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Performance of Adaptive Antenna with Downlink Power Control for WCDMA System

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Abstract: The application and implementation of smart antenna system have been considered in the Second Generation (2G) and the Third Generation (3G) system. By knowing the positions of mobiles, a base station can steer the beam, direct and control the power of a beam towards a single lone mobile or a groups of mobile stations. The system can be implemented using either an adaptive or a switched beam technique. In this project, we develop, simulate and evaluate the SINR and E_b/N_0 performances of an adaptive beam technique in the WCDMA system for downlink with and without power control algorithm. The performance is then compared with an omnidirectional antenna system. Simulation shows that the best performance can be achieved when all the mobiles with different distance from base station have the same Angle-of-Arrival in one beam. Furthermore, the maximum capacity for different data rate users that can be accommodated by the system was determined in this paper.

Key words: WCDMA, adaptive antenna, SINR, power control

INTRODUCTION

Wideband Code Division Multiple Access (WCDMA) has emerged as the mainstream air interface solution for the 3G networks. It was also selected as the Radio Transmission Technology (RTT) for Universal Mobile Telecommunications System (UMTS), which is the European Third Generation mobile communications system developed by European Telecommunications Standards Institute (ETSI) (Saleh Al-Jazzar, 2000; (Christoffer, 2001). The system performance is expected to be improved in term of spectral efficiency, capacity, data rates, support for multimedia and packet switched services and innovative seamless applications such as mobile video conferencing and web browsing. However, this technology needs to tackle challenges like path loss, multi-path fading, Inter-Symbol Interference (ISI) and power control.

WCDMA is interference limited multiple access system (De Sousa *et al*., 2003; Liberti and Rappaport, 1999). Because all users transmit on the same frequency, intracell interference generated by the system and intercell interference are the most significant factors in determining system capacity and call quality. The transmit power for each user must be reduced to limit interference, however, the power should be enough to maintain the required E_b/N_0 (signal to noise ratio) for a satisfactory call quality. Maximum capacity is achieved when E_b/N_0 of every user is at the minimum level needed for the acceptable channel performance. The aim of the dynamic power control is to limit transmitted power on both the links while maintaining link quality under all conditions. Additional advantages are longer mobile battery life and longer life span of BTS power amplifiers (Gunaratne *et al*., 2001).

CLASSIFICATION OF SMART ANTENNA

Smart antenna sometime also referred to as intelligent antenna, adaptive array or dynamic or adaptive sectoring and can be implemented using either switched beam or adaptive beam technique.

Switch beam antenna: Switched beam or switched lobe antennas are directional antennas deployed at base stations of a cell. They have only a basic switching function between separate directive antennas or predefined beams of an array. The setting that gives the best performance, usually in terms of received power, is

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chosen. The outputs of the various elements are sampled periodically to ascertain which has the best reception beam. Because of the higher directivity compared to a conventional antenna, some gain is achieved. Such an antenna is easier to implement in existing cell structures than the more sophisticated adaptive arrays, but it gives a limited improvement.

The switched-beam system is achieved by utilizing multiple narrow fixed beams (15 to 30° horizontal beamwidth) in a single sector. Since the beam pattern in a sector is predetermined, the mobile station is not always in the main lobe or center of the beam. The beam can also be on or off depending on the spatial distribution of the mobile. Switched-beam systems are more economical to implement, requiring only a static beamforming network, RF switch and control.

Adaptive beam antenna: The adaptive array system used a similar idea but different approach in allocating the beams with respect to the user. It utilizes more complicated signal processing algorithms to allow the system to use a varying beam pattern in response to the movement of the user and the changing environment.

The main idea behind such a system is its ability to allocate the main lobe of the antenna array to the users and nulls to all the other interferers. This clearly optimized the performance of the wireless system. However, it added much complexity to the systems, as algorithms to continuously distinguish between the signals from the user, the interfering signals from other signals and multi-path signals are required. In addition, the angle of arrival for the signal must be determined so as to point the main lobe exactly at the desired signal.

Adaptive antenna are a set of antenna elements that can change their antenna radiation or reception pattern dynamically to adjust to variations in channel noise and interference, in order to improve the SINR of a desired signal. The name smart refers to the signal processing power that is part and parcel of the adaptive antenna. It controls the antenna pattern by updating a set of antenna weights.

It is possible for adaptive systems to achieve greater system performance than switched-beam systems. Using array signal processing allows the antenna system to take advantage of path diversity by combining coherent multipath components. The adaptive pattern that is created can be optimised to enhance the desired user's signal while simultaneously suppressing interfering signals. However, the theoretical performance benefits achieved by an adaptive system may be offset by the cost and complexities encountered in implementation.

SIMULATION ENVIRONMENT

In this research, we develop a simulation model to study the performance of a cellular system utilizing beam forming technique employing adaptive array antenna for downlink WCDMA system with and without power control. The basic components of this simulation are:

Cell topology: In the simulation, we use hexagonal shape cells without any overlapping area. The use of the hexagonal shape is dictated by the need to simply planning and design of cellular system. In this simulation, we use macrocell model consisting of 7 cells each with adaptive array antenna.

Propagation model: The performance of wireless communication systems depends significantly on the mobile radio channel. The radio wave propagates through the mobile radio channel through different mechanism such as reflection, diffraction and scattering. Propagation models predict average signal strength and its ability at a given distance from the transmitter.

The macrocell propagation model for this scenario based on hata model (Anderson *et al*., 1995).

$$L_{hata} = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_t + h_b) - ((1.1\log_{10}(f_c) - 0.7)h_m - (1.56\log_{10}(f_c) - 0.8)) + (44.9 - 6.55\log_{10}(h_t + h_b))\log_{10}(d) \quad (1)$$

where:

f_c is the carrier frequency (in MHz)
d is the MS-BS separation distance (in km)
h_t is the base station antenna height (in meters) above rooftop
h_b is the rooftop height (in meters) and
h_m is the mobile station antenna height (in meters).

Antenna parameter: The overall gains in look direction of horizontal plane depend on antenna 3-dB beam width, β and its deviation from the main lobe, ϕ. By assuming that gain, G and directivity, D, are nearly the same, the gain versus beam width relationship can be approximated as follow (Ismail, 1995):

$$G = D = \begin{cases} \dfrac{32,400}{\phi\theta} & \text{For small } \phi \text{ and } \theta \ (\phi \text{ and } \theta < 40°) \\ \dfrac{41,253}{\phi\theta} & \text{For large } \phi \text{ and } \theta \ (\phi \text{ and } \geq 40°) \end{cases} \quad (2)$$

Where ϕ and θ are the 3-dB beamwidth in two planes. The antenna pattern gain is modeled by a sinc^2 function (Anderson *et al*., 1995).

SINR calculation for downlink is shown as below (Ghorashi *et al.*, 2001):

$$\text{SINR}(i)_{\text{downlink}} = \frac{G_P G_A P_{ki} / L_{ki}}{\sum_{k=1}^{N} I_{ik} + P_N} \quad (3)$$

where G_p is processing gain, P_{ki} is the transmit power for BS # k to MS #i, $L_{k,i}$ is the pathloss between BS # k to MS #i, P_{ij} is transmit power of MS #i to BS #j, N is number of base station interferer, M is number of mobiles interferer and P_N is thermal noise power.

Adaptive beamforming technique: The beam formation at every base station is based on the mobiles' DOAs. Figure 1 shows the actual parameters used in the algorithm. Given the j[th] base station and two mobiles, say the i[th] and the k[th], the angles of arrival are denoted a α_{ij} and α_{kj} respectively while the separation angle between the mobiles is γ^j_{ik}. By setting a minimum separation angle between adjacent mobiles, say γ, we are then in a position to narrow or widen antenna beamwidths after all directions of arrivals have been sorted.

Figure 2a shows an example of beam formation where

$(\alpha_{2j}-\alpha_{1j}) < \gamma$ and $(\alpha_{3j}-\alpha_{2j}) < \gamma$,
$(\alpha_{4j}-\alpha_{3j}) > \gamma$ and $(\alpha_{5j}-\alpha_{4j}) < \gamma$,
$(\alpha_{6j}-\alpha_{5j}) > \gamma$,
$(\alpha_{7j}-\alpha_{6j}) > \gamma$ and
$(\alpha_{8j}-\alpha_{7j}) > \gamma$

Henceforth, beam number 1 and 2 respectively will cater for a group of three and two mobiles, while beams numbers 3, 4 and 5 will cater each for a single mobile. The beams sizes are given by $(\alpha_{ij}-\alpha_{pj} + \gamma)$ where i and p represent the first and the last mobiles in the same beam respectively. If a new call arrived and served by the same BS_j such that,

$(\alpha_{2j}-\alpha_{1j}) < \gamma$ and $(\alpha_{3j}-\alpha_{2j}) < \gamma$,
$(\alpha_{4j}-\alpha_{3j}) > \gamma$ and $(\alpha_{5j}-\alpha_{4j}) < \gamma$,
$(\alpha_{6j}-\alpha_{5j}) > \gamma$, $(\alpha_{newj} - \alpha_{6j}) < \gamma$,
$(\alpha_{7j}-\alpha_{6j}) > \gamma$ and $(\alpha_{8j}-\alpha_{7j}) > \gamma$

Then, the new formation of beams are as shown in Fig. 2b. It can be seen that the number of beam is reduced from five to four and there are only two beams serving lone mobile instead of four.

Downlink interference analysis: There are two types of interference intracell interference and intercell interferences both of them will be described here.

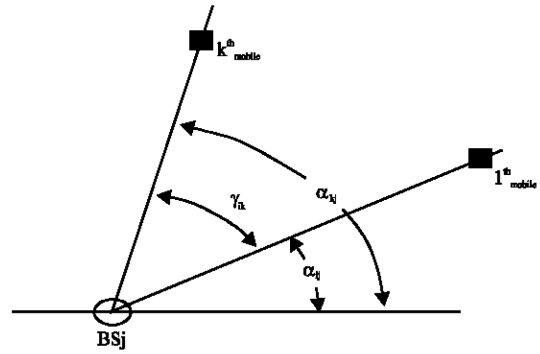

Fig. 1: Parameters used in Adaptive Beamforming Technique

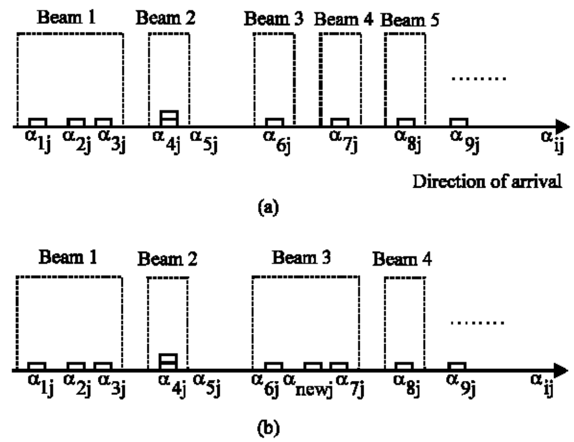

Fig. 2: (a) Examples of beam formation and (b) Beam reformation to accommodate a new call

Intracell interference: This interference occurs due to receiving the transmitted power to other users in the same cell, also there are two types of this interference.

Intrabeam interference: This interference occurs because the interested user will receive the power of all other users in the same cell multiplied by its gain and the correlation factor, it is calculated based on formula below.

$$I_{intra\_beam} = \frac{(N-1) \times P_t \times G_t(\theta) \times G_t(\phi) \times (1-\alpha)}{L} \quad (4)$$

Where

N is the number of users in the same cell.
α is the orthogonal factor.
L is the losses.

Interbeam interference: This interference due to receiving the power of other users multiplied by the gain of interference beam and correlation factor.

$$I_{inter\_beam} = \sum_{i=1}^{M} \frac{(N-1)\times P_t \times G_{ti}(\theta)\times G_{ti}(\phi)\times(1-\alpha)}{L} \quad (5)$$

Where

M is the number of beams interfering with the user.

Interbeam interference depends on the interference gain, number of users in the same cell, orthogonal factor and separation angle in the beamforming algorithm. Figure 3 shows both types of intracell interference.

Intercell interference: This interference occur due to the interfering beams related to neighboring cell, to calculate this interference in the first we have to calculate the angle between the user and interfering base station after that we calculate the gain of all the beams related to that base station in this angle and after that we calculate the received power from the beams of that base station at the user.

$$I_{intercell} = \sum_{j=1}^{B} \sum_{i=1}^{M} \frac{(N-1)\times P_t \times G_{ti,j}(\theta)\times G_{ti,j}(\phi)\times(1-\alpha)}{L} \quad (6)$$

Where

B is the number of base stations interfering with the user.

M is the number of beams in the interfering base station.

Simulation process and simulation parameters: The simulation consists of four stages. First is to calculate the average SINR and E_b/N_o at MSs in different separation angle of beamforming algorithm. This is done to evaluate the best separation angle for certain range of number of users. It repeats for ten times and then calculates the average SINR and E_b/N_o at each cycle. After that, takes the average value of these ten values and repeats the same calculation after changing the separation angle. At last, plots the relationship between the separation angle and average received SINR and E_b/N_o at MS.

The second stage is to calculate the average SINR and E_b/N_o at MSs for different number of users. It repeats for ten times too and then calculates the average SINR and E_b/N_o at each cycle. After that, takes the average value of these ten values and repeats the same calculation after changing the number of users. Again, plots the relationship between the number of users and average received SINR and E_b/N_o at MS, the calculation is done and plotted in various bit rates and cell radius.

The third stage is to compare between receive SINR and E_b/N_o in adaptive array antenna and omnidirectional antenna at same MS distribution. The comparison is carried out by changing number of users and E_b/N_o for both antennas.

The forth stage is applying power control on downlink adaptive array antenna, calculate and plot EIRP, SINR and E_b/N_o for each MS before and after power control. The average value in the transmitted power levels is assumed the initial transmitted power of the BSs, without taking interference effect.

At every power control cycle, the data for every MS as MS received power, interference at MSs, SIR at MSs, BER and E_b/N_0 will be computed, the power control algorithm based on comparing the minimum received E_b/N_o at MS with the threshold value to increase or decrease BS transmitted power by a specified step size.

The default simulation parameters are shown in Table 1 and user defined simulation parameters are shown in Table 2.

Simulation results: Figure 3 shows the relationship between downlink average E_b/N_o and threshold separation angle for beamforming algorithm in adaptive beam array antenna at number of users equal to one hundred.

From Fig. 3, the best threshold separation angle for this number of users is zero. Threshold separation angle equal to zero means that only users with same angle of arrive will be formed in a one beam. Thus for downlink performance analysis, beamforming algorithm with this

Table 1: Parameters of simulation

Parameter	Value	Explanation
fc	2000	DL carrier frequency (MHz)
Chip_rate	3.84	Chip rate (Mcps)
BW	5	Channel bandwidth (MHz)
hbs	30	BS antenna height (m)
hm	2	MS antenna height (m)
X_init	0	x-coordinate of centre BS (m)
Y_init	0	y-coordinate of centre BS (m)
ptx	5	BS transmit power towards each MS (dB) (=35dBm)
Gr	0	MS antenna gain (dB)
Noise_figure	5	Noise figure at BS and MS in dB
Xcorr	0.61	Code cross correlation
ptxmin	5	Minimum Bs transmitted power for PC stage
NO_BS	7	Number of base stations

Table 2: Simulation input parameters (user-defined)

Parameter	Description
Model (1, 2, 3, or 4)	Path loss model selection (FSPL, ARIB, Lee or Hata)
NO_MS	Number of mobile stations
Data rate (1, 2, 3, or 4)	Data rate selection (12.2, 64, 144, or 384 kb $psec^{-1}$)
step	Power control step size (0.5, 1.0, or 2.0 dB)
Cell_radius	The cell radius

threshold separation angle is used to evaluate the average SINR and E_b/N_0 in downlink WCDMA adaptive array antenna.

Figure 4 and 5 show the SINR and E_b/N_0 for adaptive array antenna in downlink WCDMA system. The simulation was run for 10 cycles with threshold separation angle for beamforming set to zero.

In Fig. 4, the average downlink SINR in unit dB versus the number of MSs for data rates is ranging from data rate 1 (12.2 kbps) to data rate 4 (384 kbps). From the figure, it can be clearly observed that the lower data rate yields higher downlink SINR as the number of MSs becomes lower.

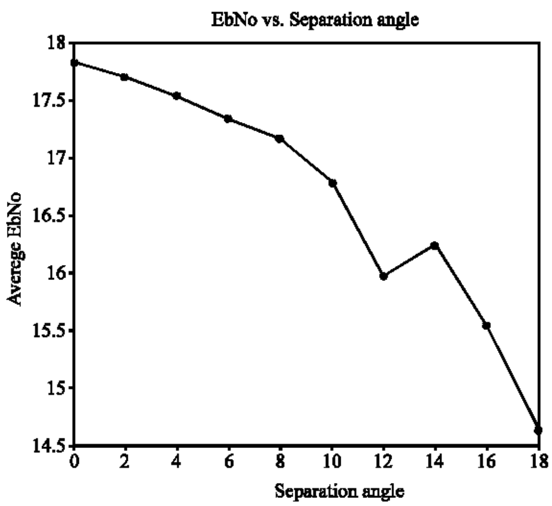

Fig. 3: Average E_b/N_0 for adaptive array antenna in downlink WCDMA

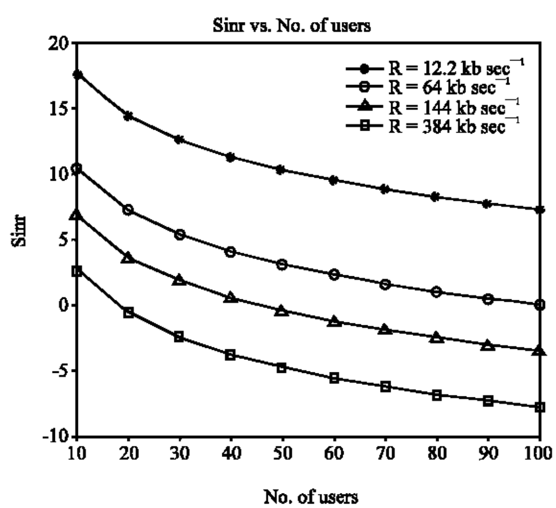

Fig. 4: SINR for adaptive array antenna in downlink WCDMA system

Figure 5 shows the average E_b/N_0 in unit dB versus the number of users. From the figure, it can be observed that the E_b/N_0 threshold was achieved for data rates 12.2, 64 and 144 kb sec^{-1} with one hundred users. However, for data rate 384 kb sec^{-1}, the E_b/N_0 threshold can only be achieved until number of users about 82 users. This is due to the E_b/N_0 threshold value of data rate 384 kb sec^{-1} is 3 dB.

Meanwhile, the maximum number of users can be accommodated for each bit rate can be determined by knowing E_b/N_0 threshold for each bit rate. Table 3 shows the E_b/N_0 threshold for each bit rate.

From the simulation, it is found that for 12.2 kb sec^{-1}, the maximum allowable number of users is more than

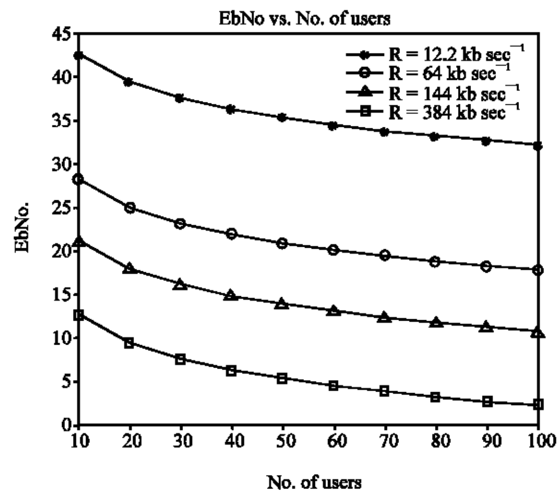

Fig. 5: Average E_b/N_0 in unit dB versus the number of users

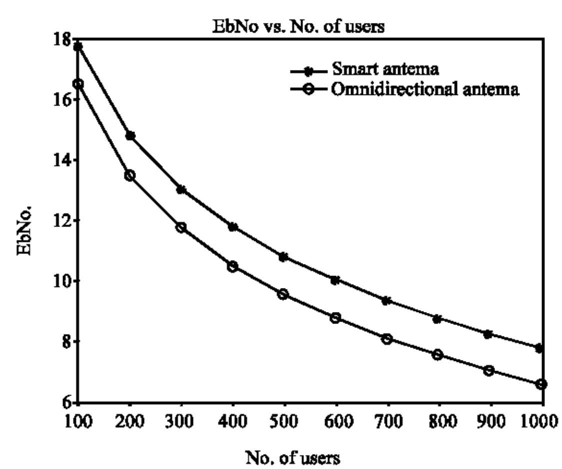

Fig. 6: Average downlink E_b/N_0 for omnidirectional and adaptive array antennas

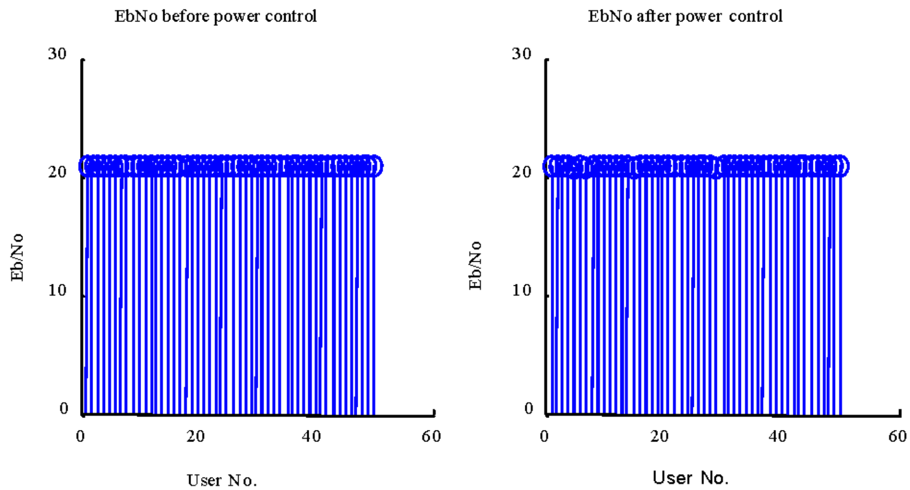

Fig. 7: E_b/N_o for each mobile before and after power control

Table 3: Eb/No threshold for each bit rate

	12.2 kbp sec^{-1}	64 kbp sec^{-1}	144 kbp sec^{-1}	384 kbp sec^{-1}
E_b/N_o	6dB	4.5dB	3dB	3dB
Data rate 1	100%	-	-	-
Data rate 2	-	100%	-	-
Data rate 3	-	-	100%	-
Data rate 4	-	-	-	100%

10000 users. As for 64 kb sec^{-1}, the number of users can be accommodated is 2100 users and for 144 kb sec^{-1}, the number of users can be accommodated are 573 users. As for 384 kb sec^{-1}, the maximum number of users can be accommodated is 82 users.

Figure 6 shows the comparison between adaptive array antenna using single beam for users with same angle of arrival and omnidirectional antenna in downlink WCDMA system. The comparison was done by calculating average E_b/N_o for both antennas with number of users using bit rates 64 kb sec^{-1}.

Simulation result shows that until 1000 users, adaptive array antenna is better than omnidirectional antenna by about 2 dB.

For downlink power control of adaptive array antenna with 50 users and bit rate 64 kb sec^{-1}. Figure 7 shows the E_b/N_o for each user when the threshold separation angle for beam forming algorithm is zero.

CONCLUSIONS

WCDMA power controlled downlink performance with adaptive array antenna was studied in this paper. The best downlink performance can be achieved when the separation angle for beamforming algorithm is zero degree (single beam for users with same angle of arrive) due to this separation angle adaptive array antenna gives highest average downlink SINR and E_b/N_o. The numbers of users that can be accommodated with applying single beam for users with same angle of arrive and bit rate 12.2 kb sec^{-1} can be more than 10000 users. The maximum number of users can be accommodated by the system is degrading while the bit rate increases. With 64 kb sec^{-1} bit rate, number of users can be accommodated is about 2100 users, 573 users with 144 kb sec^{-1} and 82 users with 384 kb sec^{-1}. Higher bit rate has increased the interbeam interference and thus, reduce the maximum allowable number of users in the beam.

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