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DS-CDMA Microcellular Networks with Adaptive Antennas

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Abstract: This paper considers the performance of a DS-CDMA system which employs adaptive antenna technology at the basestation site of a microcell. Results for a typical microcellular environment produced with the help of a ray tracing tool highlight the behaviour of the adaptive antenna and with the help of a Monte-Carlo type DS-CDMA capacity analysis, the potential performance enhancement of the system is evaluated. Finally, scenarios with inter cell interference and moving users are discussed, and the fixed beam steering and the reduced sidelobe techniques are considered against the adaptive antenna technique.

I. INTRODUCTION

The deployment of spectrum efficient air interface techniques such as Direct Sequence Code Division Multiple Access (DS-CDMA), [1-3], are at the forefront of research along with research on the application of adaptive antenna technology to the cellular networks, [4-12]. The capacity enhancement offered by an adaptive antenna is by means of spatial filtering of the plethora of signals at the cell site. This can be exploited in many ways such as reducing co-channel interference or multipath fading, supporting mixed cell architectures or helping to mitigate the near-far effect in mixed cell structures.

However, research considering adaptive antennas has been largely focused towards the use of this technology in large cell operational environments. As such, the application of this technology to small cell systems has received little attention, although it is well known that third generation systems will include both micro and pico-cellular environments. Ray Tracing modelling techniques, have emerged as the dominant techniques for site specific propagation modelling [13-17]. In particular for the case of adaptive antennas in small cell scenarios, ray-tracing is most beneficial because it can not only provide the impulse response of the radio channel, but it can also provide the site dependent information in terms of the Angle Of Arrival (AOA), as well as it can incorporate 3D radiation patterns. Furthermore, due to the fact that ray-tracing produces deterministic channel models by processing user-defined environments (databases), the analysis can be easily repeated for a variety of different operational environments.

The analysis presented here shows that adaptive antennas can improve the signal to interference ratio of the interference limited DS-CDMA systems. This processing ultimately leads to an increase of the spectrum efficiency of the network.

III. SIMULATION MODEL

The developed simulation model can be separated into three basic blocks, as it is shown in figure 1 [6, 18]:

a) *Multipath Channel Model:* Impulse responses from the environment under investigation are generated using a 3D ray- tracing simulation tool that was developed at the University of Bristol, [13]. The input parameters to this tool include geographical data bases of the service areas, the number of reflections, transmissions and diffractions, the transmitted power, 3D antenna radiation patterns etc. The output file includes the electric field, the time delay and the angle of arrival.
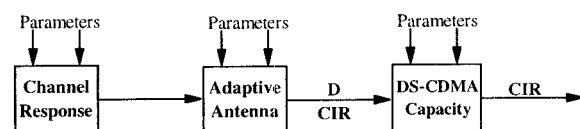

Figure 1: Simulation model block diagram.

b) *Adaptive Antenna Array:* The type of adaptive antenna that is considered here, is an antenna array that is capable of modifying its radiation pattern, frequency response and other parameters by means of internal feedback control while the antenna system is operating, so as to maximise the signal-to-noise ratio of some desired signal which is received in the presence of noise and interference, at the receiver output.

If $x_n(k)$ is the sample of the total received signal at the nth element at instant $t = kT$, where T is the sampling interval, as well as being the chip duration of the PN sequence and k is the sample number, then the output from the adaptive array in vector notation is: $y(k) = \mathbf{w}^T(k)\mathbf{x}(k)$, where $\mathbf{w}(k)$ and $\mathbf{x}(k)$ are the weight and element vectors respectively:

$$y(k) = \sum_{n=1}^{N} w_n(k) \left\{ \sum_{m=1}^{M} \sum_{r=1}^{R} h_{mr} e^{jk_u d(n-1)\sin(\vartheta_r)} r_m(k-t_r) + N(k) \right\}$$

N is the total number of antenna elements, the desired or reference signal $r_0(k)$ is simply the PN sequence from one user, and the error signal is defined as the difference between the array output and the desired signal $e(k) = y(k) - r_0(k)$. h_{mr} $r_m(k)$ are the elements of the vectors of the impulse response and the DS-CDMA signal from the mth user respectively. $\mathbf{r}_m(k) = \mathbf{d}_m(k) \cdot \mathbf{PN}_m(k) \cdot e^{j\xi_m}$, with $\mathbf{d}_m(k)$ the binary data and ξ_m the carrier phase of user m. $N(k)$ represents the random Gaussian noise. M is the total number of users, R is the total number of rays, d is the interelement distance, k_u is the wave number, ϑ_r and t_r are the angle of arrival and the delay of each ray and $[\ ]^T$ denotes the transpose. Although the total received signal at the nth antenna element is calculated by considering the interelement phase shift for each incoming ray, i.e. $(n-1)kd\sin(\vartheta_r)$, depending on the environment under investigation, it can also be calculated directly from the ray tracing tool.

c) *DS-CDMA Capacity Analysis:* Based upon the Monte-Carlo technique described in [19], a simulation model was used for the capacity calculations of the DS-CDMA system. The basic idea behind this kind of simulation is to generate a large number of random deployments of mobile users under realistic loading conditions. Using the co-ordinates of the basestation antennas, it is then possible to assign mobiles to base stations. The decision is based upon the shadowing and path loss experienced, and the selected basestation is the one which maximises the received signal power. For each deployment, a signal-to-interference ratio SIR can be calculated and after many runs the complete cumulative distribution function of the SIR values can be produced. Given the SIR threshold for a particular BER requirement, the outage probability can then be generated, i.e. the percentage of time that the SIR falls below the given threshold.

3. RESULTS

The model for the adaptive antenna employed here offers the capability of selecting one from several adaptive processing algorithms. In [18] different algorithms for an adaptive antenna in a microcellular environment, were compared and the superiority of the recursive least squares based algorithms (RLS-SQRLS), was demonstrated. This is also supported from [20] even for the case of moving users with high speeds.
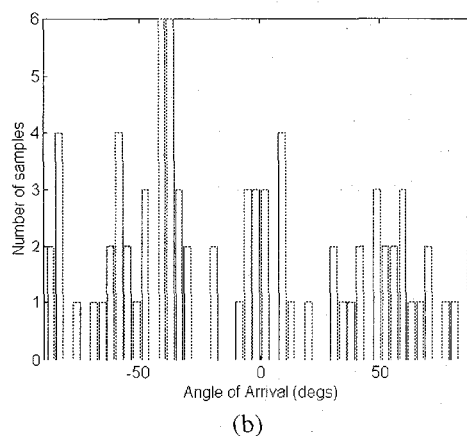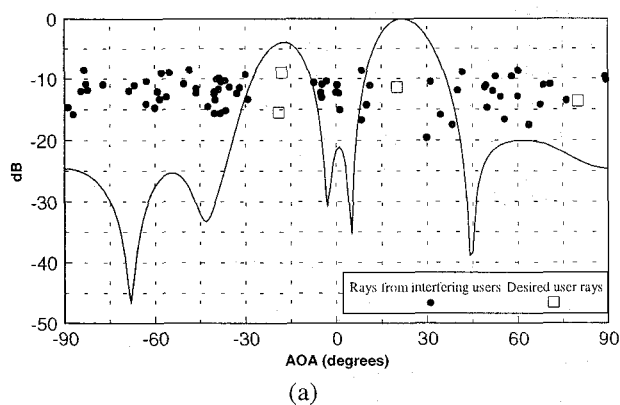

(a)

(b)

Figure 2: a): Radiation patterns produced for the case of 20 users. b): The distribution of the Angles of Arrival for the scenario considered.

General parameters that were used in the simulations include: averaging over 10 runs, 500 samples and 8 antenna elements with $\lambda/2$ interelement spacing. The simulated area here was the area of the centre of Bristol.

From figure 2 can be seen that given the spatial distribution of the interfering and the desired signals, the adaptive antenna attempts to generate the optimum radiation pattern which corresponds to the optimum output SIR. As a result of that the adaptive antenna has steered its main beam towards the second strongest multipath whilst the strongest multipath is only supported by a secondary lobe. The distribution of the arriving at the base station multipath signals, is shown in figure 2b. There it can be seen that due to the lower height of the BS antenna and the close proximity of the scattering objects in a microcellular environment, the angular spread of the multipath signals can be very wide.

For different simulation scenarios and for different number of users, the above simulations were repeated and from the produced radiation patterns, values for the directivities ranging between 6dB and 9dB, were calculated, as discussed in [21]. The values calculated for the directivities were then used in the DS-CDMA capacity analysis. In order to find an approximate lower bound for the predicted improvement, we considered the worst case of the simulation scenarios, i.e. for the scenario that the adaptive antenna responds with the lowest directivity radiation pattern, (~6dB). It was shown in [21] that almost a five fold increase could be achieved when an adaptive instead of an omnidirectional antenna, is used at the basestation of a microcell.

Next, the effect that the additional users in the tiers of the cellular system, can have on the performance of an adaptive antenna, is considered. The simplified approach of considering all inter-cell interferers as noise with power which depends on which tier they belong [22 - 23], is used. All the users in the first tier contribute 36% of the total interference seen from the central cell. Following the same concept, the contribution of the users in the second tier is 2.4% of the total interference in the central cell and that of the users in the third cell is 0.54%. From the simulation results several things can be noticed: First, there isn't any further decrease in the output SINR when considering more than one tiers, because from the model used, the difference in the interference contributions between one and three tiers is rather small (less than 3% of that of the central cell), which

effectively means that the SNR will not change considerably. Then it was noticed the radiation patterns for the cases with inter cell interference produce generally lower sidelobes and better nulls towards the interference, than the one without inter cell interference. This could possibly be explained on the following basis: The error signal is made up of three components: 1) the desired signal minus the reference signal, 2) noise, 3) interference. To minimise the overall MSE, the array feedback makes a compromise between these three components. In general, the weights that yield minimum error signal do not match the array output signal to the reference signal exactly. Rather, they compromise between noise, interference and desired signal contributions to the error signal. If the noise in the array is increased (the noise from the users in the tiers for our case), the noise component in the error signal becomes larger. In response to this, the array feedback lowers the weights to reduce the noise. In the process, the output desired signal is lowered as well, so the mismatch between the array output desired signal and the reference signal increases. The final weight setting compromises between decreasing the noise and increasing the desired signal mismatch. The overall result is a reduced desired signal output from the array. Furthermore, the interference power has a stronger effect on output desired signal power when the noise is large. This is the reason why the radiation patterns for the cases with noise produce generally lower sidelobes and better nulls towards the interference, than the one with no noise.

All the results presented up to here, have considered static or very slowly moving users. In order to see how the adaptive antenna performs when the users are moving, a simple scenario with one desired user and four interferers was considered. For simplification reasons, only the strongest ray of the impulse response of each user is considered and the users are supposed to move slowly (less than 30mph). The route that the users follow, is shown in figure 3a. The desired user is moving straight at -20 degrees, two interferers are moving straight at -60 and 30 degrees, and two interferers start from 0 and 60 degrees and finish to 60 and 0 degrees respectively. The RLS algorithm is used here. It can be seen that the system is always able to both support the desired user and produce deep nulls for the interferers (less than -40dB). The scenario considered here is a simple one and a reduction in the performance of the algorithm is expected when the users travel with speeds higher than 20mph when the

LMS algorithms are used or more than 60mph when the RLS algorithms are used, as it was discussed in [20]. However, it was shown in [20] that for the RLS algorithms and for speeds up to 60mph, the performance reduction is within 0.2dB from the performance with the static case.
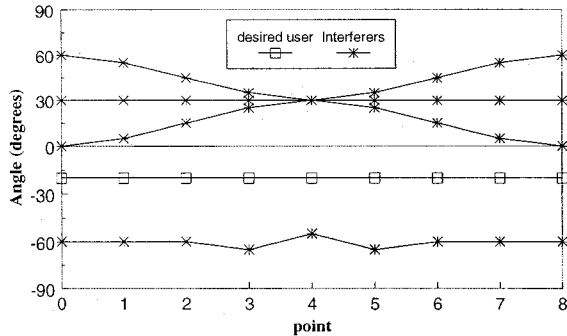
(a)
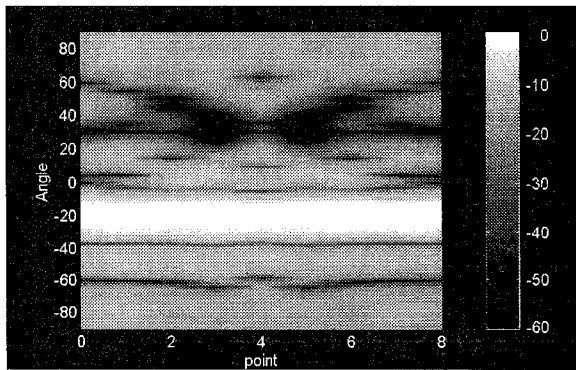
(b)

Figure 3: a) Simulation scenario for moving users, b) The response of the adaptive antenna (ground plan of the 3D radiation pattern).

In the following, a comparison is made between the gain that can be achieved with an adaptive antenna in a microcellular environment, the gain when a linear antenna with main beam steered towards the same direction as the adaptive antenna main beam, and the gain with a linear array with reduced sidelobe levels. The environment is that with 21 users (see figure 2), the RLS algorithm is employed and in order to reduce the sidelobe levels, a Dolph-Tchebyscheff technique is used [24]. The assumption that is made here is that the linear and the reduced sidelobe level patterns are driven from the adaptive antenna, i.e. the adaptive antenna finds first

one desired direction and then both the other patterns steer their main lobe towards that direction.

From a first look it may seem reasonable to conclude that the lower the sidelobe level, the higher the achieved gain. This is true up to a point. The reason why although the sidelobe level is reduced, the gain is not increased so much, is because the main lobe beamwidth is increased [31]. Hence the advantage that is gained from the reduction of the sidelobe levels in terms of interference nulling is counterbalanced from the main beam broadening, which leads to more interference reception. The exact multipath distribution around the desired user multipath is critical. If there is not much interfering multipath around the desired multipath, then the effect from the beam broadening will be small, but if there is strong interfering multipath around the desired multipath, then the effect from the beam broadening will be more pronounced. Another approach could be to introduce a constraint in the optimisation problem and reduce the sidelobe levels of the radiation pattern produced from the adaptive antenna. Nevertheless, care must be taken in order not to reduce any sidelobe levels which support desired multipath.

IV. CONCLUSIONS

A new ray based simulation model for an adaptive antenna in a DS-CDMA system was presented. Results for a typical microcellular environment highlighted the behaviour of an adaptive antenna when used in conjunction with DS-CDMA and showed that substantial gain in terms of output SIR can be achieved even in difficult multipath situations. DS-CDMA capacity analysis for the scenarios considered showed a minimum of five fold increase in the overall spectrum efficiency. Scenarios with inter cell interference and moving users were discussed and finally, the fixed beam steering and the reduced sidelobe techniques were considered against the adaptive antenna technique.

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