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ICEPT – An Integrated Cellular Network Planning Tool

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Abstract: In this paper, we present ICEPT, a new mobile radio network planning tool that is based on an integrated design approach. The new approach starts with the analysis of the spatial distribution of the expected teletraffic within the service area of the cellular system. Employing this principle, the ICEPT tool considers concurrently the four major design areas of cellular networks: Radio Transmission, Mobile Subscriber, Resource Allocation, and System Architecture. ICEPT uses these factors as input for the automatic network design algorithm ABPA which locates the base stations in the supplying area.

I. Introduction

The planning of future cellular mobile radio networks faces four major challenges: *a)* the tremendous world wide increase in demand for mobile telecommunication services; *b)* the extremely limited number of resources in radio networks (e.g. mainly the number of available frequencies); *c)* new emerging technologies like Space Division Multiple Access (SDMA) or Code Division Multiple Access (CDMA) which require more advanced cellular network design methods and *d)* mobile system operators asking for fast and optimal network deployment methods which minimize the required hardware investments and enable a network operation without a long set-up period. Since these challenges state partly contradictory design constraints, an efficient network planning method has to address these objectives in a comprehensive way in order to achieve truly optimized network configurations.

Most conventional mobile network planning tools, such as GRAND (cf. [11]) or PLANET (cf. [13]) are based on the so-called *analytical* design method which was first introduced by Gamst et al. (cf. [6]). This approach separates the network design task in four steps: Radio Network Definition, Propagation Analysis, Frequency Allocation, and Radio Network Analysis; but focuses mainly on modeling the radio wave propagation and the interference analysis. Moreover, the analytical approach neglects important design factors and design areas, like *user behavior*, *demand distribution*, or *core network design*, and does not address the strong interaction among all the design factors. Therefore, planning tools based on the analytical approach can be regarded more as complex desktop calculators which only assist the experienced engineer during the propagation analysis. The cellular network design process still relies on the personal experience of the design engineer.

To obtain an optimal overall network configuration under the new complex constraints, the network design engineer requires a new generation of planning tools which are able to optimize more than one parameter at a time. Additionally, in order to handle a further increase of the expected voice traffic, a network planning tool has to consider the teletraffic issue at a very early stage of the planning process in order to achieve an efficient system configuration. Therefore, the Department of Distributed Systems of the University of Würzburg has developed a prototype for the new generation of planning tools: ICEPT – (Integrated Cellular network Planning Tool. ICEPT obtains optimized network configurations without operator interaction, since it *integrates* the major design factors into the network design process. This characteristic and the fact that emphasis is laid on a demand-based system planning, distinguishes ICEPT from conventional tools.

The paper is organized as follows. In the second section we describe the demand based cellular network planning approach which is realized by ICEPT. We outline the *Integrated Mobile Network Planning Concept* on which ICEPT is based, explain the demand estimation for the *Mobile User Characterization* used within the integrated concept, and describe how an *Automatic Transmitter Locating* is performed by the concept. In the third section we outline the capabilities of the ICEPT tool and in the fourth part we show some first planning results obtained by ICEPT using ABPA (Adaptive Base station Positioning Algorithm). The fifth section summarizes our presentation and gives an outlook on the future development of the ICEPT tool.

II. Demand-based cellular network planning

A. The Integrated Planning concept

The ICEPT planning tool is based on the integrated design concept which was first introduced in [14]. The enhanced concept is depicted in Figure 1. It comprises the four major design aspects of cellular mobile communication systems:

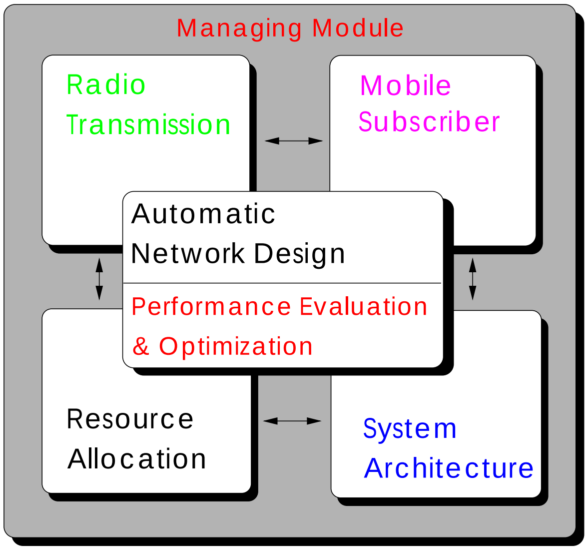


Figure 1: Integrated planning approach

Radio Transmission, Mobile Subscriber, System Architecture, and Resource Allocation. In ICEPT these aspects are represented as independent modules, permitting a generic implementation of the tool; we are denoting these components as the *lower level modules*. The arrows between the lower level modules indicate some of the dependencies among the design factors. For example, there is an arrow between the Radio Transmission and the Resource Allocation since the radio wave propagation determines the wave interference which has to be considered during the frequency allocation. The lower level components are embedded in the Managing Module which conducts the network design process and controls the information flow within the tool.

The integration of the design aspects into the planning process is performed by the Automatic Network Design module. It is the *higher level component* and responsible for obtaining an efficient and feasible network configuration under the different, often contrary, design constraints. As an important feature of the integrated concept, that all lower level modules are contributing equally to the automatic network design.

Due to the modularity, ICEPT can be configured to use modules with various complexities depending on the current design objective. For example, in the case of future micro cell planning the Radio Transmission module can easily be replaced by one which is better suited for this environment.

B. Mobile User Characterization

In contrast to the conventional mobile design method, the new integrated approach considers the expected teletraffic of the service area as an equally contributing factor for the network planning. Moreover, the integrated method starts its network design sequence with an analysis of the expected teletraffic demand within the considered supplying area.

Demand Node Concept

The core technique of the integrated method is the representation of the spatial distribution of the demand for teletraffic by discrete points, called *demand nodes*. Demand nodes are widely used in economics for solving facility location problems (cf. [7]). In the context of the integrated cellular network planning approach, a demand node represents the center of an area that contains a quantum of demand from teletraffic viewpoint, accounted in a fixed number of call requests per time unit. These demand nodes form the common basis of all components in ICEPT (cf. [14]).

The demand node concept leads to a discretization of traffic demand in both space and demand. It constitutes a *static population model* for the description of the mobile subscriber behavior. An illustration for the demand node concept is shown in Fig. 2. In Fig. 2(a) publicly available map data from an area of size $15km \times 15km$ around the city of Würzburg, Germany, characterizes the demand distribution in the *service area*. Fig. 2(b) shows a simplified result of the demand discretization. Here, demand nodes are dense in areas of high demand and sparse in regions of low demand.

Traffic Model and Demand Estimation

Exploiting the above described *demand node concept*, the complete process of the mobile user characterization comprises three phases: ① the preprocessing of the information in the geographical and demographical data base, ② the definition of a spatial traffic model for the teletraffic demand, and ③ the generation of the *discrete* demand node distribution.

Phase ① is required since mostly the data in geographical information systems like ATKIS (cf. [2]) or MapInfo (cf. [12]), is not collected with respect to cellular mobile network planning. Before using this data, the relevant information has first to be extracted from the data base and to be processed in an appropriate way; e.g. it is necessary to assign the land use classes their corresponding teletraffic values per area unit.

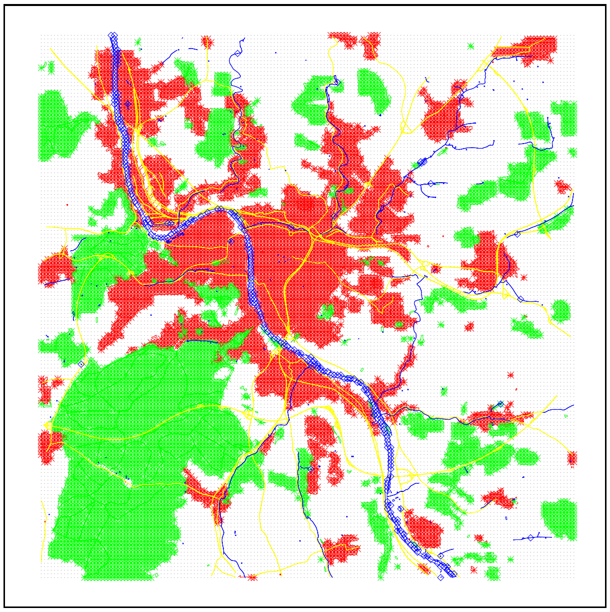
In phase ② of the mobile user characterization, one has to specify the *traffic model* which is valid for the service area. The traffic model estimates the spatial distribution of the total demand for teletraffic $E(x, y)$. In the current version of ICEPT, the total traffic depends on the spatial distribution of the traffic in the various land use categories:

$$E(x, y) = \eta_1 E_1(x, y) + \ldots + \eta_5 E_5(x, y), \qquad (1)$$

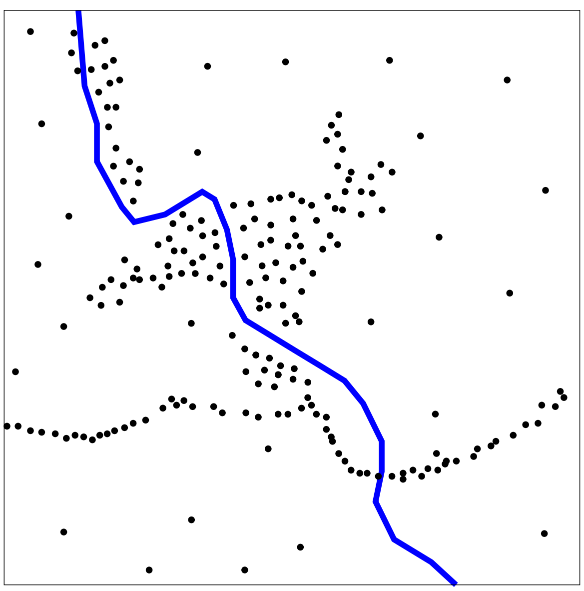
where η_i are scaling factors and $E_i(x, y)$ the expected teletraffic accounted in Erlang originating from land use class i at coordinate (x, y). Due to the nature of the available data, we consider so far five land use categories: urban, vehicular traffic, open area, forest and water. However, since the information in these classes is very limited for mobile network planning, it is indicated to use more accurate data (cf. [8]).

Demand node generation

The generation of the demand nodes in phase ③ of the characterization is performed by a *Recursive Partitioning* algorithm which belongs to the class of *Partitional Clustering* methods (cf. [10]). The algorithm assumes a rectangular shape of the service area and obtains the spatial total teletraffic distribution $E(x, y)$ in this region as input. To generate the demand nodes, the algorithm divides the initial rectangle into two rectangles with the same expected traffic and repeats the splitting of the rectangles until a predefined even recursion depth. In every recursion step, the orientation of the partitioning line is turned by 90^o. The demand node location is the center of gravity of the tessellation pieces when the recursion stops. The use of an even recursion depth assures that all directions of the partitioning line are equally preferred. To illustrate the *Recursive Partitioning* algorithm, in Figure 3(a) we assume a circular continuous teletraffic distribution, with the center of the traffic located in the middle of the service area. Figure 3(b) depicts the discretization obtained after four recursion steps. The numbers next to the partition lines represent the recursion depth.

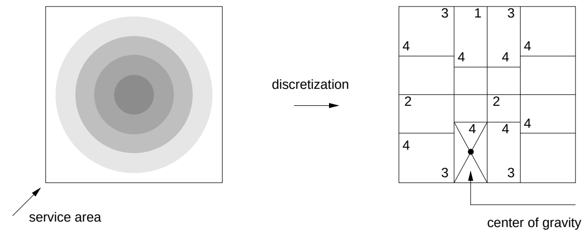


(a) Geographical and demographical data



(b) Demand node distribution

Figure 2: Demand node concept



(a) Continous teletraffic distribution

(b) Partitioned service area

Figure 3: Partitioning of the supplying area for the demand node generation

C. Automatic Transmitter Locating

The demand node concept is very useful for the mobile subscriber characterization. Its additional feature is the transformation of the continuous transmitter location problem into an equivalent discrete optimization problem: supplying users is equivalent to *covering* demand nodes. An algorithm has to determine the location of the transmitters such that the proportion of demand nodes within the permitted service range is maximized. In wireless systems the permitted service range is usually the allowed path loss on the down- and uplink. Hence, the base station locating problem is reduced to a *Maximal Covering Location Problem (MCLP)* (cf. [4]).

The integration of the design aspects is performed by the ABPA algorithm (cf. [5]). The objective of ABPA is to maximize the number of uniquely supplied demand nodes. ABPA finds the solution by smoothly increasing the transmission power and gradually moving the transmitter in the virtual three-dimensional scenario of the planning case. The adjustment of transmission power and the displacement of base stations 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 converging to only locally optimal configurations, the algorithm is allowed to make transitions to a worse configuration with a predefined probability, as in Simulated Annealing (cf. [1]).

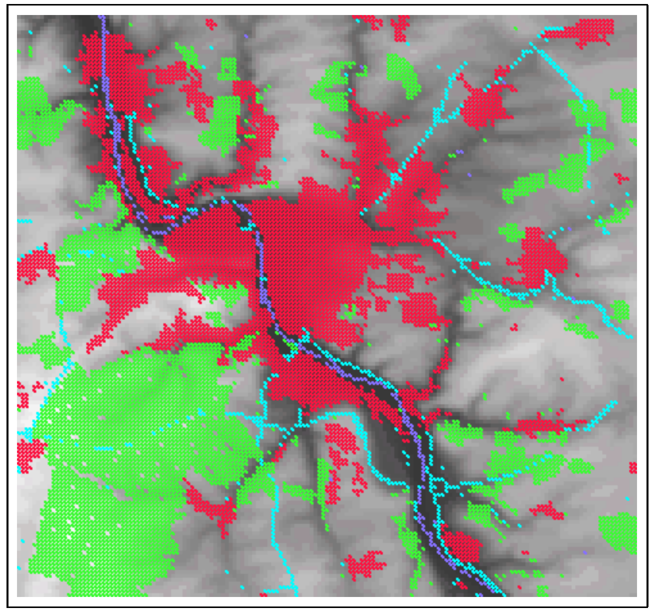
III. The ICEPT Planning Tool

To prove the capability of the new design approach, ICEPT was implemented at the University of Würzburg and tested on a realistic planning case. Despite being a prototype, ICEPT already includes the following features: use of real–world data, a fast network design algorithm, scalable accuracy and speed, a modular program structure, and an easy–to–use graphical user interface.

The current version of ICEPT 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 a third module, the network design algorithm ABPA.

The mobile subscriber component is represented by a distribution of demand nodes. It is created using the partitional clustering algorithm introduced in Section II. Figure 4(a) shows the continuous demand distribution of the investigated area around the city of Würzburg, Germany. The land use classes are superimposed on the digital terrain model. The continuous demand distribution was obtained by processing the information of the ATKIS map data base for Würzburg. The resulting discrete population model is depicted in Figure 4(b). Currently, methods which use more accurate geographic and demographic data are investigated.

The radio transmission module of ICEPT consists of a Fast-Ray-Tracing (FRT) method for field strength prediction (cf. [15]). FRT takes advantage of the topological information inherited in the three-dimensional digital terrain model used by the prototype. Thus, the field strength prediction is significantly speeded-up compared to conventional estimation algorithms. Additionally, the two standard two-dimensional prediction methods Hata (cf. [9]) and Cost231 (cf. [3]) are also implemented.



(a) Land use classes superimposed on the digital terrain model

(b) Demand node distribution

Figure 4: Input data for ICEPT

IV. Results

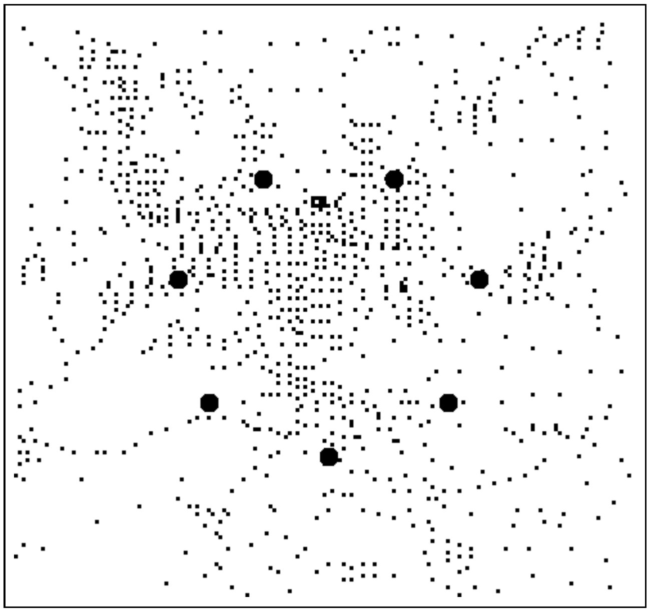
To prove the practical use of ICEPT, the tool was tested on the topography around the city center of Würzburg. ICEPT was used to find the optimal locations of seven transmitters in this terrain. The initial configuration of the transmitters and the demand nodes is depicted in Figure 5(a).

Figure 5(b) shows the resulting base station locations after 10000 adaption steps. The different supplying areas for the individual base station are marked by splines surrounding the set of demand nodes which are supplied by this transmitter. We point out that ABPA converges in every simulation run to a reasonable solution. As expected, it locates the transmitter on the top of hills and near places with high user density, respectively. For this rather difficult terrain, ICEPT obtains a *user coverage* of almost 80%.

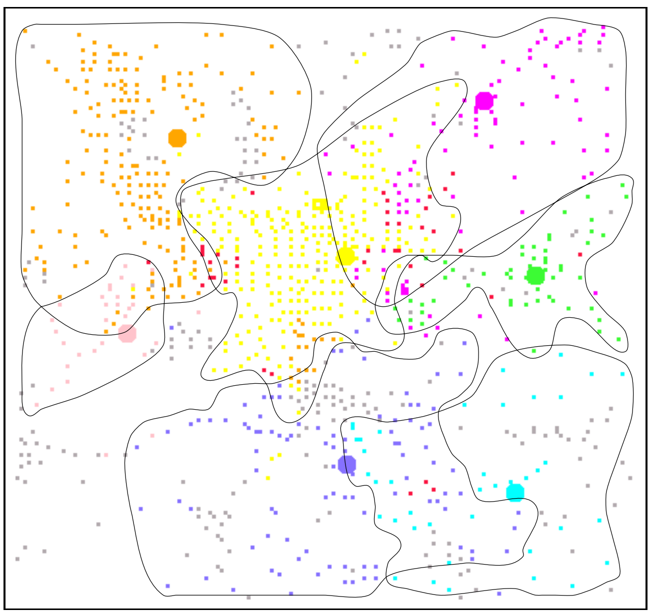
However, since the wave interference between the frequencies assigned to the transmitters is so far not considered by the ICEPT prototype, the ABPA algorithm locates the base stations also on hill tops. To overcome this disadvantage, interference constraints will be included in the next version.

V. Conclusion and Outlook

ICEPT is among the first tools in cellular planning that considers all four major design aspects of mobile radio systems at a time. Its appealing features are: *a)* the analysis of the spatial distribution of the teletraffic demand and *b)*



(a) Initial configuration



(b) Resulting base station locations

Figure 5: Graphical output of an ICEPT session

the integration into an automatic network design method. ICEPT has proven its practical usability on realistic planning cases.

In future versions of ICEPT, we enhance the integration of the design factors Resource Allocation and System Architecture. Especially, methods and components for the planning of CDMA networks are under investigation. This technique requires that many design factors have to be addressed in parallel during the network design. For example, since every user constitutes an interferer in a CDMA system, the "cell size" depends on both the radio wave propagation and the number of subscribers in the "cell".

We estimate that ICEPT's first application will be either a "from scratch" planning of a new mobile network or an evaluationary, optimizing redesign of an existing configuration. The latter point will become more and more important since, under the assumption of further growth, today's networks will reach their capacity limits soon. ICEPT is currently being investigated by Nortel Wireless Networks, Richardson, TX, to be used for commercial network planning.

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References

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

[2] ATKIS. Amtliches Topographisches Kartographisches Informations System; Bavarian land survey office, Munich, FRG, 1991.

[3] COST231. Evolution of land mobile radio (including personal) communications. Technical report, Commision of the European Communities, 1994.

[4] Z. Drezner. *Facility Location: A Survey of Applications and Methods*. Springer, New York, 1995.

[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, February 1986.

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

[8] S. Grasso, F. Mercuri, G. Roso, and D. Tacchino. DEMON: A forecasting tool for demand evaluation of mobile network resources. In *Proc. Networks '96*, pages 145–150, Sydney, Australia, November 1996.

[9] M. Hata. Empirical formula for propagation loss in land mobile radio services. *IEEE Transactions on Vehicular Technology*, 29(3):317–325, August 1980.

[10] A. K. Jain and R. C. Dubes. *Algorithms for Clustering Data*. Prentice Hall, Englewood Cliffs, NJ, 1988.

[11] M. Kr"uger and R. Beck. GRAND - Ein Programmsystem zur Funknetzplanung. *Philips: Technische Mitteilung*, (2):7–12, 1990.

[12] MapInfo. MapInfo Cooperation, Troy, NY.

[13] PLANET. Mobile Systems International Ltd.

[14] K. Tutschku, N. Gerlich, and P. Tran-Gia. An integrated approach to cellular network planning. In *Proceedings of the 7th International Network Planning Symposium (Networks 96)*, 1996.

[15] K. Tutschku and K. Leibnitz. Fast ray tracing for field strength prediction in cellular mobile communication networks. In *Proceedings of the IEEE/VTS 46th Vehicular Technology Conference, Atlanta*, pages 541–545. IEEE, 1996.