Application of Adaptive Antenna Technology to Third Generation Mixed Cell Radio Architectures

George V. Tsoulos, Mark A. Beach and Simon C. Swales
Centre for Communications Research
University of Bristol
Bristol BS8 1TR, UK
Fax: +44 272 255265, Tel: +44 272 303030 ext. 3027

***Abstract*-Recent work at Bristol has considered the application of adaptive antenna technology to a mixed cell architecture employing DS-CDMA as the air interface. In the scenario considered, both the Umbrella cells and the underlying Micro cells operate within the same RF bandwidth in an attempt to support a seamless handover between different cell types.**

This paper will present an overview of the proposed mixed cell architecture employing adaptive antenna technology at the Umbrella cell site, as well as the benefits that can be obtained from such a deployment. This will be expressed in terms of the critical near-far problem and the system's capacity. Simulation and propagation results provide evidence for the claimed capabilities of the proposed system and estimates of the likely increased spectrum efficiency.

1. INTRODUCTION

The two systems that have been proposed to take the wireless communications into the 21st century are the CCITT FPLMTS (Future Public Land Mobile Telecommunications System) and the European UMTS (Universal Mobile Telecommunications System). If either is to be universally accepted they will have to meet a number of stringent criteria such as [1]:

- FLEXIBILITY: Service & Operational.
- QUALITY: Speech, Coverage & Reliability.
- CAPACITY: System.
- HARDWARE : Cost & Power.

The air interface technique chosen for the third generation system will be one of the key issues for the definition of this system. Two candidates among the others for the access techniques are TDMA (with or without frequency hopping) and CDMA (direct sequence [2] or frequency hopping [3], [4]). All the work in this paper has been focused towards a DS-CDMA system.

2. MIXED CELL STRUCTURES IN UMTS

Recognising that the requirements of UMTS can not be fulfilled with the known cellular architectures (macro, micro, pico cells) led to the conception of the idea of a mixed cell scenario [5]. The key issue for this type of cell architecture is to apply multiple cell layers to each service area, with the size of each layered cell tailored to match the required traffic demand and environmental constraints as depicted in figure 1. In essence, microcells will provide the basic radio coverage and will be overlaid by Umbrella cells which will provide background coverage in order to maintain ubiquitous and continuous coverage. Due to adverse propagation characteristics, umbrella cells will support a limited subset of services.

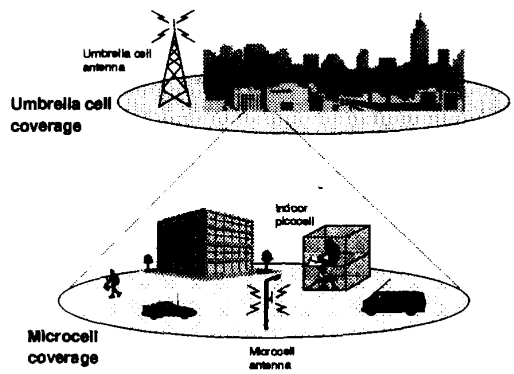

Figure 1: Mixed cell structure concept

The advantages and disadvantages of this cell structure will be described in the following sections.

2.1 Handover

Perhaps one of the key issues for a cellular system is its ability to handover calls when the mobile moves from one area of coverage to another [6]. Due to the small size of microcells, the frequency of handover is going to be much larger than in conventional cells, reducing the available time for the system to recognise the need for a handover and to perform it. For the same reason of size, more base stations are needed to cover a certain area which, with the increased frequency for handovers, may well lead to a large increase in the amount of signalling. In a mixed cell structure, this can be partially combated if the high mobility mobile is directly transferred to the Umbrella cell whenever the microcellular system can not support the handover process.

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The handover between different cell types introduces a few problems. Firstly, the mobile user must adjust its transmit power to meet the link budget requirements of the new cell. Also the propagation conditions in the new cell may differ considerably and so it would be desirable to either upgrade or downgrade the call, e.g. downgrade a video call to voice only as the user moves from a microcell to a larger macrocell.

2.2 Near-far effect

This is maybe the most critical problem of a DS-CDMA system and is due to the difference in transmit powers required for operation in different cell types. DS-CDMA necessitates the use of either power control mechanisms [2] or near-far resistant techniques [7], in order to ensure that any unwanted users are received at a power level equal to or below that of the wanted code channel. The former requirement becomes increasingly difficult to implement in any form of practical system employing multiple uncoordinated operators within the same geographical area such as with the case of a mixed cell structure. For the DS-CDMA system which uses the power control technique [2], macro diversity involving both macro and micro cells within the same frequency band is very difficult due to the closed loop power control algorithm which would reject transmission at the increased macrocell power level [8]. Simulations from [8], [9] showed that the system capacity is very sensitive to power control errors and this is the reason why the near-far effect becomes very serious within a mixed cell structure. In order to cope with the above problems the simplest solution proposed is to have different cell types on different carrier frequencies[10]. The disadvantages of this technique are :

- Increased hardware complexity added from the extra receiver needed to monitor different frequencies for a mobile assisted handover (MAHO) [10].

- Reduced spreading gain. It has to be emphasised that a bandwidth restricted DS-CDMA air interface is unlikely to meet the goals of UMTS because greatest benefits from CDMA are obtained when a large number of users operate within the same DS-CDMA channel and also the propagation characteristics of the wideband CDMA are found to be less hostile to mobile data communications [11].

- Poor power efficiency because the user supported by the umbrella cell will have to transmit with high power.

- Reduction in the overall system's spectrum efficiency, (see section 4.2).

2.3 Coverage

When a mobile for some reason has to handover to the umbrella cell and is moving in a street where the buildings structure looks like a canyon, then the most possible situation is that no line of sight exists between the umbrella cell and the mobile. The basic propagation mechanism for the large cells is via roof top diffraction but in some cases subsequent obstructions may cause holes or "dead-spots" in the radio coverage. A practical solution to this problem could be the use of *On-Frequency Repeaters* [12].

3. ADAPTIVE ANTENNAS

3.1 Applications to mobile communications

An adaptive antenna array may be defined as an 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. A number of approaches have been considered in order to achieve this goal, among which the use of null steering properties to isolate co-channel users [13], optimum combining to reduce multipath fading and suppress interfering signals [14-16], and beam steering to focus energy towards the desired users [17-19]. Recent proposals for employing adaptive antennas in current TDMA systems such as GSM, IS-54 [20, 21] and DECT [22], reflect the confidence that such an antenna system can give a possible solution to many of the problems which emerge in current mobile communications systems and, as it will be shown in the following sections, to future third generation systems as well.

3.2 An Adaptive Base Station Antenna in a mixed cell scenario with DS-CDMA

The need for new mobile communication systems with increased spectrum efficiency is paramount in the drive towards 3rd generation systems. FDMA, TDMA and CDMA schemes along with their various hybrids, are currently being considered in this context. However, except for modifications of these schemes that use fixed multisector antennas to further increase capacity, which is roughly equivalent to subdividing each cell into smaller cells, none of these schemes fully exploits the multiplicity of spatial channels that arises because each mobile user occupies a unique spatial location. Spatial filtering at the base station separates spectrally and temporally overlapping signals of multiple mobile units during transmission from and reception at the BS and mitigates multipath fading and shadowing.

Employing directional base station antennas can significantly reduce interference over both the reverse and the forward link, leading to an increase in capacity [23]. However spatial filtering at the mobile station tends to be impractical because of the presence of numerous scatters and reflectors in the vicinity of a typical mobile [24] and also because the cost and the size of the array would be an unreasonable burden on the users.

The following sections describe the benefits of employing an adaptive antenna at an Umbrella BS site.

3.2.1 Mitigation of the near-far effect with DS-CDMA

This is possible because:

a) For the desired signals the antenna beams can be adjusted on one hand to their maximum value so that the mobiles can reduce their powers to the minimum possible and on the other hand to attenuate the larger of these signals, if necessary, to provide an equivalent to the power control scheme already used for the microcells.

b) For the interference signals, the depth of the nulls is dependent on the received interference power [25].

Better performance with the near-far effect reduces the potential for self-interference and thus enhances the capacity.

3.2.2 Capacity enhancement

By exploiting the spatial filtering that an adaptive antenna offers, it is possible to confine the radio energy associated with a given mobile to a small addressed volume, thus reducing interference experienced from co-channel users. This ultimately leads to a capacity enhancement for the interference limited DS-CDMA system. This capacity enhancement can be exploited in many ways one of which can be as a technique for reducing the need for very small cell sizes and consequently reducing the infrastructure costs.

3.2.3 More efficient handover

In order to support the soft handoff quality enhancement technique for DS-CDMA [2] within a mixed cell environment, all cell types must operate on identical carrier frequencies. The only foreseeable way of achieving the necessary RF power balancing within each area of a mixed cell scenario, needed in order to provide seamless handover, and simultaneously avoiding the near-far effect, is to exploit the spatial filtering properties offered by an adaptive antenna. More efficient handover leads to greater Quality of Service.

3.2.4 Ability to support high data rates

Through the ability of the adaptive antennas to focus energy towards a user, the multipath activity is reduced [19] and consequently the delay spread [26]. This results in less ISI (InterSymbol Interference) and hence the support of higher bit rate services, which is important for UMTS, can be achieved.

3.2.5 "In-fill" coverage for the dead-spots

This is due to the ability of an adaptive antenna to focus energy towards a small area, as is depicted in figure 2. The "in-fill" coverage achieved by the adaptive antennas could ultimately eliminate the need for *On-Frequency Repeaters.*

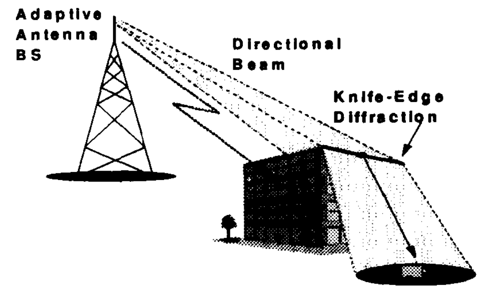

Figure 2: "In-fill" coverage for the dead spots

4. PROPAGATION MEASUREMENTS AND SIMULATION RESULTS

4.1 Propagation measurements

Two sets of measurements were performed employing a narrowband channel sounder developed at the CCR, Bristol, to show an umbrella cell situation with two different base station antennas as follows:

a. Omnidirectional antenna (JayBeam 7276 end-fed dipole with G=1dBd).

b. Directional antenna (JayBeam 7360 shrouded yagi with G=15dBd and $\approx 25^0$ half power beamwidths for the E and H planes).

A 1.823 GHz continuous wave was transmitted with 36dBm power from the base station antenna, which was mounted on a mast with adjustable height at the roof of the University's Senate House (approximately 50m height). The received signal at the mobile was filtered, down-converted and amplified by a logarithmic amplifier, the output of which was sampled with the help of an external distance pulse generator and stored in dB values. The chosen route for the mobile represents a typical situation where the received signal strength, (possibly transmitted by a microcell antenna), is rapidly decreased when the mobile turns from a bigger street to a shadowed or blocked road and rapid handover to the Umbrella cell is required. The results from these measurements are depicted in figure 3.

Two important observations can be made from this figure:

1. The advantage in received signal strength at the mobile, offered by the directive/adaptive base station antenna, can be equal to the antenna gain, (15dB), in some points of the street under coverage. This advantage is the maximum

that can be achieved and is usually decreased due to the multipath and scattering effect. In terms of the near-far effect this improvement in received signal strength means that the mobile can now transmit less power (up to the antenna gain) when an adaptive antenna is used at the Umbrella cell base station.

2. Due to scattering, the coverage from the directive/adaptive antenna will be increased. The results suggest a 54% increase in the effective beam width. Possible problems caused by the broadening of the antenna beam can be increased interference from adjacent Umbrella cell users as well as increased interference into adjacent microcells which are not covered in principle by this umbrella cell antenna beam. Note that in a mixed cell scenario the umbrella cell is only employed to solve problems of coverage and handover with the underlaying microcell system. Therefore, the capacity demands on the umbrella cell system are unlikely to be great, and the problem of increased interference due to a wider beamwidth can be ignored. The key issue is to allow the former microcell user to transmit with reduced power and thereby minimising the impact on the microcellular system where capacity is at a premium.

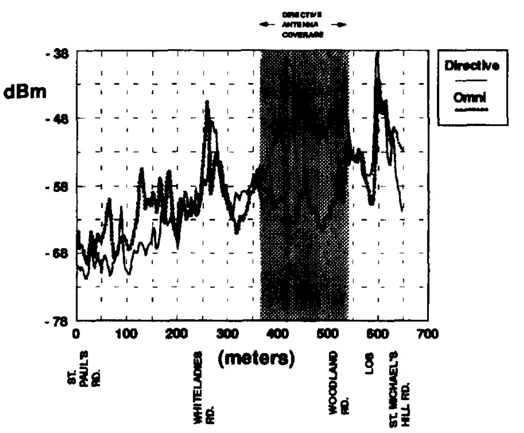

Figure 3: Results from the field trials along Tyndall's Park Road

4.2 Simulation results

The following describes in full the parameters for the basic DS-CDMA system simulation used in the subsequent analysis. The approach is based upon the work presented in [10, 11].

- Total number of base-stations: 37
- Umbrella cell radius: 5 times that of the microcells
- Path loss exponent for the microcells: 4
- Path loss for the macrocells: Single slope (4), Hata's or Bertoni's
- Log-normal shadowing std. dev.: 8 dB
- Power control: Shadowing & Path loss
- Voice activity: 0.5
- Data rate, Rb: 8 kbps
- Eb/No for BER $\leq$ 0.001: 7 dB
- Total spreading bandwidth: 1 MHz

Simulation results on the effect that different macrocell propagation models have on the capacity of an umbrella cell are depicted in figure 4.

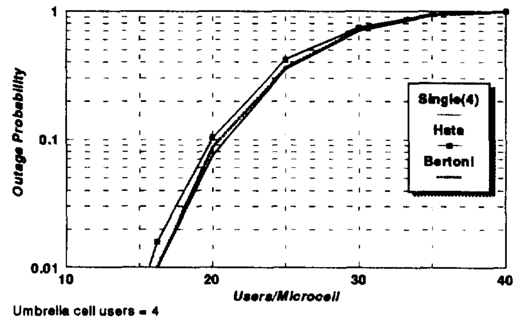

Figure 4: Simulation results for different propagation models for the Umbrella cell.

This clearly shows that the choice of model for the scenario considered for the umbrella cell, is negligible and that the chosen single slope model is perfectly valid.

Capacity results for several scenarios are shown in figure 5.

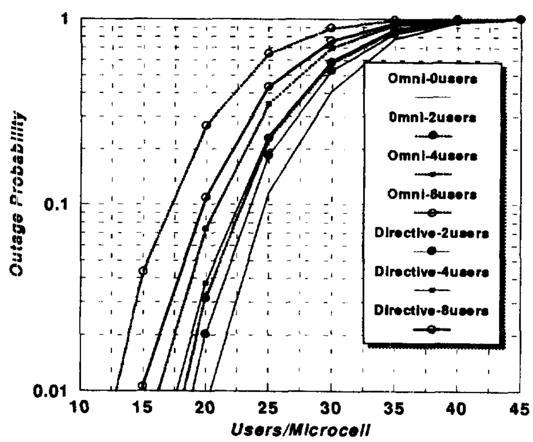

Figure 5: Omnidirectional versus directional antennas under different Umbrella cell loading conditions.

The effect of the use of a high gain antenna, as the adaptive antenna, at the umbrella cell base station, is clear from this figure. For 8 users in an umbrella cell which covers 25 microcells with 1km^2 area each, both for the same and for different frequencies with 1MHz bandwidth each, and for an outage probability of 1%, the results depicted in Table 1 for the spectrum efficiency can be calculated.

	Spectrum Efficiency (Users/MHz/km^2)			
	Umbrella cell	Microcell	Overall	Percentage Improvement over Omn/al at Diff. Freqs.
Omni - directional	0.32	13	13.32	24.95
Directional	0.32	15	15.32	43.7
Omni - directional at Different Frequencies	0.32	21	10.66	-

Table 1: Spectrum Efficiencies of different mixed cell systems

Also it should be mentioned that the spectral efficiency improvement with a directional BS antenna over the omnidirectional at the same frequency band is 15%.

5. DISCUSSION

Simulation and propagation measurements work presented in this paper have provided evidence that the adaptive antenna can mitigate the problems which emerge in a mixed cell structure and offer advantages such as better performance against the near-far effect, more efficient handover, ability to support high data rates and better coverage in problematic areas. Also was shown that the adaptive antennas offer greater spectral efficiency when compared with omnidirectional antennas in a mixed cell scenario at both different and the same frequency bands for the different cell types.

Work that will follow in the future will provide:

- Proof for the claimed capability of the adaptive antennas to support higher data rates and detailed consideration on how much the scattering effect affects this ability as well as how it can be combated.
- Detailed simulation for the adaptive antennas in a mixed cell scenario and for the near-far effect.
- Study of key issues associated with adaptive antenna techniques to mixed cell structures such as: Efficient algorithms, identification of the mobile users and implementation issues.

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