Proactive Dynamic Resource Distribution Based on Borrowing and Control Engineering Methods for GSM-like Systems

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ABSTRACT

This paper presents some work that has been performed on a dynamic resource allocation or, more precisely, resource distribution algorithm for radio networks. The goal is to establish a proactive network management system that predicts fault situations and enhances network performance parameters automatically in advance and predictively. Three decentralised algorithms have been investigated. The first and second ones are threshold based schemes based on a cost function with and without prediction, respectively. The third method is based on a control engineering algorithm.

1. INTRODUCTION

The main focus of our investigation is to find means for the proactive resource allocation in radio networks. Proactive here means that the scheme evaluates all available information, e.g. trends of degradations of QoS or network performance parameters, and makes a forecast into the future in order to determine its behaviour. This principle is in contrast to reactive methods.

The resources that are subject to our research work are frequency borrowing methods with varying control mechanisms, [15]. The results presented here are a first step and are based on fully decentralised mechanisms. In a next step, we will consider resource allocation methods which are centrally controlled for a certain geographic area.

Our results have been obtained with our completely SDL based mobile network simulation tool (MoSIT) that was developed for system level performance simulations of second and third generation mobile radio systems, [14], [13]. The simulations are partly based on traffic measurements of a German GSM network provider.

It seems to us quite promising to optimise the resource allocation by exploiting knowledge available in the network. Each base station has a quite regular traffic profile. One task should be to extract regularities in this regular traffic pattern by learning. Of course irregularities should also be detected and the network should react to them.

One of the criteria was stability of the used resource allocation methods. Borrowing a frequency in one cell should not lead to periodic processes in the radio network.

In this paper, we present initial results of our investigations. It is organised as follows: The second clause describes the simulation environment. The subject of the third clause is the network management architecture, followed by the description of the three applied resource distribution algorithms in the fourth clause. First simulation results are given in clause six. The paper concludes with a summary and an outlook.

2. SIMULATION ENVIRONMENT

The structure of the simulation tool is depicted in figure [**1**]. It is designed such that it allows us to reproduce the test environment (or the virtual network) for the comparison of different resource allocation algorithms. To examine the impact of channel allocation algorithms on the network load, it is required to model changing network conditions including moving mobiles and traffic generators.

When evaluating new protocols, the user data source coding can be skipped in most cases. The bit error probability or carrier-to-interference ratio (CIR) values and blocking rates are a sufficient measure of the link quality to compare different algorithms which enables the use of a simplified simulation model of the physical layer.

The simulation model is initialised by parameter files for an arbitrary but defined number of base stations with individually adjustable parameters. Mobile stations are placed randomly or deterministically by pattern files. Each mobile station changes its direction and speed randomly within an adjustable range or is controlled by movement pattern files. The complete parameter set for a simulation is kept in a central data base.

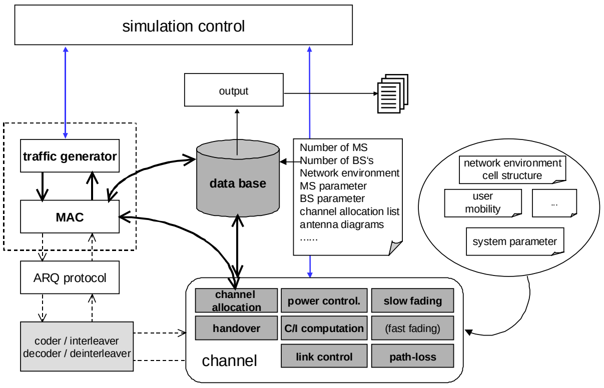

Figure 1: Tool structure of MOSIT

The activity of the mobiles is controlled by a traffic generator. This traffic generator contains models for voice, video (constant bit rate model) and data services (variable bitrate) e.g. http, ftp and e-mail. For voice services, an on/off model for the activity is used. The subscriber activity is assumed to be uncorrelated. The traffic generator delivers ATM AAL-frames which are divided into ATM cells before passing them to the Medium Access Control (MAC). The simulator contains MAC algorithms for a standard GSM switched circuit (voice service), PRMA++ packet reservation [7] (packet data and channel allocation for every activity phase of voice data) and mixed schemes (packet data and voice data with discontinuous transmission/voice channel remains allocated).

An example for a virtual network generated by the simulator is shown in figure **2**. For each base station, one or more antenna sectors, one or more frequencies and a number of channels can be assigned. The frequency and channel allocation can either be static or dynamic. Hierarchical cell structures can be built according to the set of transmission powers. Each mobile station controls its transmission power with the support of the serving base station. This transmission power control is performed by the asynchronous and decentralised CIR-based IPC-algorithm [2], which has proven to be very robust in the simulation. Currently, three standard path-loss models are implemented to predict the CIR value: Indoor, vehicular and pedestrian (indoor to outdoor) models. The implemented lognormal distributed slow fading model has been suggested in [4] (ARMA, Auto-Regressive-Moving-Average Markovian model of order (1,2) with moving shadowers).

Dynamically adjustable antenna diagrams and transmit sectors can be assigned to the antennas of the base stations. Two models for adaptive antennas have been implemented. One is based on the description of phased arrays with M sinus or omnidirectional elements. The other one uses beams with parabola approximations.

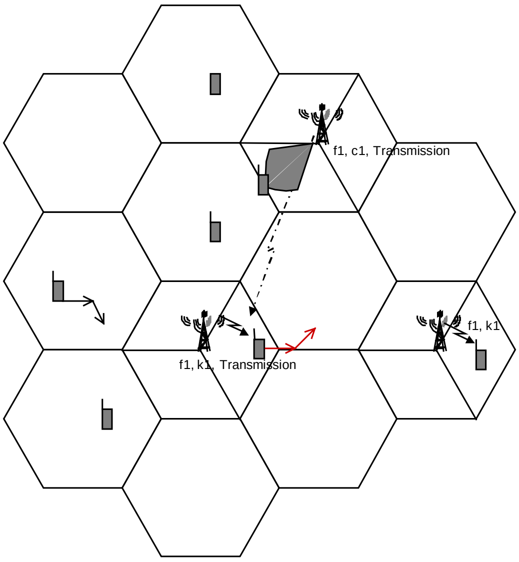

Figure 2: Virtual network environment model

3. PROACTIVE NETWORK MANAGEMENT ARCHITECTURE

The basic proposed network management architecture is split in two levels: Cell agents which determine the resource requirements and an Area Manager (AM), as shown in figure [3]. The agents send their resource requests to the Area manager that is responsible to distribute the resources which, in our case, are frequency channels. Of course, some aspects have to be considered, such as the number of transmitters in an antenna sector as well as criteria for borrowing and returning of resources, especially in overload situations.

The schemes presented in this paper are decentralised, i.e. the autonomous agents borrow and return resources by exchanging them with their nearest neighbours, based on their local knowledge. Work is ongoing which focuses on more centralised solutions using the Area manager, which should also adapt the threshold for handover, power control and link adaptation to optimise the global quality of the network.

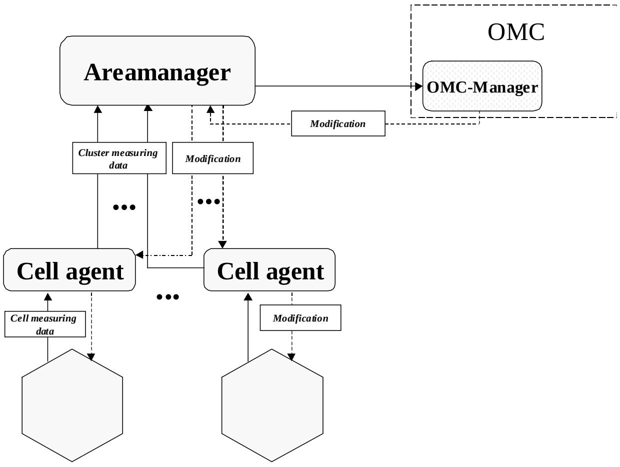

Figure 3: Overview of the network management system

4. RESOURCE DISTRIBUTION

Our method is based on a hybrid frequency or channel borrowing technique [15]. Every cell has a fixed amount of N_{fix} channels. It should not confused with algorithms for frequency planing.

During the cell planning phase, a number of channels is allocated to each cell. These channels have either the attribute "fixed" or "moveable". The $N_{moveable}$ channels can be borrowed by a neighbour cell (acceptor) that needs them because of its traffic situation, as shown in figure 4. Mechanisms for channel borrowing and returning have to be defined adapted to the local traffic and the prediction of the near future. Because of CIR-distances, frequencies have to be locked in neighbouring cells (donator). N_{max} is given by the number of transmitters.

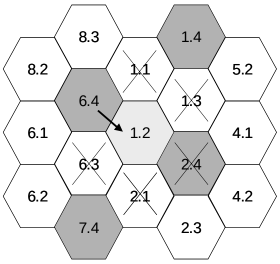

Figure 4: Channel borrowing and locking

We examined some mechanisms for the decision for moving or not moving a frequency and for returning them which will be described in the following clause. Note that autonomous cell agents have only the knowledge of parameters of their neighbours. Hence, frequencies can only be returned to the donator.

A. Simple Threshold based resource allocation algorithm (STBR)

STBR is calculated in each radio cell. The acceptor requests an additional channel when all its available resources are used. The frequency f_N is lend by the donator when it's own resources minus f_N are still sufficient. The decision of borrowing resources can be done based on the following cost function

$$Costs_{borrow}(t)=\sum_{i}^{C} w_{new}{}^{i}\, B_{new\,A_i(t),N_{newi}(t)}^{i}(t)-\sum_{i}^{C} w^{i} B^{i}_{A_i(t),N_i(t)}(t) \qquad (1)$$

Assuming Erlang traffic as a first approximation, the mean traffic loss B^i for cell i with N^i channels in the given situation is added up in the second sum of equation (1). The firsts sum adds up the estimated weighted traffic loss in the situation when resources would have been allocated. The w^i is the weight in the cell i.

Because the real mean demand A^i for cell i is not really known in the case of existing loss B,, it has to be estimated based on the mean loss B^i , the resource requests ζ for a communication link in terms of numbers of channels, and the mean communication time t_m for a given time window. With this A, the new loss B_{new} can be calculated when allocating new resources (N_{new}).

This algorithm can be enhanced with a prediction of the traffic load of the acceptor and the donator (**P-STBR**). Equation (2) predicts the borrowing cost with the same cost function for a given time interval later.

$$Costs_{borrow}(t+\Delta t)=$$

$$\sum_{i}^{C} w_{new}{}^{i}\, B_{new\,A_i(t+\Delta t),N_{newi}(t+\Delta t)}^{i}(t+\Delta t)-\sum_{i}^{C} w^{i} B^{i}_{A_i(t+\Delta t),N_i(t+\Delta t)}(t+\Delta t) \qquad (2)$$

If the loss gain

$$\begin{aligned} G = -\big[&\mathrm{C}_{\mathrm{threshold}} + Costs_{borrow}(t) + \\ &w_j \cdot \{Costs_{borrow}(t+\Delta t) - Costs_{borrow}(t)\}\big] \\ &0 < w_j < 1 \end{aligned} \qquad (3)$$

is bigger than zero, resources should be moved.

CIR values will be better (in our simulations 2 db) in the case of moving resources from a donator to acceptor because the mean interference distance will be increased, in particular in the case where sectored cells are used. This is because potential interferers are locked, as can be seen in figure 4.

Two methods for the return of a frequency have been investigated: (1) The frequency is returned when no further request arrives in a given time window; (2) the frequency is only returned when the donator needs it back.

B. Control method based resource allocation algorithm (CMRA)

CRMA controls the number of borrowed channels such that the mean loss B for a mean demand A or for a predicted demand $A_{(t+\Delta T)}$ is approximated to an objective value, based on the estimated traffic. An additional objective is to avoid oscillations. CMRA is able to allocate more than one channel/frequency in one step.

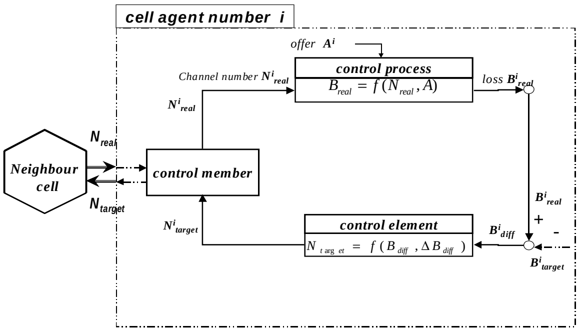

Figure 5: Control engineering cycle

The requests A and $A(t+\Delta T)$ are calculated by the cell agent with the Erlang formula. The control entity tries to borrow or return the number of channels, that are estimated by the control element.

The control element decides how the number of requested resources based on the curve given in figure 6. The equation we used is an approximation of the Erlang distribution:

$$\frac{N_{target}}{N_{max}} = 1 - e^{-RF \cdot B_{diff}} \qquad (4)$$

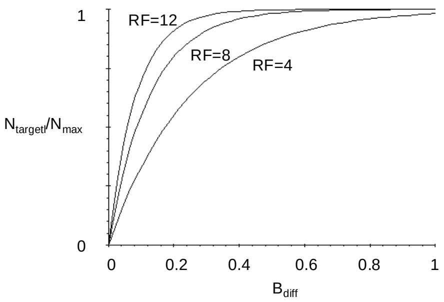

Figure 6: Control element

Channels/Frequencies are returned when the blocking loss in the donator cell is larger than in the acceptor cell.

5. SIMULATIONS AND FIRST RESULTS

A. Performance

To compare these mechanisms to fixed channel allocation schemes, two different types of simulations were performed. The first one uses 60 mobile stations that are uniformly distributed and two trains to simulate a moving hotspot with 20 mobiles per train. Blocking rates, borrowing and returning rates as well as CIR values have been observed.

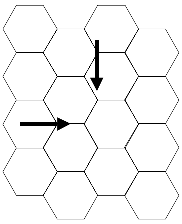

Figure 7: Two trains (moving hotspots)

Figure 8 shows first simulation results. All control methods outperform fixed channel allocation (FCA). The STBR-method seems to be a good solution. As the main traffic is randomly distributed, the P-STBR method is not able to deliver a gain by predicting the traffic development. But we think that this method could be enhanced in correlated traffic environments with regular traffic patterns.

Depending on the factor *A* in equation (4), different effects for the CMRA algorithm can be observed. If the values of *A* are too high, resources are always moved. Is *A* too small, the blocking rate increases because resources are moved too slowly. CMRA without prediction performs worse than the STBR-method because CRMA tries to control the real demand of a cell whereas the STBR method tries to allocate one channel more than actually needed.

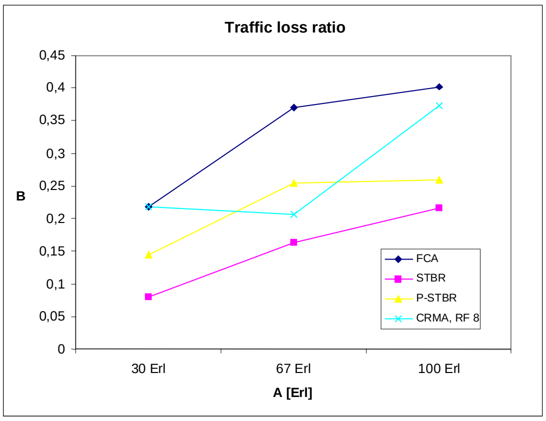

Figure 8: Traffic loss ratio

B. Stability

In a second step, a highly loaded network in a stable state with 24 mobiles at fixed places is triggered with an impulse of three mobile stations appearing in one cell, see figure 9. This simulation was intended to detect instabilities, e.g. more borrowing and returning events than necessary or chain effects with oscillating channel allocations. One problem with our simulation library MoSiT is that fixed traffic values can not be adjusted because the traffic generators are restricted to Poisson traffic. Therefore, the stability observation is quite tricky.

Table 2 : Total of changes (channels) in the observed radio cell for a given method

method	Control element				STBR	P-STBR
	RF 12; 0,5s	RF 12; 2s	RF 8; 0,5s	RF 8, 2s		
Sector 1.3	2	2	0	0	0	0
Sector 2.3	7	7	2	2	6	2
Sector 3.3	6	4	2	2	20	5
Sector 4.3	0	0	0	0	14	2
Sum	15	13	4	4	40	9

Results can be found in table 2 and in the appendix (figures A.1-A.3). The STBR-method displays oscillating borrowing events, though, but the P-STBR and the CMRA-method are fairly stable. With the predictive P-STBR-method, one channel is permanently kept in the new cell.

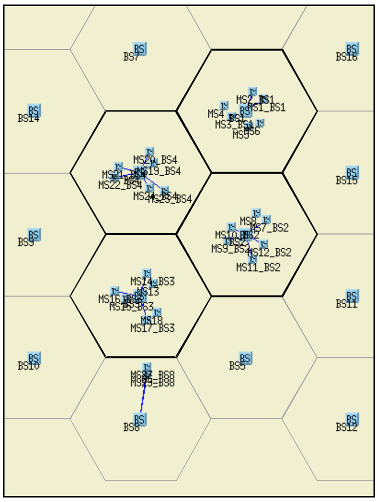

Figure 9: Scenario for stability observation

6. SUMMARY AND OUTLOOK

Our first results for the observed channel borrowing and resource controlling methods promise good results for more enhanced methods that will be observed in the future. The work presented will be extended such that the proactive aspect of the resource allocation is more emphasised. Not only blocked calls but also interference, blocked handover and other performance parameters will be investigated. Optimisation methods used for frequency planing seem quite promising for the allocation of resources to a radio cell. Other subjects will be dynamic beam forming, power control and handover.

ACKNOWLEDGEMENT

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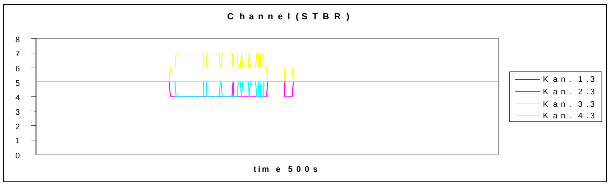
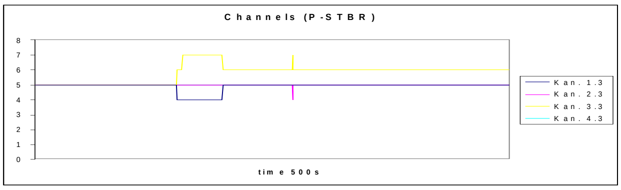
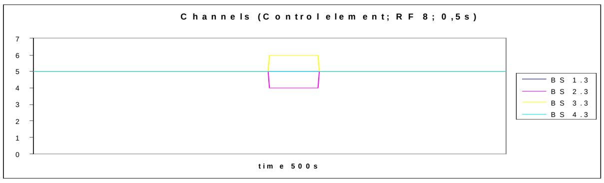
APPENDIX



A.1 Stability for the STBR-method



A.2 Stability for the STBR-method



A.3 Stability for the CMRA-method