Sharma, S., Spilling, AG., & Nix, AR. (2001). Adaptive coverage for UMTS macrocells based on situation awareness. In *IEEE Vehicular Technology Conference (VTC Spring-2001), Rhodes, Greece* (Vol. 4, pp. 2786 - 2790). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/VETECS.2001.944108

Adaptive Coverage for UMTS Macrocells Based on Situation Awareness

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Abstract-*The following paper examines the capability of extending basestation sector beams in order to assume coverage in a partially or fully failed neighbouring cell. Increasing the transmit power of the sector to reach out for new users is not possible in UMTS since it increases interference in the system. This paper considers how adaptive coverage can be implemented in practice. Analysis suggests that performance is downlink limited. A balanced link power algorithm is required to provide the extra power for increasing the range capability of the sector Furthermore, it is found that up to 25% of users (premium rate customers) in a failed heavily loaded cell can be supported by sector extension. This figure approaches 100% for a lightly loaded cell, or the more practical case of sector failure. In all cases, SA significantly enhances the number of users that can be supported anywhere in the failed cell.*

1. Introduction

The complexity involved in the deployment of a third generation UMTS network has been highlighted in a number of recent papers [1][2][[3]. Network dimensioning is made difficult since the system performance is dependent on traffic distribution. Alternative methods to traditional fixed planning, such as 'Self-organisation', have been proposed as a means to organise future wireless networks and to make them more flexible and adaptive [4]. Future networks require the deployment of many thousands of basestations in microcellular and picocellular scenarios. Fixed planning is made difficult due to inaccuracies in the propagation modelling process. Either propagation models must be significantly improved or more dynamic networks will have to be deployed.

This paper is part of an ongoing study to implement Situation Awareness (SA) functionality in cellular networks. Ultimately the work aims to determine the extent to which 'self organising' networks can be deployed [5]. This involves making basestations more aware of their environment, in order that they can react to time varying imbalances such as variations in the propagation environment or traffic load within the network. In addition, self organisation can help overcome changes in topography, for example seasonal variations or the construction/demolition of building structures.

The provision of continuous coverage is important for any operator, especially in areas of high traffic concentration. Basestation or sector failure in these areas translates to substantial loss in revenue and a poor perceived QoS. The motivation of the work is to devise a network that could respond dynamically to these outages.

In CDMA systems, coverage is mostly affected by the tendency of cells to change in size or 'breathe' [6]. As the number of users entering the cell increases, ambient RF noise and link loss increases, causing the signal quality to degrade. The overall effect results in a reduction of the cell radius as the number of subscribers increases. CDMA specifications include a 3dB margin for cell breathing. However, this implies that the number of cells must be increased in order to meet the capacity and coverage requirements. This costly constraint could be avoided by the use of an adaptive coverage system.

Adaptive coverage can also simplify the process of addition or removal of basestations in the network. The normal implication in such a case is that an extensive replanning exercise is required and this will be both time consuming and costly. A network that can adapt its coverage area according to the scenario described above would have numerous advantages. This paper proposes to evaluate the parameters required to implement such functionality by studying the specific scenario of basestation or sector failure. A simulator has been devised to model a hexagonal UMTS network. The basestations are arranged on a regular grid and a COST 231 symmetrical propagation model is assumed for both uplink and downlink. A 6-sector configuration (narrow beamwidth) was chosen for each basestation so that the overlap area during beam extensions is minimal, thereby preventing any reduction in capacity due to increased interference. The paper is divided into three sections. The first section covers the basestation failure scenario and the power control algorithms used. The second section describes the results obtained from the simulation

0-7803-6728-6/01/$10.00 ©2001 IEEE.

scenario. Finally, the paper includes a set of conclusions and observations based on the simulation studies performed to date.

2. Simulator and scenario description

Spilling and Nix [5] proposed the inclusion of additional information (BS identification, position in latitude and longitude, broadcast control channel transmit power) on the broadcast control channel to ease the implementation of dynamic coverage. Additional parameters are required to implement adaptive coverage and these include communicating: (i) Loading conditions of basestations to neighbouring cells and (ii) Location of nearest neighbours to each basestation.

In a situation-aware cellular network, details of the propagation environment would be obtained from User Equipment (UE) located within the coverage area of each basestation. This allows the network to establish the relative path loss between basestations so that each individual basestation can increase or decrease its transmit power in order to achieve the required coverage. However, for the purposes of our simulation, the propagation samples around the basestations are modelled indirectly.

Basestations can be placed and then activated or failed on the grid of the simulator. Mobile users can also be deployed uniformly over the simulation area thereby making it possible to estimate individual path losses and relative distances.

2.1 Basestation failure scenario

In the following scenario a basestation is deactivated to simulate failure and the proposed adaptive coverage algorithm is applied in an attempt to heal the resulting outage. The network detects the location of the site and the coverage gap. The algorithm then determines, as per the loading conditions, two sectors belonging to basestations in the first tier which could be extended to cover users in the failed cell. The concept is shown in Figure 1.

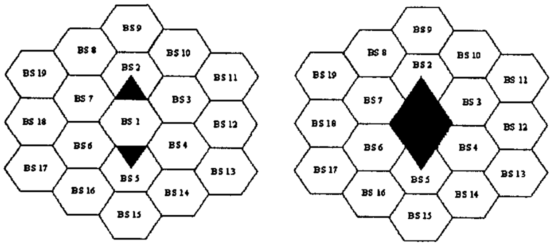

Figure 1: Sectors from BS2 and BS5 close the gap left by the failure of BS1

2.2 Assumptions

The following assumptions are made in the modelling and simulation process.

- Perfect power control assumed (finite range)
- Voice activity factor not taken into account
- No limitations on available codes for downlink

2.3 Simulation Specification

In order to demonstrate the capabilities and benefits of range extension in the context of situation-aware adaptive coverage, a set of simulations were performed using the parameters listed in Table 1.

Parameter	Value
Cell Layout	Hexagonal
Propagation model	Cost 231
Bandwidth	5 MHz
Channel rate	15kbps
Basestation antenna gain	13dBi
Mobile station antenna gain	0dBi
Shadowing standard deviation	8dB
Basestation max. transmit power	43dBm
Downlink dynamic range	30dB
Mobile station max. transmit power	24dBm
Uplink dynamic range	80dB
Power control step size (both links)	0.5dB
Target Eb/No on downlink	6.1dBm
Target Eb/No on uplink	3.3dBm
Pilot signal power	20%

Table 1: UMTS simulation parameters

3. Beam extension

The interference characteristics of both uplink and downlink differ for a spatially uniform traffic distribution condition. In addition, both links have different constraints to range extension and must therefore be modelled separately.

3.1 Downlink power control

In the downlink, factors such as the loading condition, the maximum transmit power of the power amplifier at the basestation and the user bit rate determine the maximum range. Of these three parameters, it is easier to control the power amplifier for the purposes of beam extension. The total power available in a cell is limited by the linearity of its power amplifier. An algorithm that maintains sufficient transmission quality for each downlink channel while providing extra power for beam extension is highly desirable. A downlink power algorithm that balances link quality is implemented by solving equation (1) (maximising the minimum transmission quality for users of cell k) [7].

$$\gamma_k = \underset{P_{ik}}{\max}\ \underset{i \in I_k}{\min} \left\{ \frac{G_{ik} P_{ik} / R}{\left(\sum_{j=1}^{N} G_{ij} P_j + \eta_i\right) / W}, i \in I_k \right\} \quad (1)$$

Where γ_k represents the transmission quality for cell k and I_k are the set of mobiles served by cell k. G_{ik} denotes the link gain on the path between the *ith* mobile and the *kth* cell site and W is the bandwidth. R is the channel rate, P_j denotes the transmit power of basestation j. Finally, p_{ik} is the amount of power dedicated to the traffic signal of mobile i in cell k.

The algorithm consists of two parts: (i) allocating and (ii) adjusting. The basestation will allocate power, on a first pass, to mobiles in its service area. It will then determine the link qualities and reallocate power evenly so that all links enjoy the same quality. The transmission power of several basestations is adaptively controlled.

3.2 Downlink beam extension

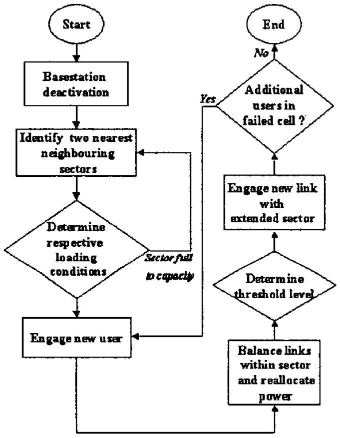

Figure 2: Downlink beam extension algorithm

The operation of downlink beam extension is illustrated in Figure 2. Two sectors are extended from the neighbouring cells in order to reach half way across the failed cell. Each new user is allocated sufficient power in order to establish a link. All links within the sector are balanced. In the event that the transmission quality falls below a minimum threshold, the transmit power of the sector is increased in steps of 0.5dB. The power amplifier will track the balanced link quality of the sector as shown in Figure 3. Initially, the basestation is transmitting at maximum power. However, as new users are admitted in the sector, the link quality is evaluated. If it is superior to the threshold, the power is decreased proportionately. As the sector reaches its capacity limit, the link quality goes below the threshold and the power has to be increased once again.

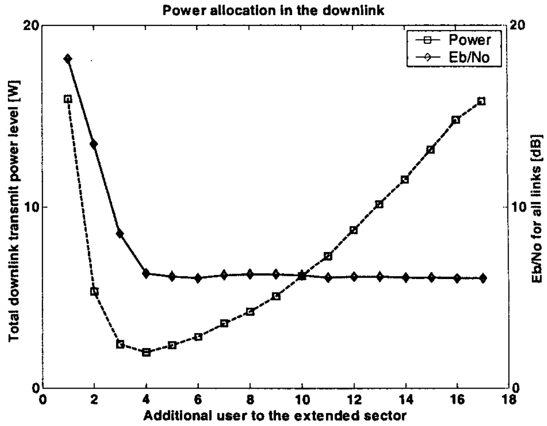

Figure 3: Downlink power control

The beam may be extended fully to the centre of the failed cell (d = 4.14km) depending on its loading conditions.

3.3 Uplink range extension

The range in the uplink is principally constrained by the transmit power of the mobile station. A perfectly balanced link power algorithm is not possible because of the asynchronous nature of the link. Each mobile station is made to transmit at a minimum power level so that each link achieves an Eb/No value above the threshold (γ_i). The power control problem is then to find the minimum values for P_l such that: $\Gamma_i \geq \gamma_i$, where Γ_i (set of Eb/No values for all links) is defined as:

$$\Gamma_i = \left\{ \frac{G_{ik} P_{ik} / R}{\left(\sum_{l \neq i} G_{lk} P_l + \eta_i\right) / W}, i = 1,2,\ldots,N \right\} \quad (2)$$

Where, P_l is the transmit power of user l, N is the number of users in the sector and the other variables are as defined in (1). The uplink algorithm is described in Figure 4. As the beam is extended, new users are engaged. The link qualities are then evaluated and the respective mobile transmit powers suitably adjusted. Balancing all links simultaneously is not possible, hence the objective of the algorithm is to minimise the uplink transmit power. New users are admitted in the sector as long as they can be supported. Figure 5 shows a snapshot of the respective transmit power and link quality as perceived by each user in the sector, for a particular deployment scenario.

It can be observed that while the transmit power varies considerably for each user, depending on their relative position in the sector, individual link qualities vary considerably less. The algorithm converges when all links are supported.

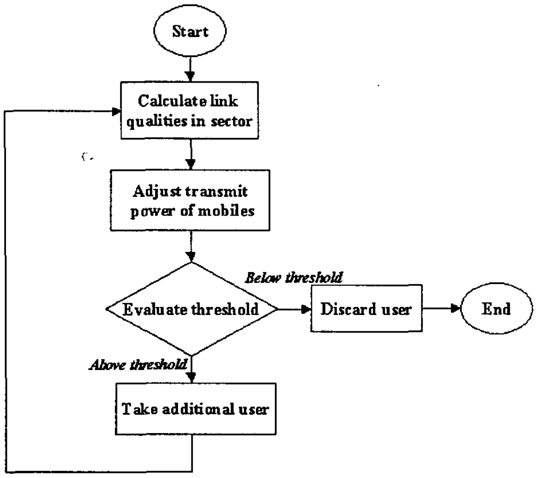

Figure 4: Uplink range extension algorithm

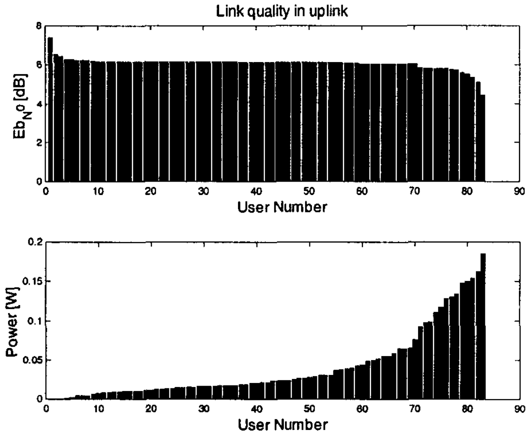

Figure 5: Uplink power control with new users

3.4 Cell Failure without situation awareness

In the following scenario, the same user deployment is applied as before, however situation-awareness is not supported in the failure process. The purpose is to form a bench mark comparison for the adaptive coverage algorithm. No neighbouring sector is extended and users re-establish their links by connecting to the next best server available. The downlink power control algorithm used in this case allocates power depending on the mobile station's Eb/No requirement. Power allocation for each mobile is calculated using equation (3) [8]. Comparative results are presented in the next section.

$$\phi_{ij} = \frac{\left(E_b/N_o\right)\sum_{j=1}^{M} P_j}{\left(\left(E_b/N_o\right)_i + \frac{W}{R}\right)\beta P_j} \qquad (3)$$

Where β is the ratio of power assigned to a mobile user as a fraction of the total basestation power and M is the number of basestations.

4. Simulation Results

4.1 Criterion of evaluation

In the simulation, the performance of one of the extended sectors used to serve users in the failed cell is evaluated. Since the algorithms are centralised, whereas in practice they should be decentralised, the requirement on computational power is excessive to perform Monte-Carlo type simulations. Consequently, users were deployed in a manner so as to meet the loading criteria of each sector. The number of successful active links connected to the extended sector forms the evaluation criterion for the algorithm.

4.2 Performance of downlink algorithm

The range[1] values for the downlink decrease with increasing load. Interestingly, the results obtained for range (R) and load (X) do not follow an $R=A/X^n$ relationship (where A is the amplitude and n is the steepness exponent) as expected from [9]. Rather, the maximum range, as seen from Table 2, decreases at a much slower rate.

Loading factor (X)	Users in failed cell	Supported users in failed cell	% of supported users	Range achieved [km]
0.1	12	12	100	4.02
0.2	24	14	58	3.51
0.3	38	16	2	3.32
0.4	48	21	44	3.17
0.5	60	19	32	3.24
0.6	72	22	31	3.02
0.7	79	23	29	3.03
0.8	88	20	23	2.77

Table 2: Simulation results for downlink

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[1] The range values quoted are also a function of user distribution within the failed cell

The range-load relationship is explained by the fact that the transmit powers of the basestations are adaptively controlled by employing a balanced link algorithm. As such the intercell interference perceived by the extended sector is considerably less than in normal conditions. The failure of the central basestation reduces this interference further.

4.3 Performance of uplink algorithm

The results in Table 3 suggest that the uplink is not the limiting factor to range extension since all users are accommodated for various loading conditions. The results could differ significantly for high rate services where mobile transmission power would be a limiting factor.

Loading factor (X)	No of users in failed cell	Users supported in failed cell	Range achieved [km]
0.1	12	12	4.02
0.2	23	23	3.51
0.3	37	37	3.32
0.4	48	48	3.17
0.5	60	60	3.24
0.6	73	73	3.02
0.7	81	81	3.03
0.8	87	87	2.77

Table 3: Simulation results for the uplink

4.4 Performance without situation awareness

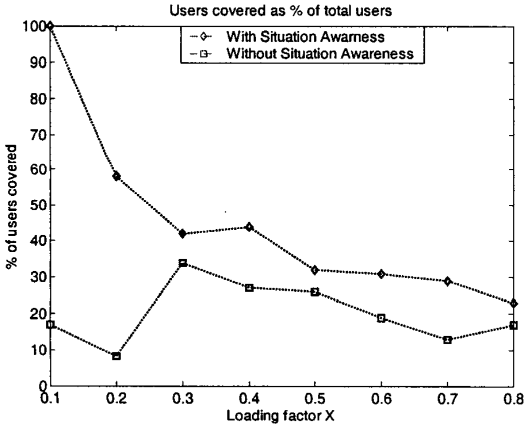

Figure 6: Comparative benefit using SA

Simulation results demonstrate that there are only a few users that can connect from the failed cell to neighbouring sectors without 'Situation Awareness'. Figure 6 suggests that there are clear benefits in utilising an adaptive coverage based on SA. It can be seen that up to 25% of users in a failed heavily loaded (X=0.8) cell can be supported by sector extension. This figure approaches 100% of users for a lightly loaded (X=0.1) cell, or the more practical and less severe case of sector failure. In all cases, SA significantly enhances the number of users that can be supported *anywhere* in the failed cell.

5. Conclusions

This paper has introduced an investigation into the use of adaptive coverage in the context of situation awareness. The parameters required for implementation in a UMTS network have been identified. A specific scenario of a failed cell (or sector) was chosen. The ramification of extending a 60° beam over half the area of the failed cell was thus accordingly studied. The downlink proved to be the limiting factor where range extension capability reached its limit for moderate and heavy loading conditions if all users are to be supported.

The techniques described in this paper demonstrate how the service quality of premium rate UMTS subscribers could be ensured, even in the event of basestation failure or time varying topography or propagation effects.

Acknowledgements

This work was undertaken as part of the BT Virtual University Research Initiative (VURI) on mobility. The authors gratefully acknowledge the support of BT Labs, Martlesham and the other member universities: University of Birmingham and Oxford University.

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