AN INTEGRATED APPROACH TO CELLULAR NETWORK PLANNING*

K. Tutschku, N. Gerlich, and P. Tran-Gia
Institute of Computer Science, University of Würzburg
Am Hubland, D-97074 Würzburg, FRG
Tel.: +49 931 888-5513
E-mail: [tutschku|gerlich|trangia]@informatik.uni-wuerzburg.de

As the demand for mobile communication services increases, network planning needs to be optimized to cope with both increased traffic demand and limited spectrum. In this paper we present a new approach to cellular network planning that integrates teletraffic issues and radio engineering to automatically achieve optimized planning solutions. The core of this technique is the notion of demand nodes. Experiments with the planning tool prototype ICEPT show the feasibility and effectivity of the approach.

1 INTRODUCTION

In the early age of wireless telephony, due to the lack of planning methodology and the step-by-step network implementation, pragmatic approaches were often used in network planning. At that time, planning meant implementing cell sites at locations chosen by experienced radio engineers, providing measurements of the running system, and adapting the system accordingly. Since the last step usually resulted in additional equipment but almost never removed superfluous equipment to use it at other cell sites, this approach tended to over-dimension the system.

In the face of tremendous customer demand towards the end of the eighties, more and more carriers joined the market and resources started to run short while at the same time customer charges had begun to drop. Consequently, a more systematic network planning was required. This led to the development of the so-called *analytical approach* to network planning [6], which is, due to its algorithmic formulation, widely found in today's planning assistance tools. This approach focuses on the radio engineering aspect of the planning process, i.e. on determining the locations of the cell sites and assigning frequencies to them by examining the radio-wave propagation environment and interferences among the cells. Other aspects of cell planning like user behavior and teletraffic issues are taken into account rather late in the planning process and treated separately. Thus, existing interactions are not included in the planning task.

For the deployment of future telecommunication systems this will be satisfactory no longer. Future telecommunication systems, by means of their technology, the market demand, and the shortage of resources, call for an optimized network planning. Optimal network configurations must be achieved with respect to technological issues as well as with regard to economic aspects [7]. In other words, integrated planning is required to cover interactions among aspects treated separately by conventional planning tools. For instance: Given a multiple access technique based on code division (CDMA, [3]) or space division (SDMA, [11]), the shape of a cell depends on the behavior of the users in the cell as well as on the users of surrounding cells. Furthermore, in such systems, the user distribution directly influences the performance of the system. Consequently, the user behavior and the traffic-related issues connected with it as well as aspects of the system architecture must be an integrative part of the planning process. In this paper we will present such an integrated approach to cellular network planning.

The paper is organized as follows. Section 2 reviews the conventional planning approach widely used in today's commercial cellular planning tools like e.g. GRAND or Planet. In Section 3 we present our new integrated approach. In Section 4 we discuss a prototypical implementation and close with the presentation of preliminary results obtained.

2 CONVENTIONAL PLANNING

Nowadays available commercial cellular planning tools, e.g. PLANET [9] or GRAND [6], are based on the so-called *analytical approach* to cellular network planning [6]. This approach focuses on radio planning aspects, i.e. selection of cell sites,

*This research project is supported by the Deutsche Forschungsgemeinschaft (DFG) under grant Tr-257/3

frequency planning, and antenna design.

In principle, the analytical approach has four phases, Radio Network Definition, Propagation Analysis, Frequency Allocation, and Radio Network Analysis, that are passed several turns in an iterative manner (cf. **Figure 1**).

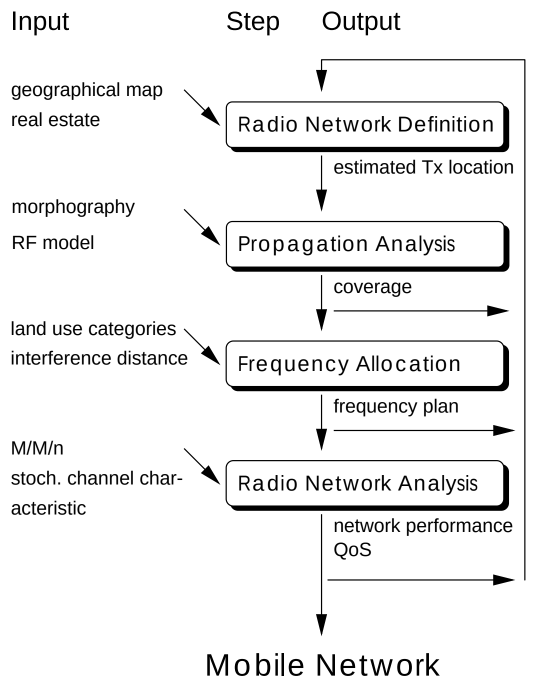

Figure 1: Conventional approach

During the *Radio Network Definition* phase, a human expert chooses cell sites, i.e. transmitter locations which are based on his planning experience and the geographical map of the area to be supplied.

Using these transmitter locations, the *Propagation Analysis* of the area evaluates the radio coverage by field strength prediction methods. Here, stochastic channel models as well as more sophisticated approaches like ray-tracing techniques are applied. Usually, several field strength prediction methods are implemented but the tools offer little if any support in choosing the appropriate propagation model.

If the planning expert decides that the coverage satisfies the given requirements, a *Frequency Allocation* is carried out, otherwise new transmitter positions must be chosen and once again the propagation be analyzed. Using an expected traffic database, usually derived from rough estimates based on land use data, the required number of traffic channels and hence frequencies of a cell are computed. This computation uses land-line capacity planning techniques like the common Erlang-B-formulae as well as correction factors that come from planning experience.

If under frequency reuse pattern and interference distance constraints it is possible to supply all the cells of the area with the required number of frequencies, the algorithm proceeds to radio network analysis. Otherwise the algorithm starts all over again.

The *Radio Network Analysis* calculates the Quality-of-Service of the area by means of blocking and hand-over dropping probabilities. Again, stochastic channel characteristics as well as user demand estimates from the traffic data-base are used to calculate the network performance. If Grade-of-Service specifications are met, the task is finished, otherwise the algorithm has to be restarted.

The major shortcomings of tools based on the analytical approach are that they focus almost only on radio design aspects. In addition, they require in each step a trained radio expert to make decisions. Furthermore, the major design aspects are treated more or less in isolation such that existing interactions are neglected and an overall optimization is not feasible. If one draws comparisons, these tools can be regarded as complex desktop calculators designed for the hands of trained radio experts.

3 INTEGRATED PLANNING AND OPTIMIZATION

3.1 The integrated design concept

The *integrated design concept* overcomes the shortcomings of the conventional approach by identifying four major design aspects of cellular mobile communication systems and considering their key issues in a comprehensive way. The new concept is depicted in **Figure 2**. The four basic design aspects of mobile communication system are: Radio Transmission, Mobile Subscriber, Resource Allocation, and System Architecture. These aspects contribute in a parallel manner to the higher-level integration component, the *Automatic Network Design*, which is responsible to manage different, often contrary, objectives. The integration component uses the contribution of the design aspects as the input to the network design algorithm (cf. Section 4.2). This algorithm defines, evaluates and optimizes the network.

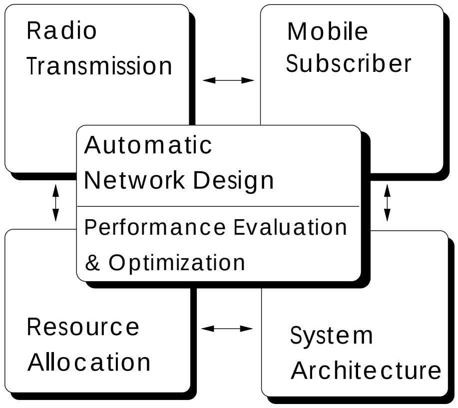

Figure 2: Integrated Planning Approach

The interactions and dependencies between these different design aspects can be included in the integrated approach by exploiting its modularity. The separation makes it possible to model the dependencies in an abstract but comprehensive way. These dependencies can be represented by applying the *demand node concept*. This method is the core technique of the integrated approach and will be explained in more detail in the upcoming sections.

Moreover, the modular structure of the new approach permits a generic implementation of the design aspects in a planning tool. For example, an inappropriate field strength prediction method in the Radio Transmission module can easily be replaced with a better one.

Since the integrated approach considers design aspects not in an isolated way, it can obtain solutions which are optimized under more than one aspect. The new approach resolves conflicting design objectives and finds better overall solutions than the conventional design method.

3.2 Demand Nodes

The core technique of our integrated approach is to represent the spatial distribution of demand for customer traffic by means of demand nodes. Demand nodes or demand points play an important role in economics when solving facility location problems (see e.g. [8]). In our context we use the following:

Definition. A demand node represents the center of an area containing a quantum of demand from teletraffic viewpoint, accounted in a fixed number of call requests per time unit.

Hence, the notion of demand nodes introduces a discretization of the traffic demand in both space and demand. In consequence, the demand nodes are dense in areas of high demand and sparse in areas of low demand.

Demand nodes are the common basis of all the components. Hereby they constitute the connecting link between the components and, by doing so, facilitate the integration of the components.

3.3 Mobile Subscriber

The behavior of the *Mobile Subscriber* in a cellular system can be described on two levels: static and dynamic behavior. The static description comprises the spatial distribution of users in the supplying area of the network. In this context the term population model is more appropriate for describing the subscriber behavior. The dynamic level describes the time-dependent behavior of users, such as their mobility patterns.

To include population models into the integrated approach, discretization methods are applied which generate a demand node distribution according to the above definitions (cf. [4]).

3.4 Radio Transmission

Careful cellular network design has to ensure that the reliability of the Radio Transmission within the supplying area is optimal under the given conditions. This objective can be achieved by placing the transmitter in such a way, that the received field strength at a service point is maximized and the interference by other radio sources is minimized.

The integration of radio transmission issues into our new approach is again done by means of demand nodes. Demand nodes serve in this context as *sensors* for the electric field strength. The field strength at a demand node is computed by using sophisticated radio wave propagation models, (cf. [2]). A node is said to be *supplied* with the mobile service if it receives the required minimum field strength from at least one base station.

This application of demand nodes transforms the base station locating problem into a discrete algebraic task. Finding the optimal location is equivalent to the *maximal covering location problem* (*MCLP*). The objective of the MCLP is to place a given number of facilities, here the transmitter, in the demand area, so that the number of supplied demand nodes is maximized.

3.5 Resource Allocation

Resource allocation is a very crucial task in cellular network engineering. Frequencies and channels are valuable since their number is physically limited and can not be arbitrarily increased. A higher traffic capacity of cellular systems is only possible if there is a high spatial reuse.

This design aspect can also be integrated into the new approach by the application of demand nodes. The *reuse distance* for frequencies defines the *reuse pattern* of a cellular system, which determines the maximum number of available channels in a cell. The number of channels limits the amount of traffic the cell can handle. Since the traffic is represented within the concept by the demand nodes, the resource allocation problem is to design cells in such a way, that the number of demand nodes in a cell does not exceed the maximum value. In other words, the reuse pattern limits the number of demand nodes in a cell. Only the cells which obey this constraint are considered for network design.

Additionally, due to the discretization of the expected traffic volume in space and demand, the integrated approach can apply more accurate performance evaluation methods, e.g. finite population queuing models. In contrast, the conventional design approach usually employs only the Erlang-B-formula.

3.6 System Architecture

The typical System Architecture of public mobile communication networks consists of two major parts: the radio transmission subsystem and the transport network. Both parts are strongly interconnected and their proper configuration is essential for good overall system performance and efficient network operation.

So far, the conventional network design does not address the interconnectivity of these parts. The configuration of the radio subsystem is completely independent of the transport network. Hence, the conventional design approach yields a large amount of superfluous hardware on the one side and overloaded system elements on the other side, (cf. [10]).

System architecture issues can be included into the integrated approach again by considering the expected offered traffic in the mobile network and its impact on the transport subsystem. The objective of the new approach is to distribute and level the traffic load emerging from the radio part equally throughout the transport network. For example, the base stations should be interconnected with the mobile switching centers in such a way that the signaling traffic is minimized and that switches are equally loaded. Since the offered traffic is represented by the demand nodes in the integrated approach, this concept can be applied once more. However, the investigation in this area is just at the beginning and more research will be necessary in this field.

4 ICEPT PLANNING TOOL

To prove the capability of the new design approach, a prototype of ICEPT (*Integrated Cellular Network Planning Tool*) is implemented and tested on a realistic planning case.

4.1 Tool design requirements

The key design issue for a prototype of a mobile network planning tool is its applicability in reality-close planning cases. It includes the following features: a) use of real-world data, b) a fast network design algorithm, c) scalable accuracy and speed, d) a modular program structure and e) an easy-to-use graphical user interface.

Although ICEPT is still a prototype, it already meets these requirements. Since it is difficult to obtain real offered traffic data of mobile networks, the tool considers only reasonable assumptions about the expected traffic. Future implementations will rely on more accurate input, e.g. official land survey data combined with demographic data.

4.2 Main Components of ICEPT

The current version of the ICEPT tool covers two design aspects of the new approach, the Mobile Subscriber component and the Radio Transmission part. The integration of these aspects is done by the third module of the prototype, the network design algorithm ABPA (*Adaptive Base Station Positioning Algorithm*).

Population Model

In ICEPT the demand nodes of the mobile subscriber model are generated by a self-organizing feature map (SOFM), (cf. [4]). Due to the lack of real user density, for training purposes of the network, it was assumed that the user density is higher in low terrain than in high terrain. Therefore the SOFM adapts the terrain of the investigated area. **Figure 3** shows the topography of the area north-west of Würzburg. The area has a size of $10km \times 10km$. The resulting population model is depicted in **Figure 4**. However,

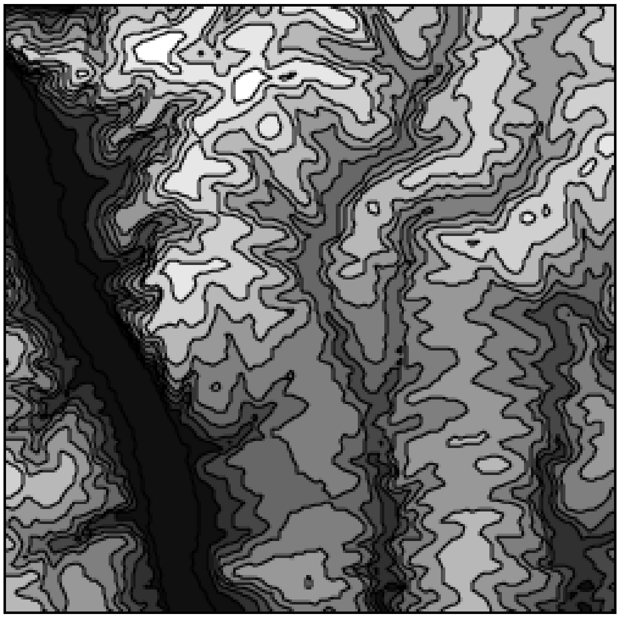

Figure 3: Digital terrain model

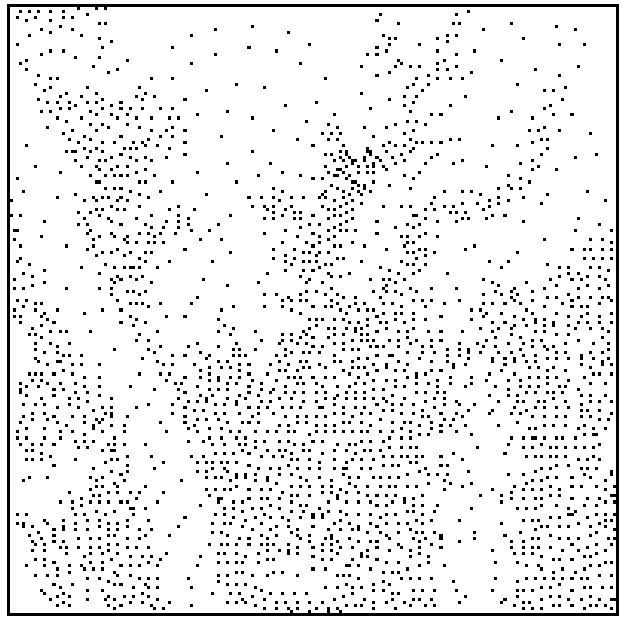

Figure 4: Demand node distribution obtained by SOFM

due to the modularity of ICEPT, this component can easily be replaced by discretization methods which use more realistic land-use data. Currently, stochastic geometry methods are explored for this purpose.

Radio Transmission

The radio transmission module of ICEPT consists of a Fast-Ray-Tracing (FRT) method for field strength prediction (cf. [12]). FRT takes advantage of the topological information inherited in the three-dimensional digital terrain model used in the prototype. In this way, it obtains a significant speed-up of the field strength prediction over common estimation methods.

Moreover, FRT is scalable in accuracy and speed. A faster prediction can be traded for a decreased accuracy. This property of FRT permits that ICEPT can be used for first configuration studies, where no high accuracy is needed, as well as for detailed network planning.

Automatic Network Design

The integration of the design aspects is done by the ABPA algorithm, (cf. [5]). The objective function of ABPA is to maximize the number of uniquely supplied demand nodes, i.e. the demand nodes which belong exactly to one base station, and to minimize the number of unsupplied and multiple-supplied demand nodes. ABPA finds the solution by smoothly increasing the transmitting power and gradually moving the transmitter in the virtual three-dimensional scenario of the planning case. The adjustment of the transmitting power and the displacement of the base station is conducted by the attraction of base stations to unsupplied demand nodes and by the repulsion from multiple-supplied demand points. To prevent ABPA from getting stuck in locally optimal configuration, the algorithm can make transitions to a worse configuration with a predefined probability as in *Simulated Annealing* (cf. [1]).

4.3 Results

To prove the capability of ICEPT, the prototype was tested on the topography northwest of Würzburg. ICEPT was used to find the optimal locations of six transmitters in this terrain. The initial configuration of the transmitter and the demand nodes are depicted in **Figure 5**. **Figure 6** shows the base station locations after 10,000 adaption steps. The transmitters are marked by • and the different supplying areas for the individual transmitters are tagged by various symbols. It can be seen that ABPA reaches a reasonable solution. As expected, it locates the transmitter on the top of hills and near places with high user density, respectively.

5 CONCLUSION

The integrated network planning method presented here is a promising approach to automatic network design. The demand node concept permits a comprehensive integration of different de-

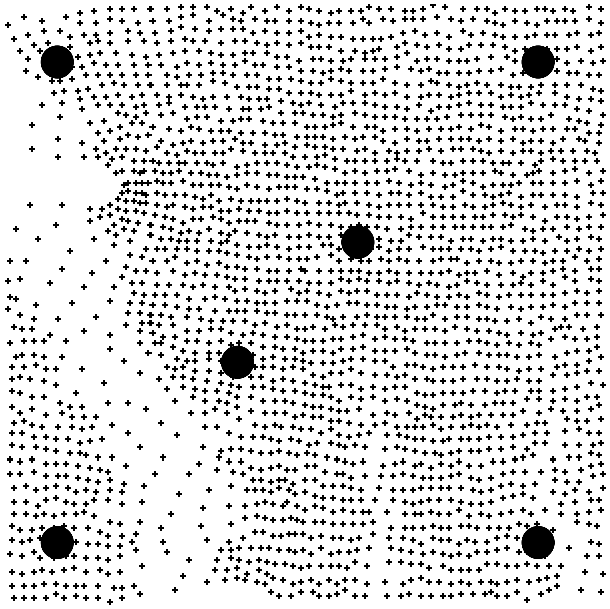

Figure 5: Initial configuration

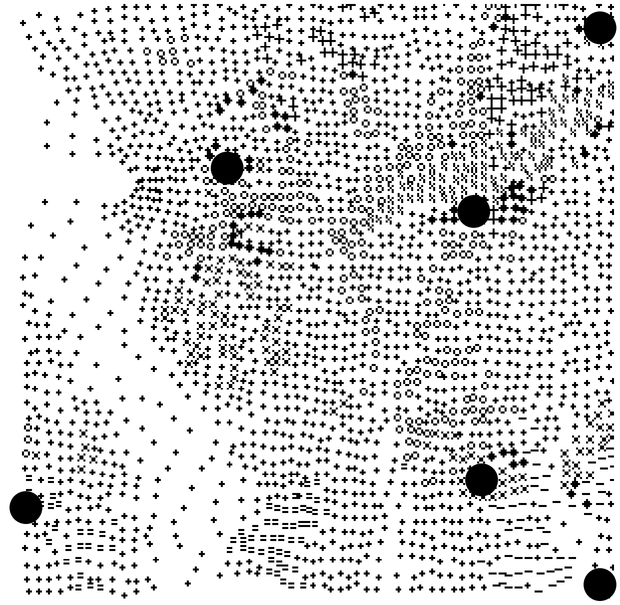

Figure 6: Base station location computed by ABPA

sign aspects into one design method. The new approach can resolve conflicting planning objectives. It obtains solutions which are optimized under more than one aspect. Moreover, the demand node concept allows the application of new efficient methods in cellular mobile network planning. The feasibility of this approach is shown by the ICEPT prototype which integrates in the first implementation phase two main components, the Mobile Subscriber and the Radio Transmission. ICEPT obtains optimized network configurations in reasonable time.
The next step is to integrate in detail other components like the Resource Allocation and the System Architecture as well as to refine the components already integrated.

Acknowledgement: The authors would like to thank Kenji Leibnitz for programming support and Oliver Rose for fruitful discussions during the course of this work.

References

[1] E. Aarts and J. Korst. *Simulated Annealing and Boltzmann Machines*. John Wiley & Sons, Chichester, 1990.

[2] J. B. Andersen, T. S. Rappaport, and S. Yoshida. Propagation messurements and models for wireless communications channels. *IEEE Communications Magazine*, 33(1):42–49, 1995.

[3] G. Calhoun. *Wireless Access and the Local Telephone Network*. Artech House, Inc., Norwood, 1992.

[4] T. Fritsch. Cellular mobile communication design using self-organizing feature maps. In N. Ansari and B. Yuhas, editors, *Neural Networks in Telecommunications*, chapter 11. Kluwer Academic Publishers, Norwell, 1994.

[5] T. Fritsch, K. Tutschku, and K. Leibnitz. Field strength prediction by ray-tracing for adaptive base station positioning in mobile communication networks. In *Proceedings of the 2nd ITG Conference on Mobile Communication '95, Neu Ulm*. VDE, Sep. 26 – Sep. 28 1995.

[6] A. Gamst, E.-G. Zinn, R. Beck, and R. Simon. Cellular radio network planning. *IEEE Aerospace and Electronic Systems Magazine*, (1):8–11, 1986.

[7] B. Gavish and S. Sridhar. Economic aspects of configuring cellular networks. *Wireless Networks*, 1:115–127, 1995.

[8] A. Ghosh and S. L. McLafferty. *Location Strategies for Retail and Service Firms*. Heath, Lexington, MA, 1987.

[9] PLANET. Mobile Systems International Ltd.

[10] S. Subramanian and S. Madhavapeddy. System partitioning in a cellular network. In *Proc. VTC 96*, pages 106–110, Atlanta. USA, May 1996.

[11] G. Tsoulos, M. Beach, and S. Swales. Application of adaptive antenna technology to third generation mixed cell radio architectures. In *Proc. VTC 94*, pages 615–619, Stockholm. Sweden, June 1994.

[12] K. Tutschku and K. Leibnitz. Fast ray-tracing for field strength prediction in cellular mobile network planning. In *Proc. VTC 96*, pages 541–545, Atlanta. USA, May 1996.