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A SPECTRUM EFFICIENT CELLULAR BASE-STATION ANTENNA ARCHITECTURE

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1. INTRODUCTION

The public demand for mobile telephony has so far exceeded capacity forecasts for the first generation of mobile cellular communications networks, and with the subscriber community set to expand rapidly over the next decade, the future generations of wireless networks will be beset with the problem of severe spectral congestion. In an attempt to provide a unified mobile access to a wide range of services, third generation systems are emerging with the CCITT Future Public Land Mobile Telecommunications System (FPLMTS) and the Universal Mobile Telecommunication System (UMTS) in Europe. Research activity primarily focuses on the modulation and access techniques and consequently this area has witnessed some of the most significant advances in the quest for spectrum efficiency and higher capacity. The base-station antenna has not experienced the same level of interest, although there has been some noteworthy research into the potential application of antenna arrays.

The utilisation of antenna arrays for space diversity combining is an established method for combatting the effects of multipath fading, although it can also be employed effectively to reduce the effects of co-channel interference [1,2]. This results in a reduction in the frequency reuse distances required for a given performance criterion, thus increasing the spectrum efficiency and capacity of the network. The main drawback is the large antenna spacings required to maintain the necessary high degree of decorrelation between antenna elements.

Adaptive antenna array technology has been employed extensively in military communications, radar, sonar and satellite communication systems. The application in civil, or cellular, communications has not been so widespread, although some potential schemes have been suggested. One of the most notable [3] proposed the use of an antenna array as an adaptive beamformer, or optimum combiner, which could steer radiation pattern nulls in such a way as to reduce the level of co-channel interference. An alternative approach has been proposed by Andersson *et al* [4] and employs a high resolution direction finding step to estimate the source angles of arrival, followed by a linear combination of the output of each antenna element to extract only the wanted signal components.

Instead of trying to cancel out the interferers, a conceptually simpler approach would be to steer a radiation pattern maxima, or beam, towards the wanted user or mobile. Figure 1 illustrates this principle and compares the optimum combining approach with the fixed beam solution described above. Telecom Australia [5] proposed a scheme along these lines, utilising multiple fixed beams to cover the cell. The process of switching calls from beam to beam is then achieved by constantly monitoring the signal levels at each of the beam ports. If, however, the base-station already knew the distribution of mobiles within its coverage area, it would then be in a

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position to form an optimum set of beams, confining the signal energy associated with a given mobile to an *addressed volume*. This concept can be further illustrated by considering the sequence of events in figure 2. The scenario depicted is realistic of many operational systems where there are lone mobiles, or groups of mobiles, dispersed throughout the cell. Using the *spatial distribution of the users acquired by the array on reception*, the antenna system can dynamically assign single narrow beams to illuminate the lone mobiles, and broad beams to the numerous groupings along the major highways. In this way, the level of co-channel interference is reduced, increasing the spectrum efficiency and ultimate capacity of the network.

The realisation of such an adaptive base-station antenna requires an architecture capable of locating and tracking the mobiles, and a beamforming network thus capable of producing the multiple independent beams. These two tasks are illustrated in figure 3 as a source estimation or direction finding (DF) processor and a beamformer.

2. POTENTIAL CAPACITY ENHANCEMENT

A preliminary study was carried out to establish a figure of merit for the proposed antenna system in terms of the increase in spectrum efficiency that could be achieved relative to conventional antenna systems [6,7]. A theoretical approach was adopted which modelled the conventional and proposed antenna systems in a typical mobile radio environment, enabling the spectrum efficiencies to be calculated for a given level of performance. The results of this work are summarised in figure 4. The graph gives the increase in spectrum efficiency that could be achieved by an idealised multiple beam base-station antenna with respect to an omni-directional antenna. The results are for the base-to-mobile link in a fading and shadowing environment with only the first tier of six interfering co-channel cells considered. Two values of protection ratio (P_R) are used to cover a range of modulation schemes, and a 70% traffic loading is employed with the outage probability (the likelihood that co-channel interference will occur) set at 1%. Also shown in figure 4 are the relative spectrum efficiencies for 120° and 60° fixed sector directional antennas when compared to an omni-directional antenna. The results were calculated using the same model, and assumed that the number of interferers in the first tier is two and one for the 120° and 60° sectors respectively.

3. DISCUSSION

Having established that there are significant gains to be made, the next stage was to consider the practical realisation of the antenna system. This requires the implementation of two fundamental tasks: the estimation of the source locations within the cell, and the formation of a number of multiple independent beams based on this information. The majority of the research effort has concentrated on the source estimation process, and a number of signal processing techniques which can be employed to determine the azimuth bearings of narrowband signal sources with an antenna array were considered. Further details of this work can be found in [8]. A further publication [9] considers in more detail how the proposed antenna system could be incorporated into an existing cellular network, and further addresses some of the initial implementation issues, e.g. the modulation/access format and the beamformer.

This programme of research has demonstrated the feasibility of a multiple beam base-station antenna system for future high capacity cellular networks, although there is still much to be accomplished before it could be incorporated into an existing network. In contrast to current methods of meeting growing public demand for service (e.g. cell splitting), the proposed system could adapt gracefully with the provision of additional beams at each base-station site. This would dramatically reduce the infrastructure costs associated with the acquisition of new base-station sites, as well as ensuring that the trunking efficiency of the network is not impaired.

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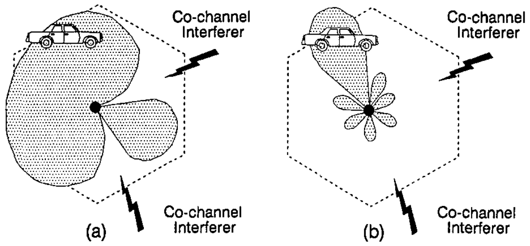

Figure 1: Rejection of co-channel interference with:
(a) optimum combining; (b) single independent beam.

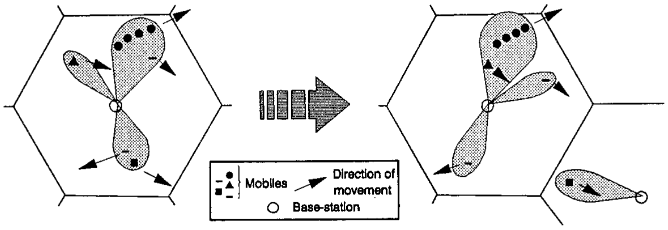

Figure 2: Multiple beam assignment within a cell.

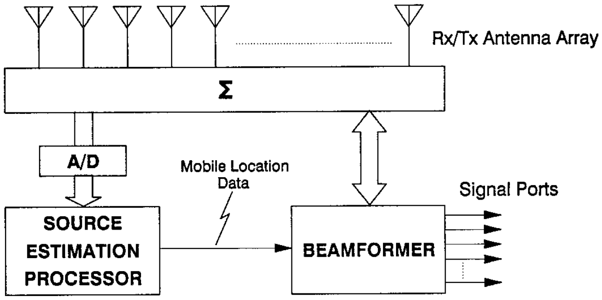

Figure 3: The base-station antenna concept.

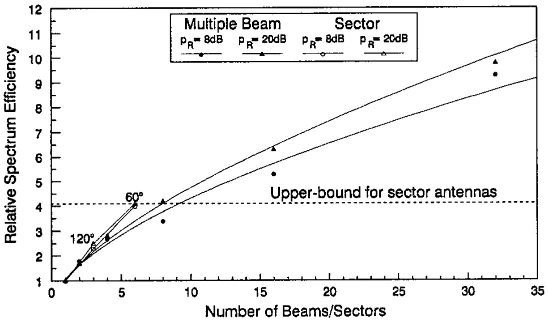

Figure 4: Relative spectral efficiency as a function of the number of beams/sectors formed.