig 3.BER Vs Eb/No performance in absence of adaptive antenna and Rake Receiver

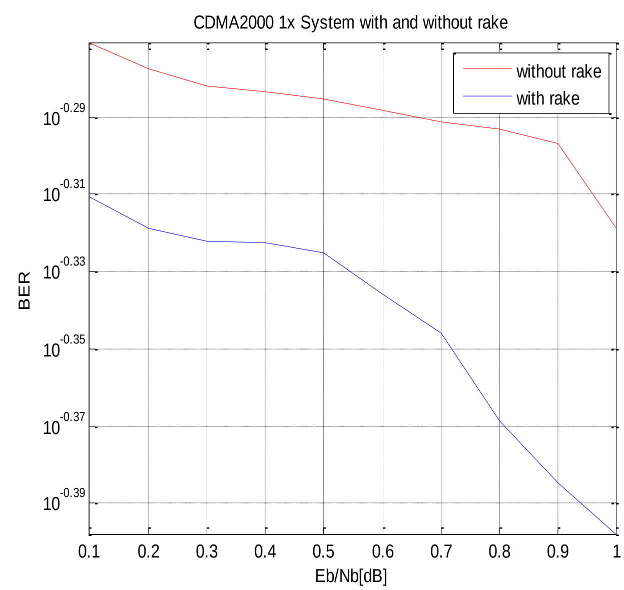

Fig 4.BER Vs Eb/No in presence of adaptive and rake Receiver

IV. SUMMARY OF RESULTS

The bit error rate at uplink with presence and absence of adaptive antenna array in CDMA20001x system is shown in Figure 4 and 3 respectively . As expected the system is interference limited when no adaptive antenna is present at receiver side. We observed that without any adaptive antenna techniques, the BER approaches to more than 10% even though Eb/No varied from 0.1 to 1dB. This is not an acceptable performance. However the BER can be pushed back to an acceptable limit with rake receiver techniques. From Figure 4, we observed that there is a significant improvement in the BER in the case with adaptive antenna as compared to that of no adaptive in which the BER does not reduce significantly even with increase in the E_b/N_o.

V. CONCLUSION

We implemented a signal simulator according to the physical layer specification of the IMT 2000 CDMA20001x system. This provides a very useful and easy way to get insight into problems in a CDMA20001x system. MATLAB and SIMULINK were used as development tool. Adaptive antenna and the Rake receiver are employed at the receiver. We investigated the Bit Error Rate (BER) in uplink. The BER depends on the channel conditions and the number of rake receiver fingers active.

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