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Adaptive networks for UMTS – An investigation of bunched basestations

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Abstract - **This paper looks at a new method of handling the expected traffic fluctuation in micro and pico cellular environment. The bunch concept, which is introduced in the UMTS proposal, is investigated under various traffic conditions. Its performance in traffic hot-spots is compared to that of a conventional microcellular network. The results show that the outage probability is dramatically reduced with the use of distributed antennas. Capacity analysis of a basestation with distributed antennas is also found to be up to 4 times higher with 8 extra antennas than for a single basestation under the same conditions.**

I Introduction

The last few years have seen a tremendous growth in the mobile communication industry. Reduced subscriber rates, improved handset technology and better service provision from the cellular operators are perhaps the main reason for this growth. The increased number of subscribers has forced the cellular operators to deploy microcellular networks in the city centres to meet the demand. The physical size of the basestation makes it difficult to position it at the optimum location. In addition, the rapid fluctuations in the capacity demand due to high bit rate services, makes the capacity planning very difficult.

In light of this situation, a novel Bunch concept consisting of a central unit and remote antenna units has been proposed for UMTS [1]. This paper sets out to investigate how effective this new concept is to handle unevenly distributed traffic. In addition, a capacity analysis is undertaken to see how much additional capacity the distributed antenna system can potentially provide.

Section 1 discusses the technical aspects of the Bunch concept. The air interface access techniques and radio resource management techniques, which will be employed in UMTS, is covered in Section 2. Section 3 discusses the network simulation and the analysis which will be undertaken. Finally in Section 4, the results are discussed and a number of conclusions are drawn.

II The UMTS bunch concept

In the SMG2 concept group Gamma #2 document on radio resource management one of the main challenges are stated as follows:

"In the pico and microcell environments the major challenge is to meet the very fast changes of the required transmission capacity on the radio interface due to high bit rate services"

There are two possible distinct network topologies that can be employed, namely distributed or centralised architecture. Distributed architecture has the advantage that decisions can be made locally and therefore will require less signalling and decrease the delays due to decision making. On the other hand, it provides less control over the overall network performance and the performance may be sub-optimal. Centralised solutions can maximise the resource utilisation and provides a great deal more flexibility but at the cost of increased signalling overhead and more complex radio resource management algorithms. In a micro and picocellular environment there will be severe fluctuations in traffic demand, user mobility and traffic types. This highly complex environment will require advanced Radio Resource Management (RRM) algorithms and it will be beneficial to have a central intelligent unit, which can maximise the resource utilisation. The *bunch concept* has been proposed as a mean to deal with the issue. It involves a central unit which controls a set of remote antennas or basestations with very little intelligence. All decisions on channel allocation, service request and handovers will be dealt with by the Central Units (CU). Algorithms for layer 2 and 1 may be controlled by the remote unit itself (such as power control). The bunch concept can be viewed as simply a very advanced basestation with a number of antennas for remote sensing. The central unit will therefore have complete control over all the traffic in its coverage area and will be able to maximise the resource utilisation for the current traffic. This provides opportunities for uplink diversity and avoids intercell handovers in its coverage area. The bunch will typically be deployed in city centres, buildings or even just a building floor. All Remote Antenna Units (RAU) within a bunch will be frame and timeslot synchronised (for WB-TDMA/CDMA). The bunch concept is well suited for hot-spot applications and can be deployed as the lowest unit in a hierarchical cell structure (HCS). It is assumed that the RAUs within a bunch is synchronised so that in the TDMA case, the CU is able to allocate connections on a timeslot basis regardless of which RAU is employed. Figure 1 visualises a UMTS scenario with a mixed cell structure where the bunch concept is used both in a hotspot application as well as in a building.

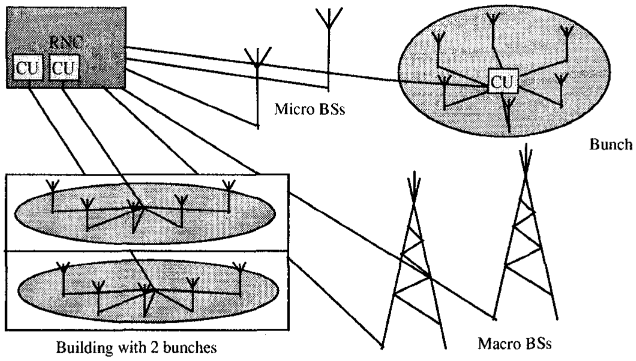

Figure 1 UMTS scenario with mixed cell structure

For hotspot configuration the central unit may be located in the area the RAU is covering. In the case of covering buildings, the CU could potentially be located on the site where the Radio Network Controller (RNC) is situated due to the possibility of accessing already existing high-speed network.

II.I Link budget analysis

To implement a bunched network, some initial analysis should be undertaken to ensure that a practical solution is possible. If one start with a simple link-budget analysis, then one should consider the effects of potentially introducing hundreds of meters of cable between the antenna and the central unit. It becomes immediately clear that a low noise amplifier would be required at the front end to reduce the over all noise factor of the receiver chain. With a LNA with noise figure of 2 dB and gain of 20 dB, one can accept relatively poor quality cable between the RAU and CU without significant loss of signal to carrier ratio. Especially when considering that a poor cable operating at 2 GHz with a bandwidth of 5 MHz only gives a loss of 24 dB per 100 meters. Free space propagation will on the other hand attenuate the signal with 78 dB over the same distance.

From [1] the thermal noise at the input of the receiver is –174 dBm/Hz and the receiver noise figure is 5 dB. This gives a total noise power of –102.8 dBm in a 4.096 MHz bandwidth. In a CDMA system, it is recommended that all users are received at the thermal noise power level if possible [2]. The total noise power in the receiver will then be dominated by the LNA. Using the numbers mentioned so far will then give a total noise power of –106 dBm. Hence, the noise contribution from the cables between the antennas and the CU can safely be ignored.

III Access techniques

The recent decision by ETSI on the UMTS air interface technique means that network solutions to support it must be developed. In the announcement ETSI decided on Wideband CDMA should be used for macro and microcells, and TDMA with spreading for picocells [3].

III.I Wideband TDMA / CDMA

One of ETSI's requirements for picocells was that its deployment and operation should be unlicensed. Hence any operator could choose to deploy picocells anywhere without any co-ordination with other operators. This would cause major problems for a pure CDMA air interface technique due to the complexity involved on the power control side. Adding TDMA gives the system greater dimensionality and reduces the overall interference level experienced by any single user. The system will be able to support the mobile stations with very high bit rate services at low speeds.

III.I.I Resource Allocation

Figure 2 portrays the layer structure, the protocols and algorithms of the FRAMES radio interface [5]. The algorithms are represented in the grey boxes. From the network organisation perspective, these algorithms hold the key to the overall performance.

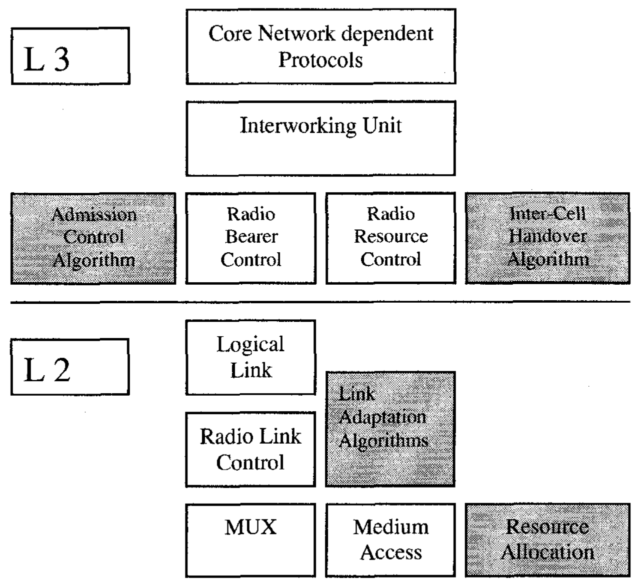

Figure 2 FRAMES Radio interface

III.I.II Radio resource management for UMTS

The RRM algorithms can be classified into Admission Control, Handover Initiation, Link Adaptation, Resource Allocation and Power control. Only the algorithms that are of relevance for the work undertaken here is covered in any further detail.

Admission control (AC) decides whether a user or the service it is requesting should be admitted to the network. The admission control handles events occurring during call set-up, handover initiation or call modification (new type of service). *Congestion control* (CC) might be required in order to stabilise the system by actively seeking to minimise the interference level.

Channel assignment (CA), also referred to as channel allocation, decides how the radio resources should be shared between the users and bearer services currently active in the system. It is also required to provide a great deal of flexibility to enable the network to adapt to changes in the radio environment and traffic fluctuations. This involves aspects of hierarchical cell structures and relayed issues of frequency planning

Power Control (PC) is used to minimise the transmit power required by the MS and BS and hence reducing the co-channel interference in the system while maintaining the quality of the link.

These different algorithms are closely related and the behaviour of one will effect all the others. It is therefore important to arrive at a concept where the algorithms are compatible rather then optimising any single one of them. In FRAMES, 4 algorithm areas are defined and are together named a radio resource management concept [4].

The analysis that follows in the next section builds on the algorithms that have been discussed here. The access technique used is however Wideband CDMA and not TDMA / CDMA.

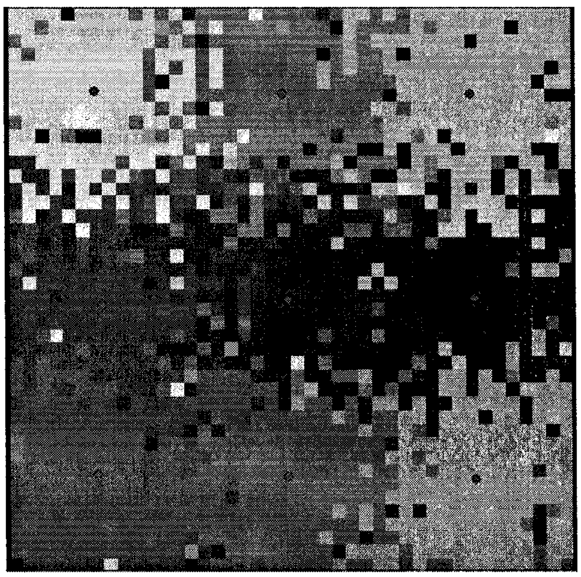

Figure 3 Basestation coverage area

IV The Network Simulation

The network is set-up in a micro cellular environment with a varying number of basestations. Figure 3 shows the network deployed with 9 nodes and illustrates typically what each basestation's coverage area would be. The specification for the system is set up according to the UMTS link budget templates [5]. The mobile stations (MS) are dropped into the network and will then try to connect to the *nearest* basestation in terms of pathloss and shadowing. The MS can then either be accepted into the network or blocked. Blockage occurs in two instances, due to lack of available transceivers in the basestation (hardware limited), or due to unacceptable interference.

A MS can also be dropped after it has been accepted if the network by accepting a new call causes the MS to experience Eb/No below the minimum required. All other relevant parameters are listed in Table 1

Parameter	Specification
Network size	1 – 9 nodes (basestations)
Codes	24 per BS[1] / unlimited
Path Loss Coefficient	$2 \leq 100m$ [6] $3.5 > 100m$
Network area	$420 \times 420\ m^2$
Shadowing St Dev.	8 dB
Voice Activity Factor	0.5
Chipping Rate	4.096 Mcps
User Bit Rate	8 kbps
Eb/No for Up Link	3.1 dB
UL Power Control range	80 dB
UL PC error St Dev.	1 dB

Table 1 Simulation Parameters UMTS [5]

IV.I Network performance in traffic hot-spots

In this first scenario the performance of a bunch with 8 remote nodes and a central unit is compared to a similar microcellular network with 9 basestations. The network area is divided into 9 squares and the traffic distribution is decided by assigning an attractivity factor to the different regions. In this particular case only the middle region is assigned a higher attractivity factor than the other regions. The surrounding regions have an attractivity of:

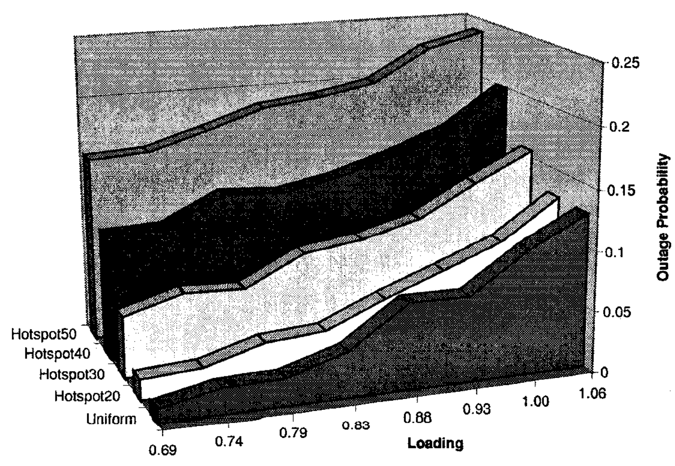

Figure 4 Conventional microcellular network with traffic hot spots

[1] The number of codes is limited to 24 as this is a normal value for the number of transceivers in a GSM basestation

$$r_k = \frac{1 - r_h}{n - 1} \in (k = 1,2..n \mid k \neq n) \qquad \textbf{Equation 1}$$

Where r_h is the probability of a user appearing in the hot spot region, r_n is the probability of a user appearing in any of the surrounding regions and n is the total number of regions.

Figure 3 shows the network with nine basestations. The network performance was monitored for varying loading levels with the probability of a user appearing in the hot spot varying from 0.1 to 0.5. The hot spot is currently in the middle of the network. Each basestation has a limited number of codes and the loading level is determined by dividing the total number of users that try to enter the network by the total number of codes, in this case 216. The blocking probability was monitored and is shown in Figure 4.

The results clearly show that even at moderate loading levels, the blocking probability quickly becomes unacceptable. When half the overall traffic is carried in the hot-spot cell, the outage

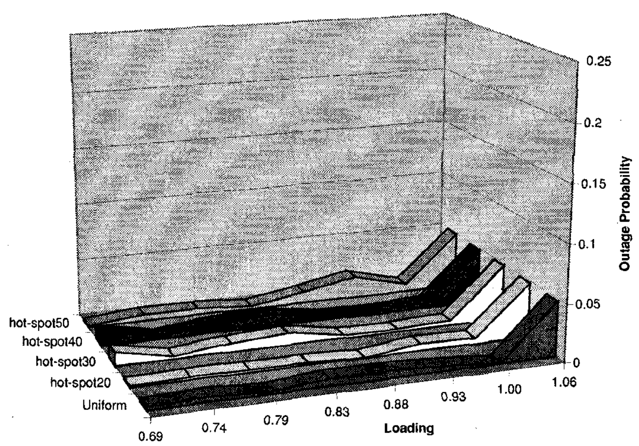

Figure 5 Bunch network with traffic hot spots

probability is at its best 0.2. This poor performance is not surprising considering that all the basestations have a limited number of codes. This is in fact the scenario the cellular operator experiences today when large concentrations of users appear in parts of the network which has inadequate capacity. From the cellular operator's point of view, this means loss of revenue, but the few occasions this occur may not justify the addition of more transceivers in the basestation in question.

In the next run the microcellular network is substituted with a bunch consisting of one central unit and eight remote antennas with the same capacity, 216 codes, which can be freely allocated to any of the remote antenna units. Effectively all users will be connected to the Central Unit, but through one of the branches, i.e. a RAU. One would expect that this should solve the problem since all the capacity is available everywhere in the network. As can be seen from Figure 5, this is also the case. Traffic hot spots have no significant effect on the performance of the network. Only when the loading level exceeds the number of available codes does the outage probability increase above 0.02. Whilst the bunch network has no more capacity in terms of hardware then the microcellular network, its flexibility reduces the blocking probability from 12% to 1% for uniform traffic which is lower than the UMTS requirements for blocking. For traffic hot spots with $r_h = 0.5$, the blocking probability is reduced even more, from 28% to 1%. This is a significant improvement which will allow the cellular operator to meet local traffic demands by diverting capacity from elsewhere in the network.

IV.II Capacity with distributed antennas

Another way of viewing the bunch concept is to consider it as a basestation with distributed antennas. Distributed antennas reduce the pathloss between the mobile and the basestation and hence the required transmit power [7]. Reduced transmit power means also that the overall interference will be reduced and hence a capacity improvement is achieved.

In the simulation a single microcell was compared with bunches with varying number of distributed antennas. It is assumed that there is an infinite number of codes and that the system is interference limited rather than hardware limited as was the case in the previous two simulations. Note that no external interference is considered and that the simulation parameters are listed in Table 1.

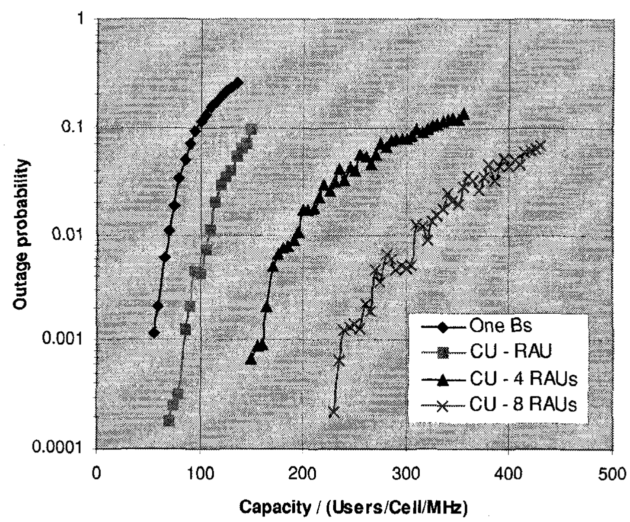

Figure 6 Capacity with distributed antennas

Figure 6 shows the capacity for a single basestation and for a basestation with 1, 4 and 8 distributed antennas. In the first case the basestation can support approximately 78 users per MHz for an outage probability of 0.02. The introduction of another antenna increases the capacity to 110 users/MHz. Remembering that inter cell interference is not included, the introduction of another antenna effectively introduces this effect and accounts for the only moderate capacity increase observed. With four extra antennas, the effect of introducing intercell interference is significantly suppressed by the gain of reducing the overall transmit power. The capacity is more than doubled and the basestation can now support 200 users. By adding another 4 antennas the capacity is almost doubled again to 350 users/MHz for the same outage probability.

The addition of distributed antennas also reduces the rapid degradation of the performance if more users are added, effectively providing soft capacity if a higher outage probability is acceptable.

Clearly, in a more realistic scenario, basestations will experience intercell interference from the surrounding basestations. For the first result regarding a single basestation, the interference contribution from other cells will significantly reduce the capacity. However, the situation different for the basestation with 8 distributed antennas. From the viewpoint of one of the antennas, all the mobiles connected to the other antennas can be considered as intercell interference. The addition of other cells around it will therefore not have such a significant effect on the capacity.

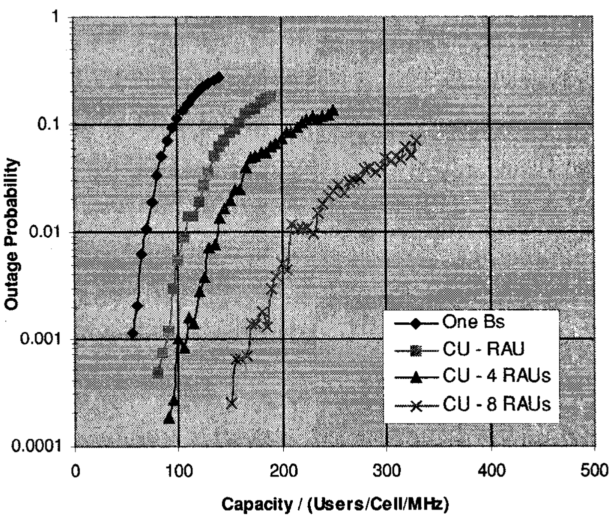

Figure 7 Capacity with distributed antennas with traffic hot spots

A further simulation was done under the same conditions except the traffic now had an uneven distribution with 40% of the traffic being carried in the centre of the network. The results are shown in Figure 7. From the figure one can observe that the capacity gain is significantly reduced for two, four and nine basestations. As one would expect, the one cell scenario remains unchanged. The reason for this capacity loss is that for the case with five and nine nodes, one node is positioned right in the middle of the traffic hotspot. This causes the centre cell to be saturated quickly which causes the outage probability to increase. The capacity improvement is however still significant compared with the single basestation scenario. To achieve maximum capacity improvement it is therefore essential that more than one RAU serves the hotspot area to avoid saturating any one RAU.

V Conclusions

The performance of the proposed UMTS bunch concept has been evaluated on its ability to support traffic in hotspot areas and provide additional capacity in a micro and picocellular environment. Simulations were undertaken for various conditions to clarify its behaviour.

The results presented in this paper clearly demonstrate the suitability of the bunch to deal with unevenly distributed traffic. The bunch's central unit containing the radio transceivers is what provides the flexibility in the system. In a rapidly changing traffic scenario it is essential to be able to divert capacity to where it is needed. As the results show, this will reduce to outage probability from over 20% to 1% in the worst case.

The use of distributed antennas in the bunch concept also increases the capacity dramatically. With 8 extra antennas covering the same area as one basestation, the capacity can be increased by as much as 400%. Best performance is achieved if the hot spot is served by more than one RAU.

Although intercell interference is not considered, the results give a good indication of how much performance capacity improvement that can be expected. With the addition of uplink diversity and interference cancellation techniques, an even greater capacity gains are possible.

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