A Realistic UMTS Planning Exercise

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***Abstract**: this paper presents the UMTS planning methodology that has been designed and developed in the framework of the STORMS project. A two step planning strategy is envisaged. The first step consists of a radio coverage optimisation which is performed by considering not only coverage but also capacity constraints expressed as a minimum required BTS density. The second step is a refined dimensioning assessment including the radio resource allocation as well as the access network optimisation. As an additional step a simulation tool is used to validate the results of the planning tool. The reference air interfaces in this paper are the ATDMA and CDMA selected by STORMS since the beginning of the ACTS Programme. The analysis of these basic reference modules has lead to an enhanced planning methodology which is capable of considering the impact of the newly introduced UTRA specification on the planning methodology.*

Introduction

This paper presents some practical results of a planning exercise conducted on a realistic UMTS network using the modules and the procedures developed by STORMS. This will illustrate the various aspects of the very complex UMTS planning tasks as a part of a coherent and well co-ordinated process. Furthermore, it will allow assessing the STORMS planning strategies and algorithms and introducing a discussion on the difficulties that future UMTS operators will encounter. The planning methodology developed in STORMS is focused on CDMA and ATDMA systems since these air interfaces were the state of the art at the time the project started its activities. Due to the uncertainties of the UMTS specifications, a generic radio resource dimensioning approach has been designed: such an approach can be further customised to take into account any specific radio access scheme selected by the operator.

Traffic Distribution Analysis

The first step of the planning process requires some user input; the features of the network to be deployed, the area to be covered, the QoS and coverage planning target, the range of services provided and other aspects need to be specified. The major objective of the initial planning step is to assess the **minimum density** of BTSs that would be required to meet the capacity requirements as a function of the expected traffic patterns and its segregation into macro and micro cellular layers. This analysis allows setting some capacity constraints subsequently used in the radio coverage optimisation phase [1, 2]. Different approaches have been designed depending upon the adopted air interface. This paper concentrates on the ATDMA and CDMA schemes.

Segregation of services into layers is achieved on the basis of service bit rate, service performance requirements, user mobility, and offered traffic load. Low bit rate services, in particular speech service, are allocated to the macro cellular layer. Such services are also typically associated with unrestricted mobility, high mobility users are part of this population. High bit rate services are on the contrary expected on limited coverage areas where the deployment of micro cells is justified, and associated to much lower mobility. Consequently, low bit rate services such as voice and low bit rate data (circuit or packet oriented) are assigned a priori to the macro cellular layer. High bit rate services are on the contrary assigned a priori to the micro cellular layer from the start. The second phase consists of handling the offered traffic load, in particular the traffic peaks. For areas not covered by micro cells, the entire offered traffic load must be carried by the macro cells (it is of course assumed that the presence of high resource demanding services in terms of traffic load is weak enough and micro cellular coverage is not needed). For areas covered both by macro cells and micro cells, a split of the overall offered traffic load is required. First the portion of traffic floor made up by low bit rate services is

assigned to the macro cellular layer, while the remaining portion consisting of high bit rate services is identified as the minimum requirement for the micro cellular layer. The portion of the peaks over the traffic floor follows an equivalent segregation.
If the segregation fails with the previous basic criteria, services that may overwhelm each other because of interference in CDMA systems or bandwidth requirements (slots) for TDMA systems are split into separate layers, however this aspect is typically solved through the simple bit rate criterion. The real issue is that the micro cellular layer offers better (denser) spectral reuse and should be packed, the macro cells aim essentially at offering large area coverage. Consequently, most of the traffic peaks must be associated with the micro cells, and this irrespective of service type, hopefully most of the load in densely populated areas where multiple services are offered are due to high bit rate services.

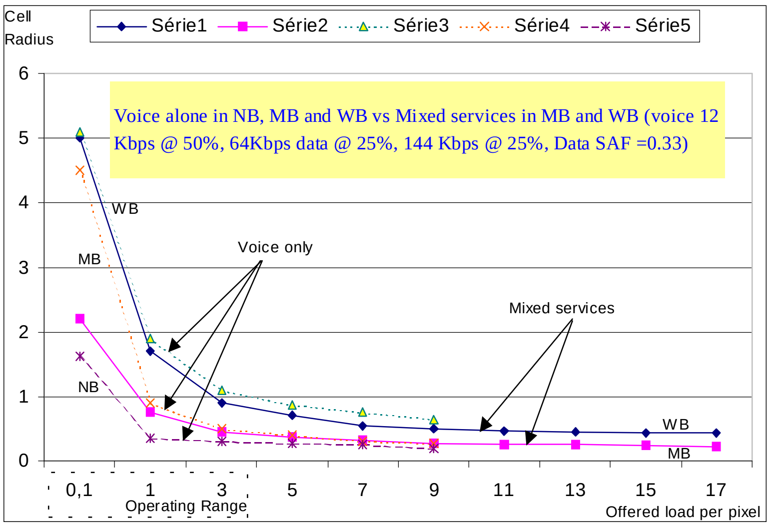

Figure 1.Cell size results from CDMA Initial dimensioning

If exceptionally low bit rate services dominate the traffic peaks, **hierarchical coverage** is an efficient means of offering the service over busy spots, and there are no major service interaction problems. If following the segregation the micro cellular layer is compelled to house all type of services (voice, data at various bit rates) then the only way out is an assessment of service interaction and influence to decide whether to share the same bandwidth in the micro cellular layer, or be forced to split the bandwidth into separate sub bands.
The set of curves obtained from the CDMA initial dimensioning process provides such an information on service segregation as shown in Figure 1. Comparing the curves corresponding to voice only service in various bandwidth sizes (Narrow Band =1MHz, Medium Band = 5 MHz, and Wide Band = 20MHz) with the scenario where services are mixed (voice with data services at 64 kbps and 144 kbps) illustrates clearly the effect on maximum cell size (or number of users admitted into the system). Indeed, services can be mixed over the same bandwidth only up to a certain extent, depending upon service activity factors and proportion. This is particularly true in the operating range (0.1 to 3.5 Erlangs of offered load per pixel) where one is better off segregating voice in medium and narrow bands, rather than mixing services over wide bands. In fact, in the presence of a 2Mbps service (scenario not shown) , the cell radius can not exceed 1km and is typically below 150 m for fairly moderate traffic loads and can be as low as 50 m for high loads. The effect of mixing services with QoS and bandwidth requirements that are too far different can lead to high network cost in terms of required number of base stations.

ATDMA Initial Dimensioning

Traffic demand analysis

In a ATDMA scheme the process involves aggregating pixels into cells by conducting a weighted sum of the offered load per service and per pixel. A Statistical Multiplexing Gain (SMG) for each service should be identified as well. The planning tool, making use of both geographic and demographic information, is capable of associating a traffic value A_{ij} on a per pixel (i) and per service (j) basis. The achieved SMG depends upon the actual amount of resource allocated to a given service and the Quality of Service (QoS) requirements.
It is assumed that services are allocated disjoint portions of the resource and that statistical multiplexing is limited or restricted to within a given service class. Pursuing with this very conservative use of the resource leads to a pessimistic assessment of carried throughput, which can be estimated for each service using the following formula:

$$\gamma_{ij} = \frac{A_{ije}}{C}(1 - P_{Bi})$$

where A_{ije} is the equivalent traffic weighted by the SMG factor, P_{Bi} is the loss probability for service i and C is the assumed BTS equipment[1] capacity. The maximum number of channels allocated to a BTS is $C = N_{carriers}\ x\ N_{I\text{-}slots}$, where $N_{carriers}$ is the maximum number of carriers allocated to a BTS and $N_{I\text{-}slots}$ is the number of slots per carrier that can be used to carry information once signalling channels have been set aside for common control channels, associated channels, and access channels. The aggregate average offered traffic load for service i for a given cell area is given as:

$$A_i = \sum_{j \in Cell\ area} A_{ije} = \sum_{j \in Cell\ area} \frac{\lambda_{ij}}{\mu_{ie}} = \sum_{j \in Cell\ area} \frac{\lambda_{ij}}{\mu_i} \frac{r_{1i}}{r_{1i} + r_{2i}}$$

Resource dimensioning

For each A_i a wide range of traffic handling policies can be used, but assume an operation on blocked calls cleared basis and independent resource allocation for each service, then the required number of channels or trunks is given by the solution to:

$$E_B(A_i, N_i) \le QoS_i\ or P_{Bi}$$

where E_B represents the Erlang-B formula. The condition must be verified for all services jointly. To identify the number of pixels to aggregate in a cell, the program starts from the centre of sub areas where pixels offer maximum traffic load, work outwards and aggregate pixels as long as the following condition is respected:

$$\sum_{i=1}^{M} N_i \le C \qquad (1)$$

N_i is the number of I-slot groups required by a given service, assuming a contiguous channel (slot) allocation for each service as a function of their respective resource requirements.

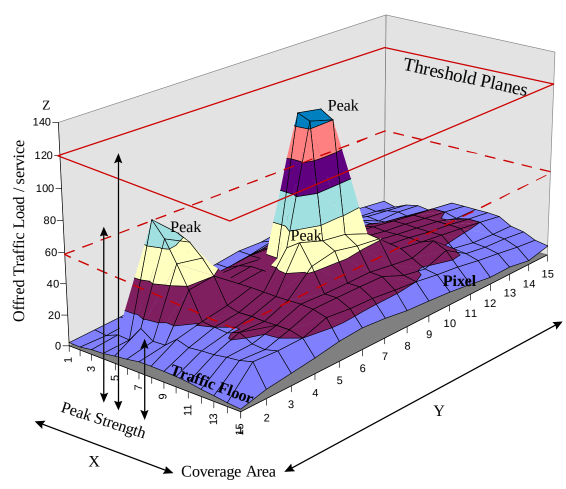

Figure 2: Aggregation of pixels to estimate cell area size requirements

Each service requires a number of Basic Band-width Units (BBU), that is a number of I-slots for TDMA systems.

Hence, the correct interpretation for equation (1) is that if service S_i requires m_i I-slots per connection then $N_i\ x\ m_i$ slots will be required. The cell area is obtained when the aggregation of pixels into a cell violates for the very first time this condition. In order to speed up this process all uniform traffic sub areas are clearly identified to simplify the search procedure. A further refinement of this process should consider that, for each service provisioned in the area of interest, the QoS requirements are not necessarily the same. In this case each service should be tagged with its own blocking rate. Figure 2 shows the graphical result achieved with such an analysis.

1 The operator is requested to define in advance the type of BTS equipment he wants to use. This can be set on a per layer basis, i.e., different types of BTS are allowed in macro and micro cellular layers. At this stage the BTS capacity is just an assumption: the actual BTS equipment is dimensioned later in the planning process.

CDMA Initial Dimensioning

The initial CDMA dimensioning process is grounded on a quasi analytic capacity model fed with approximate interference estimations[2] as defined in [3]. As already anticipated, the aim of this step is to obtain a rough estimate of the **BTS density** requested to satisfy an **offered traffic load**. At this stage, a simplified scenario must be necessarily considered. The first step of this process consists on identifying areas where traffic demand can be considered homogeneous and where the propagation conditions can be modelled in the same way.
The *quasi-analytical model* applies to multiple cell, multiple rate CDMA systems, taking into account system features such as discontinuous transmission and imperfect power control. Control channels[3] are modelled as well. According to this model, the system capacity is evaluated in terms of *maximum number of channels that can be supported for a given outage probability*; the evaluation is done assuming that the number of active users in a cell is constant. This approach can be further revised so that the system capacity can be estimated in terms of availability of the channels, when the number of active users is described as a random number, due to the fluctuating traffic demand (modelled as a Poisson distribution) from the population of subscribers.
A large number of system features and configurations can be supported by this model, and the computational complexity still remains low. This feature makes this model suitable for network planning purposes.
The dimensioning process is organised as follows:

1. The capacity (expressed as the maximum number of active users or as the mean traffic in Erlang) per service per cell per band is calculated according to the quasi-analytical model.

2. The capacity per service per cell is evaluated by multiplying the figures obtained at step 1 by the number of bands available for each cell.

3. The number of cells needed to satisfy the traffic request on the deployment area is evaluated by dividing the total offered traffic by the traffic capacity per cell obtained from step 2.

4. The area served by each cell is calculated by dividing the global area by the number of cells obtained at step 3.

A comprehensive list of parameters necessary to settle the software tool developed in STORMS is provided in [4].

Radio Coverage Optimisation

Once the capacity constraints have been settled, it is possible to start the radio coverage optimisation stage. In a third generation mobile network the radio coverage should be optimised considering both <u>propagation</u> and <u>capacity</u> (traffic) constraints. The capacity constraints obtained as a result of the initial dimensioning described in the previous section are provided in the form of minimum density of BTS or, equivalently, maximum cell radius: this requirement must not be violated throughout the following radio coverage optimisation phase. The process developed in STORMS is based on the following steps:

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2 At the time the initial resource dimensioning is performed, interference values estimated from off-line simulations will be used. This is a reasonable assumption that holds in small areas where traffic demand and propagation conditions can be considered uniform. Later on, when the refined resource dimensioning is performed, a better model of interference that considers the actual distribution of interference and the real propagation conditions will be used.

3 The control channel considered by STORMS is the PCCH specified in the CODIT air interface.

- Definition of a a set of potential BTS. Both sites, i.e., locations where it would be possible to install a BTS (Figure 3) and equipment configuration are to be set. This approach is particularly suited for the deployment of microcellular coverage in metropolitan areas where the potential sites could be public telephone booths, traffic lights or any other low cost location. The example shown in Figure 3 represents a test case with 40 BTS candidates sites in a typical urban environment;
- computation of radio coverage. Being the BTS sites and configuration set, coverage provided by each BTS is assessed. The most suitable propagation model is selected based upon the environment, i.e., macro or micro. Figure 4 shows the best server map resulting from the initial set of BTS sites;
- radio coverage optimisation. A heuristic optimisation approach has been adopted and implemented by means of a genetic algorithm technique. A fitness function assesses how convenient or "optimum" a radio network configuration is. This function, meaning cost in a broad sense, combines all factors which drive the optimisation process: coverage (in terms of geographic area served) and the overall network cost and complexity. Different fitness functions are offered to the user which can be be configured and tuned through the GUI although default values are always provided to guide the user through any operation.

A client-server architecture is the basis of the GUI that has been developed in Java. The rational behind this implementation option is allowing "remote computing" tests: the optimisation engine can be executed on a centralised powerful computer (even a parallel machine or a network of workstations) while the results can be visualised on some light computer (desktop or laptop) connected to the main unit through an Intranet or Internet connection and running a common Web browser. Furthermore, this would allow the potential user of the tool to perform remote computing on data that is stored on a central node being thus consistency of information ensured even if different planners would be accessing the same DB. This solution allows to set-up a client-server architecture that can be exploited to perform.

Figure 3: Initial locations of BTS candidate sites

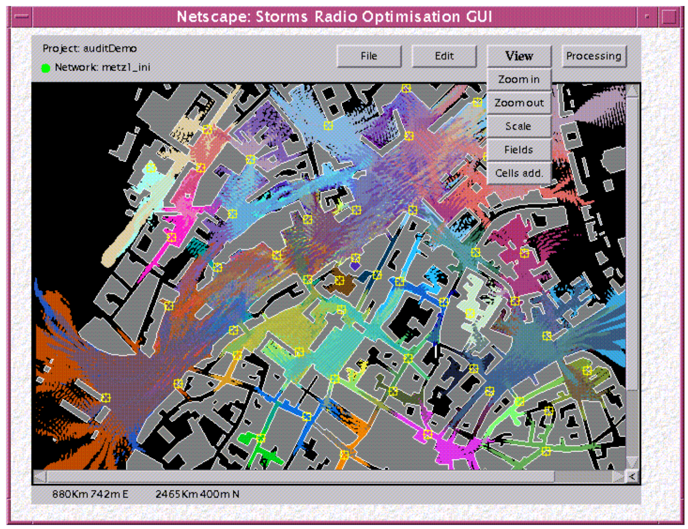

Figure 4: Initial network best server coverage map

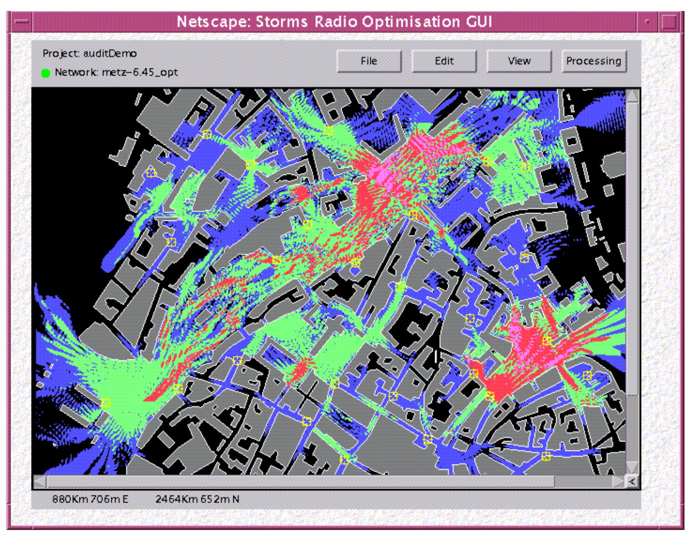

Figure 5: Final network best server coverage map

Refined Resource Dimensioning

The refined capacity evaluation is performed right after the radio coverage optimisation in order to dimension the resulting BTS network. The input of this task includes the offered traffic density and the radio network characteristics (BTS location, BTS coverage, etc.). The activity treats both ATMDA and CDMA air-interfaces and as a result a **Generic Radio Resource Dimensioning Process** has been developed. The generic process apart from the air-interfaces considered within the original plan of STORMS (i.e., ATDMA and CODIT/CDMA) can also treat a wide range of air-interface alternatives proposed for UMTS, including the UTRA proposal (i.e., WB-CDMA and TDD-CDMA) which will be analysed in the future based on this method.

Figure 7 depicts the way that the generic process treats the multi-layer cell structure of UMTS. Initially, based on the service type, the traffic load is segregated into the cell layers. Then the dimensioning of each individual cell layer is performed separately. The resulting overflow traffic in a particular layer can be allocated into another cell layer. If the system capacity proves to be inadequate a feed-back step towards the radio coverage module is triggered requesting for an increased BTS demsity.

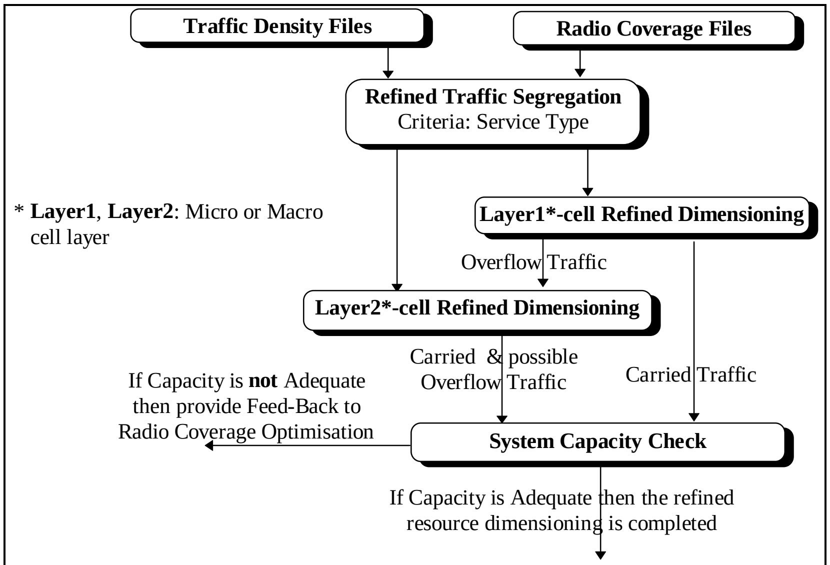

Figure 7: The generic refined planning process in a multi-layer (hierarchical) cell structure

The refined dimensioning of an individual cell layer is shown in Figure 8. The Traffic Load Scenarios' Generator determines the traffic load distribution in the cells of the layer. Depending on the applied channel allocation strategy (e.g., FCA, HCA, DCA) different scenarios can be derived (e.g., busy hour, traffic floor, time zones, etc.). The next step is the determination of the radio resource demand per BTS which depending on the air-interface type may correspond to slots, carriers, codes, etc. Right after the Radio Resource Allocation Tool distributes the available radio resources to the BTSs. This tool can be conceived as an enhancement of the Frequency Planning tool utilised in 2nd generation TDMA based systems. Then, the Power Control Handling Tool is employed so as to determine the system capacity limitations due to the power control feature of CDMA based air-interfaces. The final step of the generic process regards the estimation of the carried traffic and the overflow traffic resulting from the analysis of the complete set of traffic scenarios.

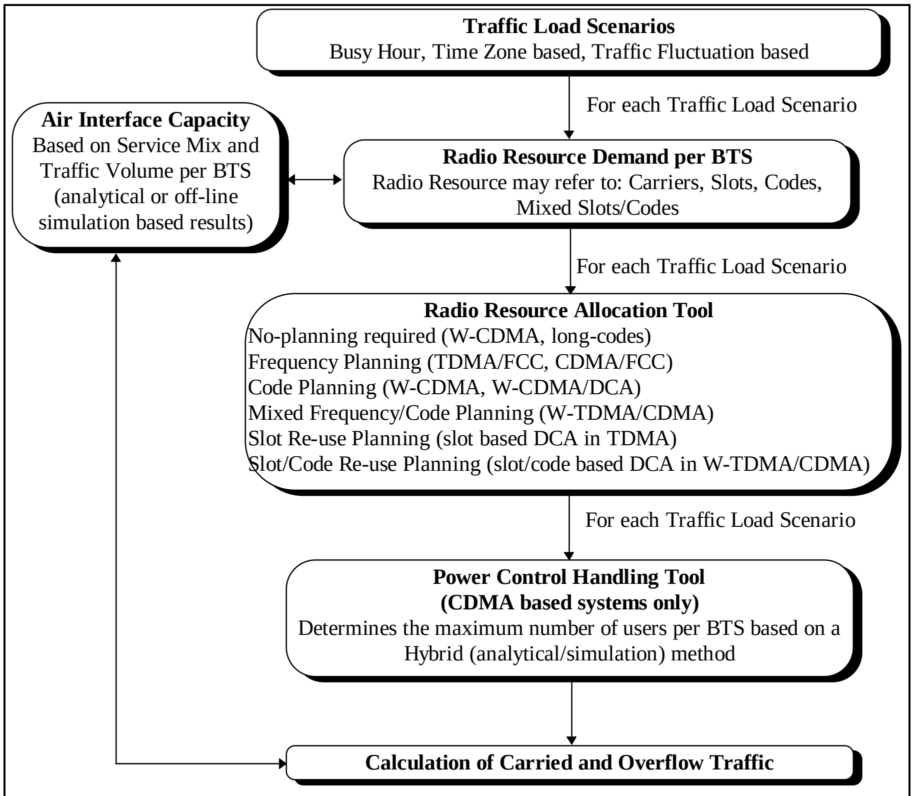

Figure 8: The generic Radio Resource Refined Dimensioning process for a single Cell Layer (Micro /Macro).

In the following figures some sample results of the refined dimensioning tool over the area of Les Vosges are provided. Note that for the ATDMA interface we assume that HCA is applied in the macro and DCA in the micro cell layer.

After the radio part planning, operators need to optimise the fixed network infrastructure that involves estimation of the optimum number and allocation of the BTS controllers (CSS), Local Exchanges (LE) and the optimisation of the Location and Paging Areas. The benefit resulting from the application of this step resides in a lower network cost, higher exploitation of the deployed equipment (CSS and LE) and minimisation of the signalling (and processing) overhead due to the mobility management procedures (Location Updating and Paging). The optimisation of the signalling overhead becomes even more attractive since next generation mobile networks should introduce the concept of the **intelligent paging**, i.e., a criterion to physically separate the location areas from the paging areas that become smaller thus minimising the paging load. In this process, the impact of counting on a satellite segment is considered.

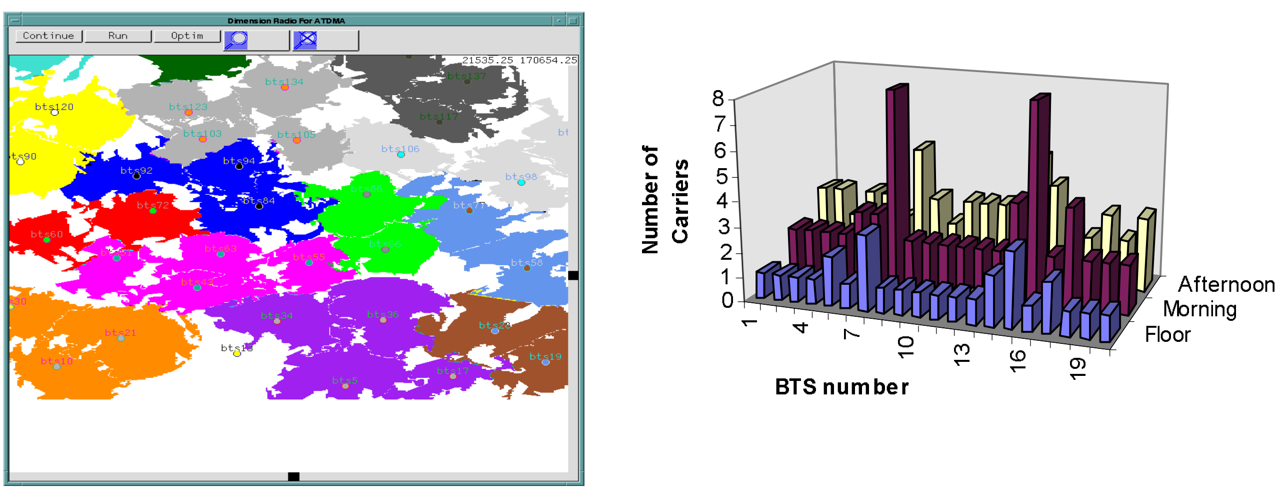

Figure 9: The number of carriers required per macro-cell BTS (for BTSs 1 to 20 of Les Vosges network) for the traffic floor, the morning and the afternoon traffic load distribution.

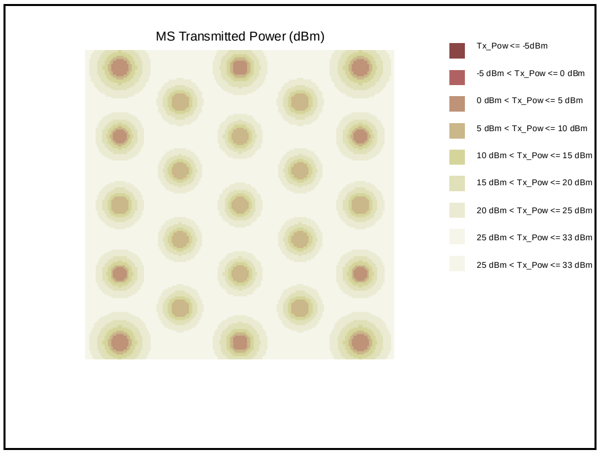

Figure 10: Power Control Tool in CDMA dimensioning: Mobile transmitted power distribution at the final iteration of the process

Network Dimensioning Validation

Before implementing a network, operators might wish to check the expected performance against the project requirements. They could also be interested in evaluating which is the network sensitivity to a different traffic pattern deriving from the introduction of a new service or a new tariff policy. Moreover, there may be aspects that are too complex to be analytically solved or increase the computational load if integrated in planning formulations.

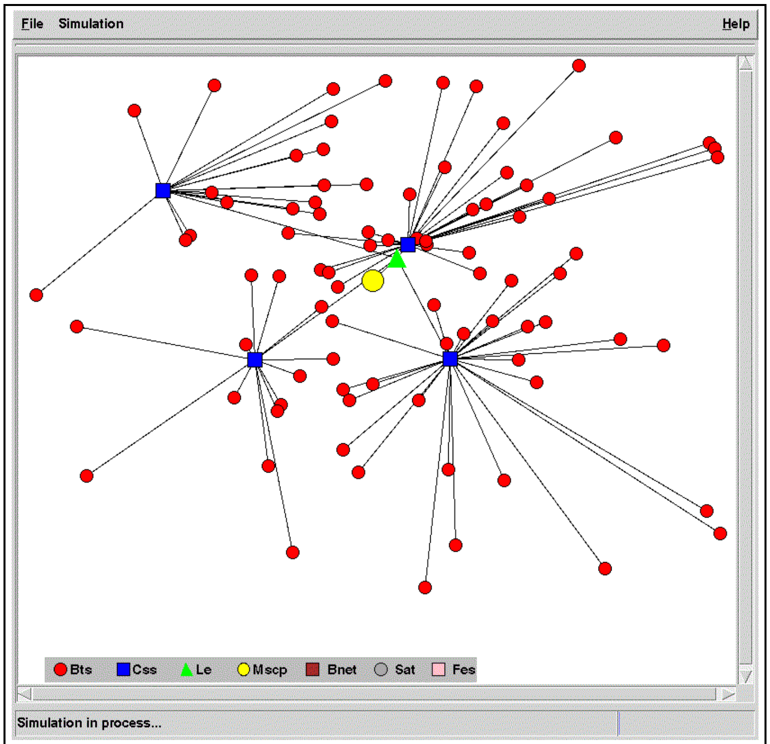

Figure 6: Display of the computer simulation

To fulfil these requests, STORMS has developed a *UMTS network simulator* module fully integrated with the previously described planning steps. It provides the means for modelling UMTS networks and their environment. It receives as input the proposed network configuration and provides as output the statistical behaviour on a per node basis and, eventually, recommendations aiming at improving the resource dimensioning stage. The simulation follows an object-oriented approach: UMTS nodes, UMTS environments (Public High Traffic, Public Low Traffic, Satellite segment) and UMTS operations and procedures (call set-up, handover, location update, user registration, etc.) have been modelled as appropriate objects. These are invoked to compose any configuration and simulate any network operation.

The UMTS simulator may be applied so as to complement the radio resource dimensioning process. In this respect, several radio resource management strategies have been integrated so as to give the possibility of estimating the expected network performances under different operational schemes. These are Hybrid Channel Allocation (HCA) and combined FCA-Channel Borrowing [5], envisaged for the macro-cellular layer, and two self-organised DCA schemes, namely, sequential channel search [5] and channel segregation [6].

Other application areas may be the evaluation of the queuing and processing delay per network entity and the delay per UMTS operation and procedure (e.g., impact on call establishment delay). Figure 6 shows the result window captured from the computer simulation developed in STORMS. The network configuration (85 BTSs with 4 CSS and 1 LE/MSCP) is easily recognised.

Conclusions

This paper has presented the planning process for third generation mobile networks proposed by project STORMS along with some examples and results achieved by running the software modules developed so far. The traffic segregation and the initial dimensioning step have been proved to be some important aspects necessary to appropriately drive the following radio engineering phase including the radio resource dimensioning. A generic radio resource dimensioning procedure has been designed to cope with the current uncertainties about the third generation air interface: this procedure is flexible enough to be customised by the user according to the specific needs arising. An object-oriented UMTS simulator has been briefly introduced as well: it ensures the final check on the proposed network configuration by suggesting improvements or simply outlining potential bottlenecks due to the user activity and behaviour.

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