Optimization of Array Topology and Capacity for 3G CDMA Network with Adaptive Antennas

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Abstract—**The capacity of forward link (FL) communication to mobile receivers is limited primarily by co–channel interference (CCI). Adaptive Antenna Arrays (AAAs) that employ antenna arrays along with advanced signal processing at the base station (BS) have been proposed to mitigate this limitation. We present FL capacity analysis for mixed voice and data user traffic scenarios in third generation (3G) CDMA cellular network, where each BS is equipped with either three–sector uniform linear array (ULA) or non–sectorized uniform circular array (UCA). We demonstrate that the FL capacity of the system is considerably affected by the antenna array topology. We find that the optimum element spacing resulting in the largest FL system capacity is 0,5λ for both ULA and UCA topologies. Also, it is found that the UCA provides larger FL capacity when compared to the ULA under the same array parameters, i.e., element spacing and number of elements per cell.**

Index Terms—**Antenna array, FDD, MC-CDMA, system outage.**

I. Introduction

THIRD generation (3G) wireless code division multiple access (CDMA) technology is designed to provide all modes of multi–rate traffic with varying quality of service (QoS) requirements. These varying services will demand high received signal power levels, especially for the high data rate users, leading to larger system interference levels. The high system capacity can be achieved by reducing the amount of these interference levels through utilization of an Adaptive Antenna Array (AAA) at the base station (BS), which dynamically adapts to a spatial channel with beam patterns.

Several researchers have studied the forward link (FL) capacity [1], [2], [3] of AAAs for CDMA systems. In [1], Naguib demonstrated capacity improvement of multi–cell IS–95 CDMA system with AAA for both the reverse link (RL) and FL when there is only line–of–sight (LOS) propagation in the channel. Chin *et al.* [2] studied the FL capacity of multi–rate CDMA with a three–sector ULA. In the interference analysis therein, multipaths are assumed to arrive at the mobile from irresolvable azimuth angles and a channel vector is taken as the array response vector corresponding to only a single direction–of–arrival (DOA). Czylwik [3] compared the average signal–to–interference ratio (SIR) performance of different antenna configurations for CDMA FDD systems employing covariance matrix based beamforming and found the optimum element spacing of both ULA and UCA. He has, however, did not consider mixed traffic scenarios and their voice activity factors as proposed in 3G CDMA.

In this paper, we present an interference analysis method for FL 3G CDMA networks and investigate the optimum array topology that yields the largest FL system capacity. By extending the previous work [4], we model the intracell and intercell interference for the desired voice and data users and derive a system outage equation that is based on the assumption that either desired voice or data user is blocked in the system. In contrast to the work in [2], we assume the resolvable multipaths in the propagation channel in our analysis. The signal modeling for a CDMA FL channel is presented in the next section. In Section 3, we present the interference modeling and system outage equation to be used in the simulations. Simulation methodology is described in Section 4. Section 5 provides numerical results that compare system capacity for various antenna configurations and antenna numbers. Finally, conclusions are given in Section 6.

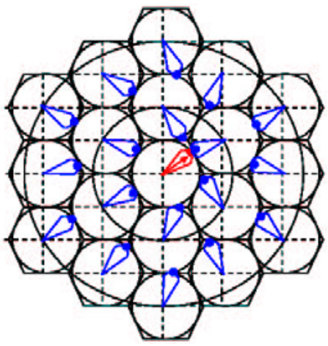

Fig. 1. Interference from first two tiers of a CDMA cellular network.

II. Signal Modeling

We consider the first two tiers of a CDMA cellular network where there are voice and data users and each BS is equipped with an AAA as shown in Fig. 1. Specifically, let us assume that BSs employ three–sector ULA or non–sectorized UCA topologies. Each BS in the network serves numerous mobile subscribers and each equipped with a single omni–directional

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antenna. We assume that there are N_1 voice users with data rate of R_1 kbps and N_2 data users with data rate of R_2 kbps. All users are uniformly distributed within [30°, 150°] for the ULA topology and [0°, 360°] for the UCA topology in each cell site. So, the total number of users is ($N_1/3+N_2/3$) per sector for ULA and (N_1+N_2) per cell for UCA. Data users are assumed to transmit in a multi–channel scheme, i.e., $Q=R_2/R_1$ parallel channels, each with the same rate as voice users since its implementation is easy for code design and receiver aspects.

At the BS transceiver of each cell site, the CDMA waveform for each user at the channel modem output is weighted by its corresponding weight vector (beamforming coefficient vector) and summed up together with other users' signals in the same cell (or sector) prior to transmission. All signals transmitted from a given BS and to a particular mobile will propagate over the same spatial vector channel, and therefore will experience the same fading and path loss. We assume that the cell site transmits the same power to all mobiles in the same class, which are controlled by that BS. Let the system noise power be σ_n^2, the number of antenna elements in the array be *M*, and the number of multipaths that the transmitted signal from the *k*th cell site to desired mobile be F_k. Assuming that the BS transmit powers for each voice channel and each parallel data channel are P_1 and P_2, respectively, which are equally shared by the multipaths, then the power of the signal arriving at the voice or data user through *f*th multipath is given by

$$P_{j,k,f} = \frac{P_j}{F_k}\frac{\left\|\alpha_{k,f}^0\right\|^2}{\left(r_k^0\right)^4} = \overline{P}_{j,k}\beta_{k,f}^2 \tag{1}$$

where, j, k, and f denotes user class (j=1 for voice user and j=2 for data user), cell number (k=0,…,K), and multipath number (f=1,…,F_k), respectively, k=0 indicates the cell site from which the desired mobile is controlled, r_k^0 is the distance from the desired user in cell-0 to cell-k. The fading parameter $\left\|\alpha_{k,f}^0\right\|$ includes fast fading and shadowing effects in the channel, which is modeled by Rayleigh distribution whose mean square value $E\{\left\|\alpha_{k,f}^0\right\|^2\}$ is log–normally distributed with standard deviation $10\log_{10}E\{\left\|\alpha_{k,f}^0\right\|^2\}$ for all signals arriving at the desired mobile along *f*th path from *k*th cell site [5]. The received baseband signal at the desired mobile terminal is

$$\begin{aligned}
x(t) = &\sum_{i_{1,0}=1}^{N_1}\psi_{i_{1,0}}\sum_{f=1}^{F_0}\sqrt{\overline{P}_{1,0}}\, b_{i_{1,0}}\left(\frac{t-\tau_{i_{1,0},f}}{T}\right)c_{i_{1,0}}\left(t-\tau_{i_{1,0},f}\right)\beta_{0,f}\,\mathbf{w}_{i_{1,0}}^H\mathbf{a}(\theta_{0,f})\\
&+\sum_{i_{2,0}=1}^{N_2}\psi_{i_{2,0}}\sum_{f=1}^{F_0}\sqrt{\overline{P}_{2,0}}\sum_{q=1}^{Q} b_{i_{2,0},q}\left(\frac{t-\tau_{i_{1,0},q,f}}{T}\right)c_{i_{2,0},q}\left(t-\tau_{i_{2,0},q,f}\right)\beta_{0,f}\,\mathbf{w}_{i_{2,0}}^H\mathbf{a}(\theta_{0,f})\\
&+\sum_{k=1}^{K}\sum_{i_{1,k}=1}^{N_1}\psi_{i_{1,k}}\sum_{f=1}^{F_k}\sqrt{\overline{P}_{1,k}}\, b_{i_{1,k}}\left(\frac{t-\tau_{i_{1,k},f}}{T}\right)c_{i_{1,k}}(t-\tau_{i_{1,k},f})\beta_{k,f}\,\mathbf{w}_{i_{1,k}}^H\mathbf{a}(\theta_{k,f})\\
&+\sum_{k=1}^{K}\sum_{i_{2,k}=1}^{N_2}\psi_{i_{2,k}}\sum_{f=1}^{F_k}\sqrt{\overline{P}_{2,k}}\sum_{q=1}^{Q} b_{i_{2,k},q}\left(\frac{t-\tau_{i_{1,k},q,f}}{T}\right)c_{i_{2,k},q}\left(t-\tau_{i_{2k},q,f}\right)\beta_{k,f}\,\mathbf{w}_{i_{2,k}}^H\mathbf{a}(\theta_{k,f})\\
&+n(t)
\end{aligned} \tag{2}$$

where, $\mathbf{a}(\theta_{k,f})$ is the array response vector of the antenna array for the *f*th multipath in the *k*th cell site, $b_{i_{j,k}}(.)$ are the information symbols of duration T, which are independent identically distributed (i.i.d.) random variables taking values ± 1 with equal probability [6], $c_{i_{j,k}}$ represents the composite of Walsh and PN spreading codes for that user, $\tau_{i_{j,k}}$ is the multipath propagation time delay, n(t) is the thermal noise with zero mean, and $\psi_{i_{j,k}}$ accounts for voice activity factor, modeled by a Bernoulli random variable. $\mathbf{w}_{i_{j,k}}$ is the transmit beamforming weight vector for the *j*th class user (j=1,2). We assume that the AAA uses the mean DOA approach is used to determine this FL weight vector, i.e.,

$$\mathbf{w}_{i_{j,k}} = \mathbf{a}\left(\hat{\theta}_{k,f}\right), \text{ where } \hat{\theta}_{k,f} = \frac{1}{2}\left\{\min(\theta_{k,f}) + \max(\theta_{k,f})\right\} \tag{3}$$

III. Interference Analysis and System Outage

The received baseband signal at the mobile is correlated with the desired user's code $c_{j,0}$ for each of F_0 multipaths and then summed up at the RAKE receiver. At a given instant of time, the desired user is either voice or data user. The post–correlation signal for the *l*th bit is given by

$$\begin{aligned}
z_{j,0}(l) &= \sum_{\gamma=1}^{F_0}\sum_{h=1}^{Q}\frac{1}{T}\int_{t_1}^{t_2} x(t)c_{j,0}^*(t-\tau_{j,0,h,\gamma})dt\\
&= s_{j,0}(l) + n_{j,0}^{(1)}(l) + n_{j,0}^{(2)}(l) + n_{j,k}^{(1)}(l) + n_{j,k}^{(2)}(l) + n_T(l)
\end{aligned} \tag{4}$$

where, $t_1 = (l-1)T$ and $t_2 = lT$. If the desired user is voice user, the number of channel used for transmission is $Q=R_1/R_1$, therefore equal to 1, else if the desired user is data user, as we described before data users are assumed to transmit in a multi–channel scheme, i.e., $Q=R_2/R_1$ parallel channels. The terms to taken up, $s_{1,0}(l)$ is the component due to multipath signals of the desired user, $n_{j,0}^{(1)}(l)$ and $n_{j,0}^{(2)}(l)$ are the intracell interferences due to voice users' and data users' signals within the desired user's cell site, respectively, $n_{j,k}^{(1)}(l)$ and $n_{j,k}^{(2)}(l)$ are the intercell interferences due to voice users' and data users' signals from outer cells, respectively, and $n_T(l)$ is the AWGN term. These variables can be written as

$$s_{j,0}(l) = \sum_{\gamma=1}^{F_o}\sum_{h=1}^{Q}\psi_{j,0}\sum_{f=1}^{F_o}\sqrt{\overline{P}_{j,0}}\sum_{q=1}^{Q} I_{j,0,\gamma,f,h,q}(l)\beta_{0,f}\mathbf{w}_{j,0}^H\,\mathbf{a}(\theta_{0,f}) \tag{5}$$

From the above desired user equation, it is easy to derive for desired voice user case, which Q=1,

$$s_{1,0}(l)=\sum_{\gamma=1}^{F_0}\psi_{1,0}\sum_{f=1}^{F_0}\sqrt{\overline{P}_{1,0}}\,I_{1,0,\gamma,f}(l)\beta_{0,f}\mathbf{w}_{1,0}^{H}\mathbf{a}(\theta_{0,f}) \tag{6}$$

We assume that the desired user is voice user, and then there are (N_1-1) voice users within the sector/cell, who act as intracell interference users.

$$n_{1,0}^{(1)}(l)=\sqrt{\overline{P}_{1,0}}\sum_{i_{1,0}=2}^{N_1}\psi_{i_{1,0}}\sum_{\gamma=1}^{F_0}\sum_{f=1}^{F_0}I_{i_{1,0},\gamma,f}(l)\beta_{0,f}\mathbf{w}_{i_{1,0}}^{H}\mathbf{a}(\theta_{0,f}) \tag{7}$$

$$n_{1,0}^{(2)}(l)=\sqrt{\overline{P}_{2,0}}\sum_{i_{2,0}=1}^{N_2}\psi_{i_{2,0}}\sum_{\gamma=1}^{F_0}\sum_{f=1}^{F_0}\sum_{q=1}^{Q}I_{i_{2,0},\gamma,f,q}(l)\beta_{0,f}\mathbf{w}_{i_{2,0}}^{H}\mathbf{a}(\theta_{0,f}) \tag{8}$$

where, $n_{1,0}^{(1)}(l)$ and $n_{1,0}^{(2)}(l)$ are intracell voice and data users, respectively, where the desired user is voice user. However, if the desired user is chosen as data user, in that case (N_2-1) data users are considered whole sector/cell as intracell interference users.

$$n_{2,0}^{(1)}(l)=\sqrt{\overline{P}_{1,0}}\sum_{i_{1,0}=1}^{N_1}\psi_{i_{1,0}}\sum_{\gamma=1}^{F_0}\sum_{f=1}^{F_0}\sum_{h=1}^{Q}I_{i_{1,0},\gamma,f,h}(l)\,\beta_{0,f}\mathbf{w}_{i_{1,0}}^{H}\mathbf{a}(\theta_{0,f}) \tag{9}$$

$$n_{2,0}^{(2)}(l)=\sqrt{\overline{P}_{2,0}}\sum_{i_{2,0}=2}^{N_2}\psi_{i_{2,0}}\sum_{\gamma=1}^{F_0}\sum_{f=1}^{F_0}\sum_{h=1}^{Q}\sum_{q=1}^{Q}I_{i_{2,0},\gamma,f,h,q}(l)\beta_{0,f}\mathbf{w}_{i_{2,0}}^{H}\mathbf{a}(\theta_{0,f}) \tag{10}$$

where, $n_{2,0}^{(1)}(l)$ and $n_{2,0}^{(2)}(l)$ are intracell voice and data users, respectively, where the desired user is data user. Furthermore, in order to calculate first two tiers of a CDMA cellular network capacity, it is important to derive intercell voice and data users for both desired user case

$$n_{j,k}^{(1)}(l)=\sum_{k=1}^{K}\sqrt{\overline{P}_{j,k}}\sum_{i_{j,k}=1}^{N_1}\psi_{i_{j,k}}\sum_{\gamma=1}^{F_0}\sum_{f=1}^{F_k}\sum_{h=1}^{Q}I_{i_{j,k},\gamma,f,h}(l)\beta_{k,f}\mathbf{w}_{i_{j,k}}^{H}\mathbf{a}(\theta_{k,f}) \tag{11}$$

$$n_{j,k}^{(2)}(l)=\sum_{k=1}^{K}\sqrt{\overline{P}_{j,k}}\sum_{i_{j,k}=1}^{N_2}\psi_{i_{j,k}}\sum_{\gamma=1}^{F_0}\sum_{f=1}^{F_k}\sum_{h=1}^{Q}\sum_{q=1}^{Q}I_{i_{j,k},\gamma,f,h,q}(l)\beta_{k,f}\mathbf{w}_{i_{j,k}}^{H}\mathbf{a}(\theta_{k,f}) \tag{12}$$

and AWGN term is

$$n_T(l)=\sum_{h=1}^{Q}\sum_{\gamma=1}^{F_0}\frac{1}{T}\int_{t_1}^{t_2}n(t)\,c_{j,0}^{*}(t-\tau_{j,0,h,\gamma})\,dt \tag{13}$$

where,

$$I_{j,0,\gamma,f,h,q}(l)=\int_{t_1}^{t_2}b_{j,0,q}\left(\frac{t-\tau_{j,0,f,q}}{T}\right)c_{j,0,q}(t-\tau_{j,0,f,q})c_{j,0}^{*}(t-\tau_{j,0,h,\gamma})dt \tag{14}$$

$$I_{i_{1,0},\gamma,f}(l)=\int_{t_1}^{t_2}b_{i_{1,0}}\left(\frac{t-\tau_{i_{1,0},f}}{T}\right)c_{i_{1,0}}(t-\tau_{i_{1,0},f})c_{1,0}^{*}(t-\tau_{1,0,\gamma})dt \tag{15}$$

$$I_{i_{2,0},\gamma,f,q}(l)=\int_{t_1}^{t_2}b_{i_{2,0},q}\left(\frac{t-\tau_{i_{2,0},f,q}}{T}\right)c_{i_{2,0},q}(t-\tau_{i_{2,0},f,q})c_{1,0}^{*}(t-\tau_{1,0,\gamma})dt \tag{16}$$

$$I_{i_{1,0},\gamma,f,h}(l)=\int_{t_1}^{t_2}b_{i_{1,0}}\left(\frac{t-\tau_{i_{1,0},f}}{T}\right)c_{i_{1,0}}(t-\tau_{i_{1,0},f})c_{2,0}^{*}(t-\tau_{2,0,h,\gamma})dt \tag{17}$$

$$I_{i_{2,0},\gamma,f,h,q}(l)=\int_{t_1}^{t_2}b_{i_{2,0},q}\left(\frac{t-\tau_{i_{2,0},f,q}}{T}\right)c_{i_{2,0},q}(t-\tau_{i_{2,0},f,q})c_{2,0}^{*}(t-\tau_{2,0,h,\gamma})dt \tag{18}$$

Powers for the desired signal and interference terms can be obtained by calculating their variances,

$$\mathrm{var}\{s_{j,0}(l)\}=\psi_{j,0}\overline{P}_{j,0}LQ^2R_{j,0}(L+(F_0-1)) \tag{19}$$

$$g_{1,0}^{(1)}=\mathrm{var}\{n_{1,0}^{(1)}\}=\overline{P}_{1,0}L\sum_{i_{1,0}=2}^{N_1}\psi_{i_{1,0}}\sum_{f=1}^{F_0}F_0|\beta_{0,f}|^2\left\|\mathbf{w}_{i_{1,0}}^{H}\mathbf{a}(\theta_{0,f})\right\|^2 \tag{20}$$

$$g_{1,0}^{(2)}=\mathrm{var}\{n_{1,0}^{(2)}\}=\overline{P}_{2,0}LQ\sum_{i_{2,0}=1}^{N_2}\psi_{i_{2,0}}\sum_{f=1}^{F_0}F_0|\beta_{0,f}|^2\left\|\mathbf{w}_{i_{2,0}}^{H}\mathbf{a}(\theta_{0,f})\right\|^2 \tag{21}$$

$$g_{2,0}^{(1)}=\mathrm{var}\{n_{2,0}^{(1)}\}=\overline{P}_{1,0}L\sum_{i_{1,0}=1}^{N_1}\psi_{i_{1,0}}\sum_{f=1}^{F_0}F_0|\beta_{0,f}|^2\left\|\mathbf{w}_{i_{1,0}}^{H}\mathbf{a}(\theta_{0,f})\right\|^2 \tag{22}$$

$$g_{2,0}^{(2)}=\mathrm{var}\{n_{2,0}^{(2)}\}=\overline{P}_{2,0}LQ\sum_{i_{2,0}=2}^{N_2}\psi_{i_{2,0}}\sum_{f=1}^{F_0}F_0|\beta_{0,f}|^2\left\|\mathbf{w}_{i_{2,0}}^{H}\mathbf{a}(\theta_{0,f})\right\|^2 \tag{23}$$

$$g_{j,k}^{(1)}=\mathrm{var}\{n_{j,k}^{(1)}\}=L\sum_{k=1}^{K}\overline{P}_{j,k}\sum_{i_{j,k}=1}^{N_1}\psi_{i_{j,k}}\sum_{f=1}^{F_k}F_0|\beta_{k,f}|^2\left\|\mathbf{w}_{i_{j,k}}^{H}\mathbf{a}(\theta_{k,f})\right\|^2 \tag{24}$$

$$g_{j,k}^{(2)}=\mathrm{var}\{n_{j,k}^{(2)}\}=LQ\sum_{k=1}^{K}\overline{P}_{j,k}\sum_{i_{j,k}=1}^{N_2}\psi_{i_{j,k}}\sum_{f=1}^{F_k}F_0|\beta_{k,f}|^2\left\|\mathbf{w}_{i_{j,k}}^{H}\mathbf{a}(\theta_{k,f})\right\|^2 \tag{25}$$

$$g_{n_T}=F_0QL\sigma_n^2 \tag{26}$$

$$\text{where, } R_{j,0}=\sum_{f=1}^{F_0}\beta_{0,f}^2\left\|\mathbf{w}_{j,0}^{H}\mathbf{a}(\theta_{0,f})\right\|^2 \tag{27}$$

Then, the bit energy to interference plus noise density ratio for the desired user is written as

$$\left(\frac{E_b}{N_0+I_0}\right)_j=\frac{\mathrm{var}\{s_{j,0}(l)\}}{g_{j,0}^{(1)}+g_{j,0}^{(2)}+g_{j,k}^{(1)}+g_{j,k}^{(2)}+g_{n_T}} \tag{28}$$

By rearranging the terms, this can be rewritten as

$$\left(\frac{E_b}{N_0+I_0}\right)_j=\frac{Q(L+(F_0-1))}{G_{j,0}^{(1)}+G_{j,0}^{(2)}+G_{j,k}^{(1)}+G_{j,k}^{(2)}+\dfrac{L\sigma_n^2F_0^2}{\overline{R}_{j,0}}} \tag{29}$$

$$\text{where, } \overline{R}_{j,0}=L\overline{P}_{j,0}R_{j,0}F_0Q \tag{30}$$

$$\text{and } G_{j,k}^{(\xi)}=\frac{g_{j,k}^{(\xi)}}{\overline{R}_{j,0}} \tag{31}$$

where, j, k, and ξ denotes user class (j=1 for voice user and j=2 for data user), cell number (k=0,…..,K), and interference component (ξ=1 for voice intracell/intercell interference and ξ=2 for data intracell/intercell interference), respectively.

We note that the variances given in (19)–(25) are themselves random variables that depend on the activity factors of voice or data users, their beamforming vectors, fading and shadowing effects in the channel. We define the outage probability of the system as the probability that the bit error rate (BER) for the desired voice or data user is greater than certain threshold, i.e.,

$$\begin{aligned} P_{out} &= \Pr(BER_1 > p_{0,1} \text{ or } BER_2 > p_{0,2}) \\ &= 1 - \Pr(BER_1 \le p_{0,1} \text{ and } BER_2 \le p_{0,2}) \end{aligned} \tag{32}$$

where, $p_{0,1}$ and $p_{0,2}$ are the BER thresholds required for acceptable performance of the desired voice and data user, respectively. Let S_1 and S_2 be the $E_b / (N_0+I_0)$ value needed for voice and data users, respectively, to achieve the required performance. Then the system outage probability is

$$P_{out} = 1 - \Pr\left\{ \begin{array}{c} \left(G_{1,0}^{(1)} + G_{1,0}^{(2)} + G_{1,k}^{(1)} + G_{1,k}^{(2)} + \dfrac{L\sigma_n^2 F_0^2}{\overline{R}_{1,0}} \right) \le \dfrac{(L + (F_0 - 1))}{s_1} \\ \text{and} \\ \left(G_{2,0}^{(1)} + G_{2,0}^{(2)} + G_{2,k}^{(1)} + G_{2,k}^{(2)} + \dfrac{L\sigma_n^2 F_0^2}{\overline{R}_{2,0}} \right) \le \dfrac{Q(L + (F_0 - 1))}{s_2} \end{array} \right\} \tag{33}$$

IV. SIMULATIONS

Since the distribution of intercell interference terms in (11) and (12) does not yield itself to analysis as in the RL case [5], the system capacity with different array topology and different antenna element number is evaluated via Monte Carlo simulations. The data rates are taken as R_1=9.6 kbps for voice users and R_2=76.8 kbps for data users as specified in [7] for mixed traffic scenarios. The percentage of data users in the network is 20%. Monte Carlo simulations are run for 10000 times. For each run; First, determined the DOAs of the desired voice or data users in the center cell by random selection from a uniform distribution. The DOAs are selected from the intervals [30°, 150°] for ULA and [0°, 360°] for UCA antennas. Using these DOAs, we then estimate the intercell interference DOAs, which are the basestation transmission directions of outer cells towards their targeted voice or data users. Next, the FL transmission weight vector for each class of desired user in each cell is determined according to the mean DOA beamforming method in (3). Since we have no prior knowledge of the FL fading coefficient, we utilize RL fading coefficients which are generated independently. For the RL fading, total of 114 Rayleigh random variables with log–normal shadowing are produced. As pointed out in [8], although the fadings in RL and FL are uncorrelated, the same behavior is preserveal in terms of relative strengths of multipaths. We consider that there are 3 resolvable multipath signals for each class of user in each cell, i.e., F_o=F_k=3. Channel vector (spatial signature vector) through which transmitted signals from the BS will arrive at the desired mobile is constructed for each class of user for all 19 cell sites by using FL fading coefficients and multipath DOAs. Therefore, we generate total of 57 random variables for voice and 57 random variables for data users to represent the FL fading coefficients, each of which is modeled by a Rayleigh random variable with log–normal standard deviation of 10 dB. For the given number of users, powers for the desired signal, intracell interferences, and intercell interferences are calculated using (29) for voice and data users, and the system outage is estimated from (33).

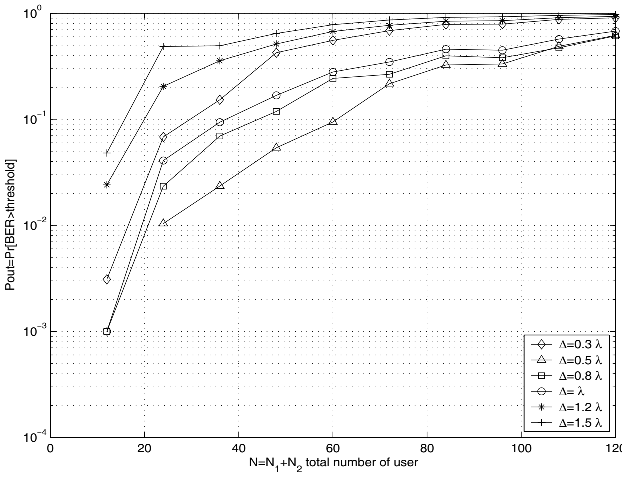


Fig. 2. Outage probability for the 5–element ULA with varying element spacing. Δθ=50°, R_2=76,8 kbps.

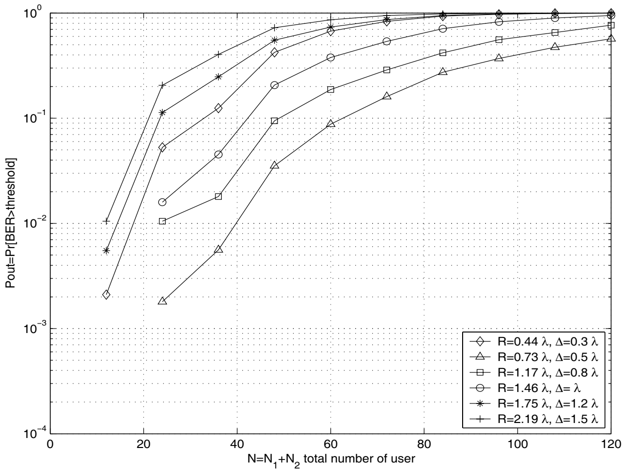
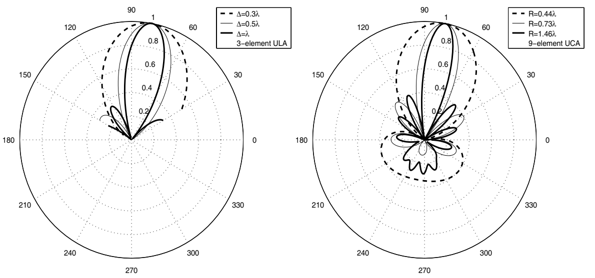


Fig. 3. Outage probability for the 15–element UCA with varying radius. Δθ=50°, R_2=76,8 kbps.

V. RESULTS

An important parameter for an antenna array is the spacing between elements (Δ). The investigation here clarifies the question of how FL performance of the network would be affected by the antenna array topology. For this purpose, we consider ULA and UCA configurations with different number of elements and element spacing under different data bit rates

(R_2) and multipath angle spread conditions. Fig. 2 shows outage probabilities as a function of cell loading for the 5–element ULA with varying element spacing at $\Delta\theta=50^o$ and $R_2=76.8^o$. Similar graphs for the 15–element UCA are given in Fig. 3. The radius (R) of UCA in this figure is adjusted so that we have the same element spacing as the ULA. It is clearly seen from both figures that the largest system performance is obtained when $R=0.73\lambda$ for the UCA and $\Delta=0.5\lambda$ for the ULA.



(a) (b)

Fig. 4. Beamforming spectrums of sectorized 3–element ULA and non–sectorized 9–element UCA topologies for the desired user DOA at 80^o.

Fig. 4 shows the spatial spectrums of sectorized 3–element ULA and non–sectorized 9–element UCA. Note that the spectrum of the ULA is within [30^o 150^o] range due to sectorization. The effects of varying element spacing for the ULA and radius for the UCA on the beamforming spectrum are displayed in Fig. 4 (a) and (b), respectively. As seen, the main lobe beamwidth of both configurations are inversely proportional to the element spacing or radius. As the beamwidth gets narrower there are more sidelobes observed in the spectrum. One may expect that the largest system capacity can be obtained with the array configuration that has the narrowest main beamwidth. This hypothesis may hold true if all the interferences accumulate within the main beamwidth of the antenna array. However, this is not the case in realistic wireless scenarios in which the interferences may arrive to the desired mobile from any direction.

In Table 1, we summarize the results obtained at 10% outage level for the FL system capacity with different ULA and the UCA topologies under varying angle spread ($\Delta\theta$) and data bit rate (R_2). In all cases, the largest system capacity is obtained when the element spacing $\Delta=0.5\lambda$. We also observed that for the same array topology, the larger system capacity is achieved with the larger number of elements. For both topologies, the system capacity is inversely proportional to the variation in angle spread and data user rate.

VI. Conclusion

We have studied FL capacity improvement for 3G CDMA network with three–sector ULA and non–sectorized UCA adaptive antennas at the BS. We have derived intracell and intercell interferences for both desired voice and data users and provided the system outage equation that considers the outage of either voice or data user at a given instant of time. We have evaluated the FL system capacity based on the above analysis for varying element spacing of the ULA and UCA topologies and found that the optimum element spacing for both antennas was 0,5λ at which the largest capacity was obtained. We have also found that when the element spacing between neighboring antenna elements was kept the same for both the ULA and the UCA, the FL capacity of the UCA was larger than that of the ULA.

TABLE I

Number of User Supported with Various Conditions

	($\Delta\theta$)=50° R_2=76.8 Kbps					
	0.3 λ	0.5 λ	0.8 λ	λ	1.2 λ	1.5 λ
3 element ULA	21	44	30	24	18	14
5 element ULA	30	60	42	38	20	16
9 element UCA	24	48	36	30	18	16
15 element UCA	32	62	45	43	24	21
	($\Delta\theta$)=10° R_2=76.8 Kbps					
	0.3 λ	0.5 λ	0.8 λ	λ	1.2 λ	1.5 λ
3 element ULA	24	50	40	36	30	20
5 element ULA	32	64	60	52	36	24
9 element UCA	26	56	50	45	33	22
15 element UCA	36	68	62	56	42	28
	($\Delta\theta$)=50° R_2=38.4 Kbps					
	0.3 λ	0.5 λ	0.8 λ	λ	1.2 λ	1.5 λ
3 element ULA	32	70	51	44	38	30
5 element ULA	48	86	66	60	50	42
9 element UCA	38	74	60	54	44	35
15 element UCA	50	90	72	64	56	46
	($\Delta\theta$)=10° R_2=38.4 Kbps					
	0.3 λ	0.5 λ	0.8 λ	λ	1.2 λ	1.5 λ
3 element ULA	36	80	64	58	48	34
5 element ULA	52	92	80	70	56	50
9 element UCA	42	82	74	65	56	42
15 element UCA	56	100	84	80	70	58

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References

[1] A.F. Naguib, A. Paulraj, T. Kailath, Capacity improvement with base station antenna arrays in cellular CDMA, *IEEE Trans. Veh. Technol.*, 43(3) (1994), pp. 691–698.

[2] F. Chin, B. Lan, Y.C. Liang, C.C. Ko, Downlink capacity of multi–rate CDMA with base station antenna array, in *Proc. VTC'99*, 5 (1999), pp. 2626–2630.

[3] A. Czylwik, Comparison and optimization of antenna concepts for downlink beamforming, in *Proc. ICT'03*, 1 (2003), pp. 192–197.

[4] A. Kavak, Adaptive antenna arrays for downlink capacity increase in third generation wireless CDMA, in *Proc. RAWCON'01*, (2001), pp. 77–80.

[5] K.S. Gilhousen, I. Jacobs, R. Padovani, A. Viterbi, L. Weaver, C. Wheatley, On the capacity of a cellular CDMA system, *IEEE Trans. Veh. Technol.*, 40(2) (1991), pp. 303–312.

[6] D.J. Torrieri, Performance of direct sequence systems with long pseduonoise sequences, *IEEE Journal on Select. Areas in Commun.*, 10(4) (1992), pp. 770–781.

[7] CDG Evaluation Study Report, Rev. 4.01, Lucent, Motorola, Nokia, Nortel, Qualcomm, and Samsung, January 2000.

[8] A. Kavak, W. Yang, G. Xu, W.J. Wogel, Characteristics of vector propagation channels in dynamic mobile scenarios, *IEEE Trans. Antennas and Propogat.*, 49(12) (2001), pp. 1695–1703.