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On the Sensitivity of the Capacity Enhancement of a TDMA system with Adaptive Multibeam Antennas

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Abstract

The paper presents results for the likely capacity improvement when an adaptive multibeam antenna is used in conjunction with air interface parameters akin to the DCS1800 system. The analysis investigates the possible capacity enhancement whilst taking in to account parameters such as power control, number of available handover channels, radiation pattern, radio channel characteristics and different frequency reuse patterns. The results show that a substantial capacity improvement can be achieved with adaptive antennas and also underline the sensitivity of the capacity upon several operational parameters. Finally, based on observations made from the simulation results, a more efficient architecture which fully supports onward beamforming on the handover process, is proposed.

I. Introduction

The increasing demand for spectrum efficient mobile communications systems motivates the need for new techniques in order to improve spectrum utilisation. With efficient use of spatial processing at a cell site, optimum receive and transmit beams can be used to improve the system's performance in terms of the available capacity and quality of service parameters. This approach is usually referred to as SDMA (Space Division Multiple Access SDMA), and enables multiple users within the same cell to be accommodated on the same frequency and time slot by exploiting the spatial filtering properties offered by the adaptive antenna. Considerable research has been undertaken and is now underway from researchers around the world [1-9], in order to fully assess the benefits of this technology to current and future mobile networks. This paper reports new

results from a capacity sensitivity analysis performed for an adaptive multi-beam antenna system.

II. Simulation Method

The cellular scenario under consideration is illustrated in figure 1. The system employs a predetermined reuse pattern. For the non adaptive case in the uplink, only one user in each co-channel cell can interfere with one user in the central cell. Similarly for the tri-sectorised case, (120° sectors), a user in the central cell receives interference from only two users, those in the sectors with the same frequency channel as the central sector. In the downlink the situation is similar, only now the sectors which can interfere with the user in the central cell are the images of the interfering sectors in the uplink.

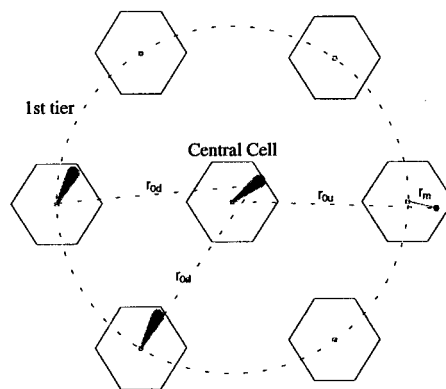


Figure 1: Cellular layout (Up and Down links).

Based upon techniques discussed in [10] and subsequently used for CDMA and adaptive antennas analysis in [1-2], a similar set of tools was developed here. The basic idea behind this simulation method is to generate a large number of random deployments of mobile users and then, using the coordinates of the base station antennas and the cell boundaries, to

assign mobiles to base stations for various adaptive control strategies.

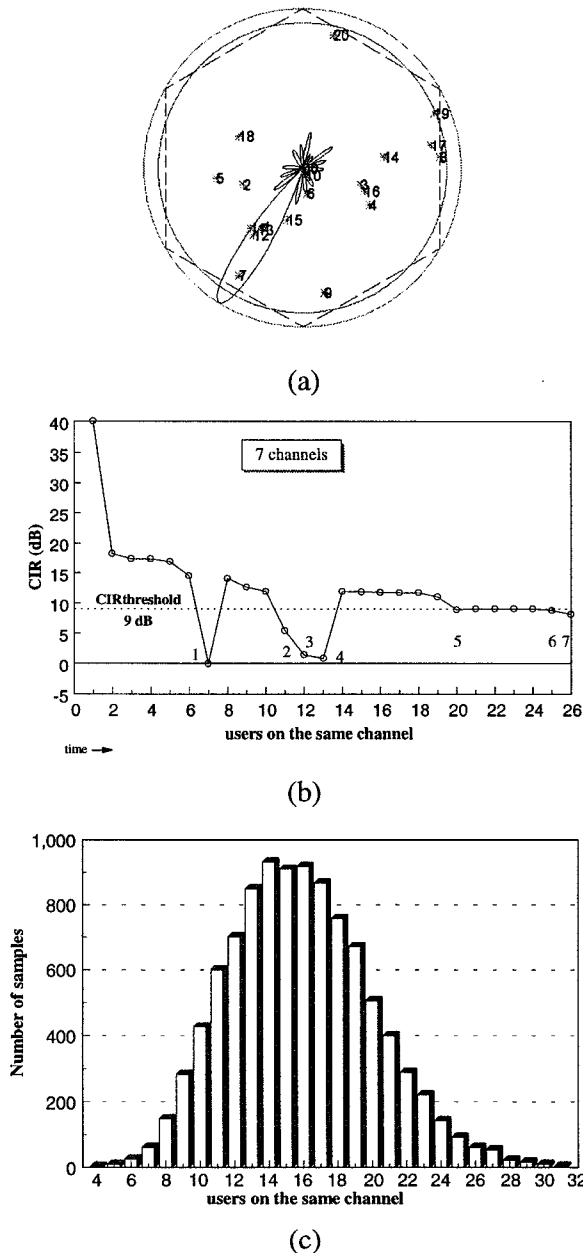


Figure 2: (a) One snapshot of the user distribution, (b) CIR history, (c) Histogram for the probability density of the number of co-channel users after 10000 iterations.

For the case of the uplink, the simulation technique is illustrated in figure 2. The simulation generates a random deployment of uniformly distributed users and then steers the main beam towards the desired user. For each new user the CIR threshold is calculated and compared with the threshold value. If

it is exceeded then the user is handed over to another channel. It can be seen that whenever one interfering user is within the main beam (e.g. users 7, 11, 12, 13), the CIR value falls below the threshold and the user must be handed over to another channel. The above calculations are repeated for 10^4 times and then the probability density function (figure 2c), and the outage probability of the number of co-channel users, are calculated.

The model can include the effects of:

- **Network Topology:** The base station topology is based upon the usual hexagonal geometry. It can be re-configured easily to consider the effects of sectorised cells. *Scenarios studied:* Central cell, central cell with 1 tier of interfering cells.
- **Path loss:** Different exponents can be employed at different ranges and also empirical models can be used. *Studied cases:* single slope pathloss exponent with value 4, dual slope pathloss exponent with values 3 up to the cell boundary and 4 beyond.
- **Log-normal shadowing:** Vary the shadowing standard deviation, given in dB. *Studied cases:* No shadowing and shadowing with 5dB standard deviation.
- **Power control:** Consider the impact of the power control errors. *Studied cases:* No power control error, and power control error with 1dB, 3dB and 5dB standard deviation.
- **Number of handover channels:** Vary the number of available channels for handover. *Studied cases:* 7, 15, 30 channels.
- **Radiation pattern:** Change parameters such as the null depth or introduce beam pointing errors. *Studied cases:* 30° beamwidth radiation pattern with the first sidelobe at $\sim -13\text{dB}$, and -60dB or -30dB maximum null depth, and 0° , 3° or 6° of main beam pointing error.
- **Frequency reuse pattern:** The multi-tier geometry employs a frequency reuse pattern which can be varied. This effectively means that the same type of simulation can be performed for a CDMA system, with a frequency reuse factor of one. *Studied cases:* 3, 4, 7.

III. Results

In order to be able to study the impact of parameter variation upon the capacity enhancement offered by

an adaptive multibeam antenna, each simulation systematically investigated for single parameter variation. Using this approach it was recognised that because of the reuse distance employed for the co-channel cells, the dominant effect occurs within the central cell and thus results for the central cell were analysed first. Hence, the effects of the power control errors and the number of available handover channels were studied within the central cell first. Following this initial sensitivity analysis, the impact of propagation parameters and frequency reuse pattern were examined for a cellular system architecture with one tier of interfering cells.

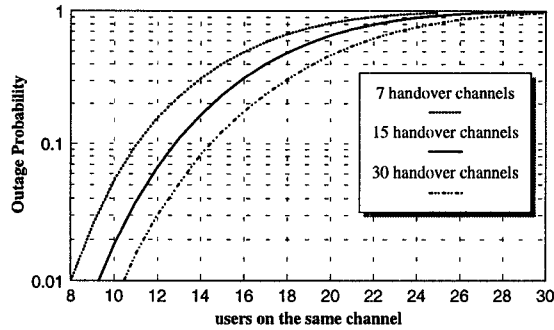
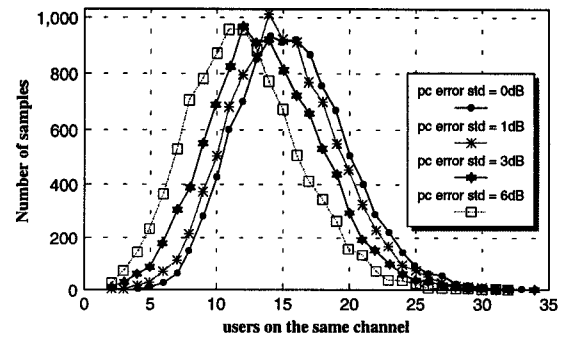


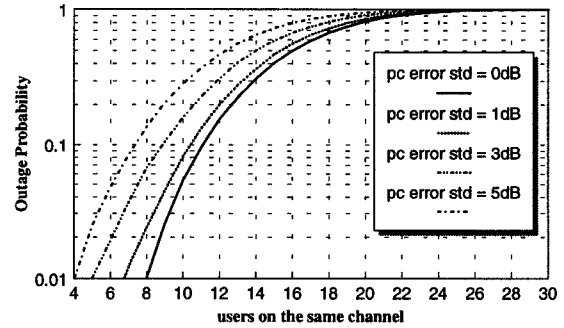
Figure 3: Capacity for different number of available channels for handover facilitation.

From figure 3 can be seen that the capacity of the system is not proportional to the number of available handover channels, as it was expected for this single level adaptive system. The capacity enhancement of 16% (7 to 15) and ~13% (15 to 30) respectively, (1% outage probability), is because the physical location of the user deployment within the cell dominates the performance. As the number of users in the same channel increases, the overall CIR value decreases, which effectively means that while at the beginning only the users within the main beam should be handed over to other channels, as the network loading increases, new users introduced on primary sidelobes must also be handed over, and only users falling in secondary sidelobes of the radiation pattern, can be accepted in SDMA mode.

It should be noted that the number of users shown, only relates to additional co-channel users supported via SDMA. In fact the total number of users should be increased by the number of the available handover channels (7, 15 or 30 here), in order to calculate the overall capacity.



(a)



(b)

Figure 4: The effect of power control inaccuracies on the achieved performance. a) Probability density, b) Outage probability.

Figure 4 shows the effect of the power control errors on the performance of the system. It can be seen that for a 1% outage probability, the system can support 8 users whilst assuming ideal power control, however when inaccuracies are introduced in the power control mechanism, the number of users is reduced e.g. by 50% for errors with 5dB standard deviation.

Figure 5 illustrates the effect that parameters such as maximum null depth and misspointing of the main beam, have on capacity. For the case of the maximum null depth of the radiation pattern, (figure 5a), it can be seen that when the ideal radiation pattern with -60dB maximum null depth is replaced with one with -30dB maximum null depth, there is ~40% reduction in capacity for 1% outage probability (note that point sources are considered). For the case of main beam pointing errors, the simulation generates a beam which is steered towards the correct angle plus an offset angle uniformly distributed throughout the 10000 iterations for either $\pm 3^\circ$ or $\pm 6^\circ$. The reduction in the capacity at 1% outage probability is ~12% and ~28% for the cases of

misspointing within 3° and 6° respectively. The above results indicate that the nulling capability of the chosen spatial reference algorithm seems to play more important role to the performance of the system, than its ability to acquire the desired user with a high degree of accuracy.

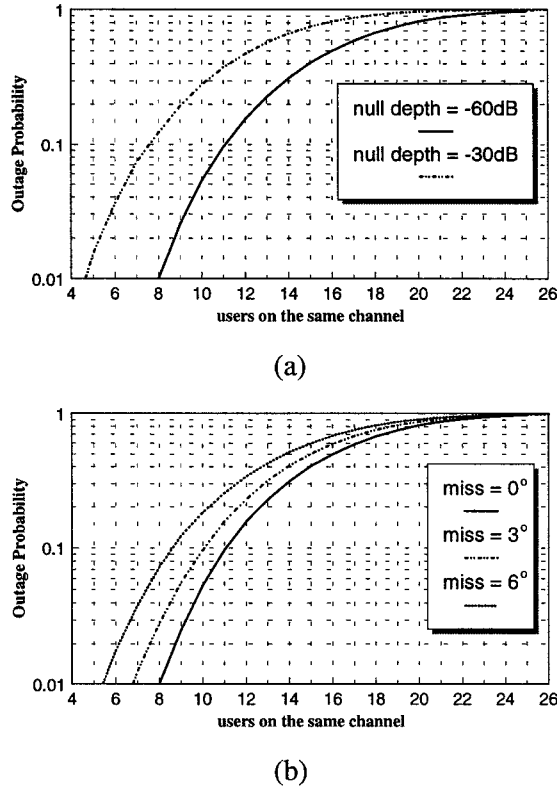


Figure 5: The effect of the radiation pattern on the achieved performance: a) Null depth, b) Misspointing.

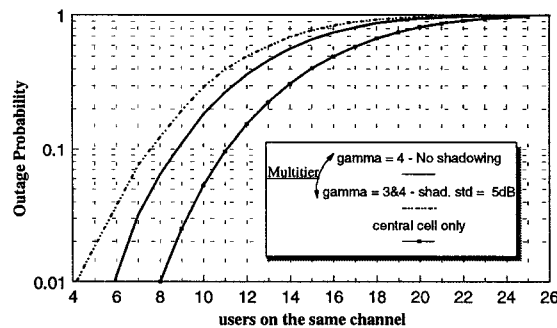


Figure 6: Capacity with different propagation characteristics for the system with one tier of interfering cells [2].

Figure 6 illustrates the effect that the propagation characteristics can have on the capacity when a more realistic scenario of one tier of interferers is

considered. It can be seen that the capacity prediction for the case of one central cell, was optimistic. The capacity is decreased when one tier of interferers is considered, with a path loss exponent of 4 and no shadowing. This again produces rather optimistic results and is further decreased when more realistic propagation characteristics are included. Here, a dual slope model for the pathloss with exponent 3 up to the cell border and 4 beyond, and 5dB standard deviation for the shadowing, have been included. The adaptive multibeam system can now support ~ 4 users with 1% outage probability.

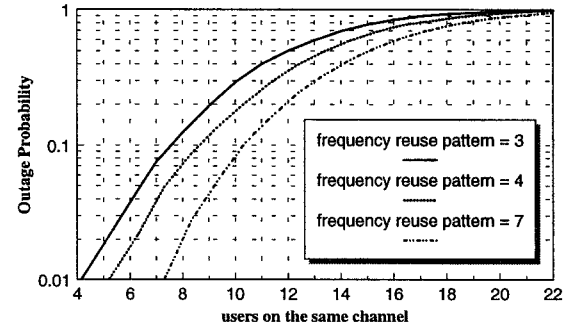


Figure 7: Capacity with different frequency reuse patterns for the system with one tier of interfering cells [2].

	Efficiency E_i/E_1 (%)	Capacity C_i/C_1 (%)
$3 \rightarrow 4$	-20	+25
$4 \rightarrow 7$	-42	+40
$3 \rightarrow 7$	-54	+75

Table 1: Relative spectrum efficiency decrease and capacity increase for different cell cluster sizes.

Although current PCS systems usually exploit a frequency reuse factor of 12 or 7 in the field, all the results presented here have assumed a frequency reuse factor of 3. The results given in figure 7 indicate that it may be desirable (especially with an adaptive antenna), not to reduce the reuse distance but to increase the capacity of the existing system with current reuse distances, through SDMA. A frequency reuse factor of 7 can almost double the capacity of the system, compared with a frequency reuse factor of 3, for 1% outage probability. Clearly,

there is a trade-off between capacity enhancement due to the better performance of the adaptive antenna with higher frequency reuse distances, and the lower spectral efficiency that these higher frequency reuse distances imply. In Table 1 the percentage increase of the capacity due to the larger cell clusters and the corresponding percentage decrease in spectrum efficiency, have been calculated. It can be seen that the best improvement is achieved when the cell cluster is expanded from 3 to 7.

Simulations were also performed for the downlink case. As expected, the downlink is not the limiting case for the system, since the users in the downlink are the users that can be supported in the uplink, i.e. SDMA operation in the uplink was considered first and those users not suited to SDMA channel access were removed from the simulation. The worst situation in the downlink occurs when the beam from one interfering cell aligns with the desired user in the central cell. However this situation will only happen occasionally, since the users in the downlink are those users that the uplink can support. This effectively means that since the uplink can not support two users within the same main beam, there is a very small probability another user to be near the desired user.

The system that was previously described can exploit the available channels in order to achieve an overall capacity improvement of the order of $N+k$, where N is the capacity gain for a single channel due to the adaptive antenna, and k is the number of available channels. A further development for this scheme would be a fully adaptive scheme where the same CIR adaptation process is repeated for every channel. This of course will increase the complexity of the system, but it has the advantage of increasing the capacity of a basic omnidirectional system ideally to Nk , i.e. it offers an increase in the capacity of the order of N , compared to the moderate $1+N/k$.

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