Thesis Proposal

M.S. Thesis Proposal

Abdul Subhan

Student ID: 230435

Computer Engineering Department

College of Computer Sciences & Engineering

King Fahd University of Petroleum & Minerals

Contents

Abstract

Network planning in mobile telephony entails planning of the supporting, switching, signalling and interconnection networks. This is a particularly complex process, partly because of the numerous intervening factors and partly because there are variable environmental conditions which must be taken into account in order to provide the user with a specified quality of service at any time.Given the intrinsic complexity of the problem and the high volume of information that has to be handled, network planning should be supported by good network design applications.

In this project we will consider the problem of assigning cells to switches in Cellular Mobile Network. First, we review the process of the cellular mobile network planning and specific problem of cell to switch assignment and few well known methods that have been proposed so far. Then, we suggest a simple formulation for the problem. This is an NP(Non Polynomial time) hard problem since this problem falls under the category of the Quadratic Assignment Problem (QAP)which is a proven NP hard problem. There are no known deterministic algorithms which can find an optimal solution for the above problem in polynomial time.Thus we solve this problem using Iterative heuristics to provide solutions based on different heuristics and compare them with existing methods. These methods are completely innovative formulation of problem and involve application of Evolutionary Computing for this complex problem that may be extended to solution of similar problems in VLSI design, distributed computing and many other applications.

Keywords: Network planning, Cellular Mobile Network, Assignment, Quadratic Assignment Problem, Heuristics, Evolutionary Computing.

1 Introduction

Mobile telephones are used extensively in the world today. The first steps were set in the forties, but the growth really stepped up in the last decade and the expectation is that the growth is going to be exponential in the near future.This exponential growth is possible because the cellular concept makes it possible for users to have freedom with respect to mobility and ease of use, while still receiving a good quality of service.Cellular networks are inherently scalable [1].

To manage this growth is a tremendous task. The first GSM networks came into service in 1992. By the middle of 1995, 75 networks were in service, in 45 countries, serving around 8 million subscribers. This represents a rapidly growing proportion of the world's total mobile phone users and more than 500,000 new subscribers a month are joining GSM and PCS networks.

Due to the huge amount of subscribers, scares available network resources and intensive competition in the telecommunication market, having more efficient and demand adaptive network design is a key factor for survival of cellular mobile network providers. Besides, the upcoming applications of cellular mobile network systems for data communication (3G, 4G and UMTS) requires more optimization demands in every aspect of technology including more optimum and flexible network structure.

In order to understand the main purpose of this project, it would be helpful to briefly review the typical cellular mobile network structure and define the key concepts of planning.

2 Background

2.1 Basics Of Communication Network

Telecommunications is the communicative technology of transmitting signals in the forms of voice, information, image, etc., which can be characterized into two types

- Fixed-line Communication Networks, including basic telephone, international telephone, public telephone and internet, etc.
- Wireless Communication Networks, including mobile phone, paging and trunked mobile, etc.

The basic purpose of mobile and fixed telephone networks is to provide voice communication between their own customers and between these and the customers of other networks, in optimum conditions of quality and price. In other words, they must provide a system of communication that the customer perceives to be as efficient, simple, fast, reliable and cheap as possible.The basic difference between a fixed network and a mobile network is the medium of subscriber access in a fixed network is by subscriber loop, and in a mobile network by radio [2].

2.2 Basics Of Cellular Network

The switching architecture of a cellular network follows a hierarchial approach and is composed of three main types of elements

1. The Base Transceiver Station (BTS)
2. The Base Station Controller (BSC)
3. The Mobile Switching Center (MSC)

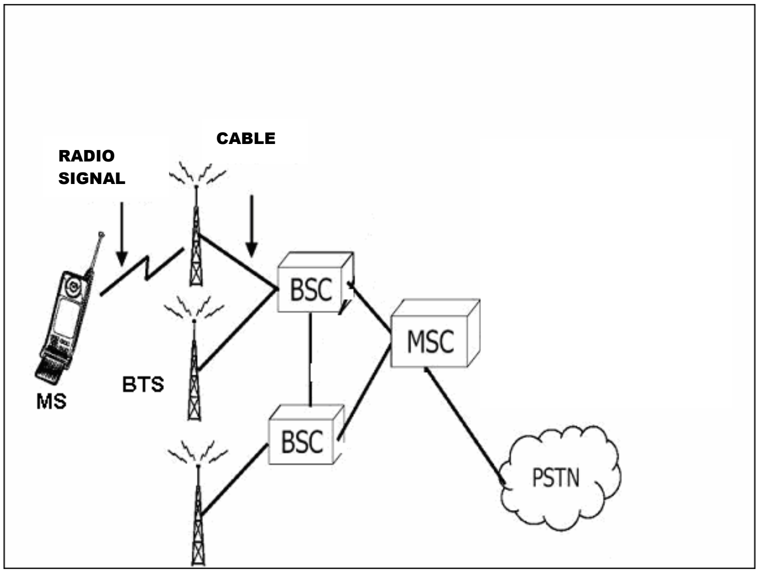

Figure 1: Basic Architecture Of Cellular Network

Mobile Station (MS) It is the user mobile terminal that allows users to communicate, and also provides means of interactions and control between users and the network.

Base Transceiver Station (BTS) The Base Transceiver Station is the entity corresponding to the site communicating with the Mobile Stations. Usually, the BTS will have an antenna with several TRXs (radio transceivers) that each communicates on radio frequency. The link-level signaling on the radio-channels is interpreted in the BTS, whereas most of the higher-level signaling is forwarded to the BSC and MSC.

Base Station Controller (BSC) Each Base Station Controller (BSC) controls the magnitude of several hundred BTSs. The BSC takes care of a number of different procedures regarding call setup, location update and handover for each MS.

Mobile Switching Center (MSC) The Mobile Switching Center is a normal ISDN-switch with extended functionality to handle mobile subscribers. The basic function of the MSC is to switch speech and data connections between BSCs, other MSCs, other Wireless networks and external non-mobile-networks. The MSC also handles a number of functions associated with mobile subscribers, among others registration, location updating and handover. There will normally exist only a few BSCs per MSC, due to the large number of BTSs connected to the BSC.

This report refers to the combination of BSC and MSC as a switch, following a similar reference made in [3]. In a typical cellular network, the area of coverage is often geographically divided into hexagonal cells. The cell is the basic unit of a cellular system. Each cell contains a BTS covering a small geographic area. Each BTS uses an antenna for communications among users with pre-assigned frequencies [4].
The BTS supplies the radio interface to mobile service users within its coverage area. Each BTS is controlled by a BSC which is connected in turn with a switch. The complete design of the mobile service terrestrial network includes the location of the switches, the interconnection layout and dimensioning of the links between these centers and their connection to the public network, and also the allocation of BTSs to switches.

2.3 Combinatorial Optimization

Combinatorial optimization is the optimization of a class of problems concerned with the efficient allocation of limited resources to meet desired objectives when the values of some or all of the variables are restricted to be integral [5] [6]. Constraints on basic resources, such as processing capacity of a switch in a computer network, bandwidth of a link, or cost of link restrict the possible alternatives that are considered feasible. Still, in most such problems, there are many possible alternatives to consider and one overall goal determines which of these alternatives is best.

The versatility of the combinatorial optimization model stems from the fact that in many practical problems, activities and resources are indivisible. Also, many problems have only a finite number of alternative choices and consequently can appropriately be formulated as combinatorial optimization problems – the word combinatorial referring to the fact that only a finite number of alternative feasible solutions exists. Combinatorial optimization models are often referred to as integer programming models where programming refers to "planning" so that these are models used in planning where some or all of the decisions can take on only a finite number of alternative possibilities.

Combinatorial optimization is the process of finding one or more best (optimal) solutions in a well defined discrete problem space. Such problems occur in almost all fields of engineering disciplines (e.g. optimal design of waterways or bridges, VLSI-circuitry design and testing, the layout of circuits to minimize the area dedicated to wires, design and analysis of data networks, solid-waste management, determination of ground states of spin-glasses, determination of minimum energy states for alloy construction, energy resource-planning models, logistics of electrical power generation and transport, the scheduling of lines in flexible manufacturing facilities, and problems in crystallography), as well as in many management fields (e.g. finance, marketing, production, scheduling, inventory control, facility location and layout, data-base management) A survey of related applications of combinatorial optimization is given in [7].

2.4 Iterative Heuristics

Combinatorial optimization problems with multiple objectives or goals are known as multi-objective problems. Achieving multi-objective optimization with the sheer complexity of cellular mobile network design is a NP-hard problem [8] for which conventional constructive techniques have often proved inadequate. Often the solution search space is too complex and vast, whereby these conventional techniques get trapped in sub-optimal solutions. Iterative heuristics on the other hand, have excelled in effectively searching for acceptable solutions for such problems. These heuristics intelligently employ non-determinism to maneuver the search space so as to escape local optimal solutions. A certain class of these heuristics, inspired by nature are referred to as Evolutionary Algorithms. In this thesis, work is focused on a algorithm of this type - Simulated Evolution [9].

The primary advantage of iterative heuristics over conventional constructive algorithms is their probabilistic ability to escape local optima. Among the earliest of these heuristics, Simulated Annealing (SA) was proposed in the early eighties [10] and enjoyed phenomenal success when applied to combinatorial optimization problems from a variety of disciplines. SA is often credited for sparking the research interest in iterative algorithms and is considered a comparison benchmark for new heuristics in its class. It has become customary that every newly reported randomized search heuristic has to prove itself by performing better than SA on a number of (benchmark) test cases. Evolutionary algorithms are a class of iterative heuristics, inspired by natures law of 'survival of the fittest', whereby high-fitness solutions have a high probability of being propagated from one iteration (generation) to the next. This thesis focuses on one such algorithm - Simulated Evolution. A brief explanation of the algorithm is given in the following paragraphs.

Simulated Evolution (SimE) is an elegant and general randomized iterative search heuristic. It adopts the generic state model where a solution is seen as a population of movable elements. Each element i is characterized by a **goodness** measure $g_i \in (0, 1)$. A goodness near 1 indicates a highly fit individual. Starting from a given initial solution, SimE repetitively executes the following steps until stopping conditions are met: Evaluation where the *goodness* is determined for each individual i of the population P. The goodness measure must be a single number expressible in the range $[0, 1]$; Selection which takes the population P together with the estimated *goodness* of each individual i as input and partitions P into two disjoint sets, a selection set P_s and a set P_r of the remaining members of the population; and finally the Allocation step where the two sets P_s and P_r are taken as input and a new population P' is generated containing all the members of the previous population P. The elements of P_s are mutated according to an allocation function $Allocation$. From the results reported in the literature, it is observed that the SimE algorithm is a sound and robust randomized search heuristic. It is guaranteed to converge to a global optimum if given enough time and has modest runtime and space requirements.

3 Literature Review

3.1 Designing Of Mobile Networks

Designing of mobile networks is one of the several computer network design problems. Computer network design problems are numerous and solutions to these problems can lead to better, fast and efficient network and network designs.The problems related to design of computer networks in general can be classified as follows.

1. Protocol specification
2. Performance analysis
3. Design of the network topology
    - Minimal cost multicomodity problem

- Minimal steiner tree problem
- Location problem

As mentioned earlier, the complete design of the mobile service terrestrial network includes the location of the switches, the interconnection layout and dimensioning of the links between these switches and their connection to the public network, and also the allocation of BTSs to switches (in the case of GSM). The design process cannot be tackled as a whole, and so it is normally divided into two parts [11][12][13].

1. Optimization of the access network (all the base stations depending on a switch)
2. Optimization of the transit network (interconnection of switches)

The main focus of this project is on the issue of Optimization of the access network.

3.2 The Planning Methodology

The principal data defining the planning exercise or scenario for designing a mobile network are: the location of each network element (base stations and controllers and/or switches) and the number of radio channels for each BS, the type of equipment which can be installed at each site, and whether or not compression of analog radio channels is possible. On the basis of these data, a software can rapidly generate optimized-cost solutions using the heuristic algorithms. It also automatically determines the switching equipment needed at each site. On the basis of the switching needs at the site, it selects the most economical set of switching equipment according to the defined engineering rules (maximum number of cards to be installed, specified switching capacity, etc.). In this way the proposed solutions conform to all the design constraints supplied by the user.Apart from cost reduction and the network design optimization the secondary aim is to be able to generate orders for transmission lines with the supplier of these, or purchase orders for equipment, on the basis of the information contained in the various reports available to the planner.

3.3 The Basis Of Network Planning

The purpose of network planning is to determine which and how many elements should be used, how and where they should be deployed, and how they should be connected to achieve sufficient network quality and reliability at the lowest possible cost.Three basic structural areas have to be considered in the planning: the switching network, the signalling network and the interconnection with other networks.

4 Problem Description

In section 4.1 we provide a brief review of the various network design problems, their classifications and simple formulations. In section 4.2 we discuss and formulate the specific problem that this project addresses.

4.1 Network Design Problems

Network design problems in general may be specified as follows

Given a set of nodes, build a network that interconnects them, that is, define which links will connect the nodes.The objective is to balance the overall investment in the network (installation of links and switches), versus the operational cost, of which the cost of delays imposed on network users are an important parcel.The main constarints are

1. Capacity of the links and switches

2. Flow conservation
3. End-to-End delay and topology
4. The hierarchical structure
5. Priority
6. Uncertain and variable demand

At an abstract level, general computer network design problems are sometimes also referred to as global computer network design problems. Global computer network design problems are very complex [14]. They can be simplified by grouping them into three categories

1. Design of networks with tree topology
2. Design of networks with distributed topology
3. Design of interconnection of networks

This project involves a cellular network design problem. At an abstract level this problem falls under the first category,design of networks with tree topology.The formulation and details of the design of networks with tree topology problem are stated here. The tree topology design problem in general can be formulated as follows

Given the location of end users, matrix of traffic requirements, delay requirements, reliability requirements, candidate sites for routers and concentrators, and cost elements (line traffic, structure, nodal processor costs, hardware costs).

Find:

1. Number of routers and concentrators to be used and their locations - *Concentrator Location Problem (CLP)*

2. How to connect them with which line capacities - *Telpak Problem*

3. Which stations should be assigned to each concentrator - *Terminal Assignment Problem*

4. How to connect them - *Terminal Layout Problem*

Objective: Minimize the total system cost

Constraints:

1. End-to-End delay

2. Reliability

3. Connectivity

Optimization of cellular network design (Assigning Cells To Switches) falls under the general category of *Terminal Assignment Problem.* The problem is to determine how the connection of BSs to their switches can be implemented so as to minimize overall transmission costs within a service area (normally a provincial area) while guaranteeing certain operating conditions.

4.2 Problem Formulation

In a cellular network, the area of coverage is often geographically divided into hexagonal cells. These cells are hierarchically set to reduce link costs, as illustrated in 2. A certain number of cells are chosen to install switches that communicate with one another and serve as relays for communication between any pair of cells. For various reasons, and above all because of mobility, switches serving as relays to a given user could change if the latter moves from its current cell. The operation that consists in detecting that a user has changed a cell and carrying out the required updates constitutes a handoff.

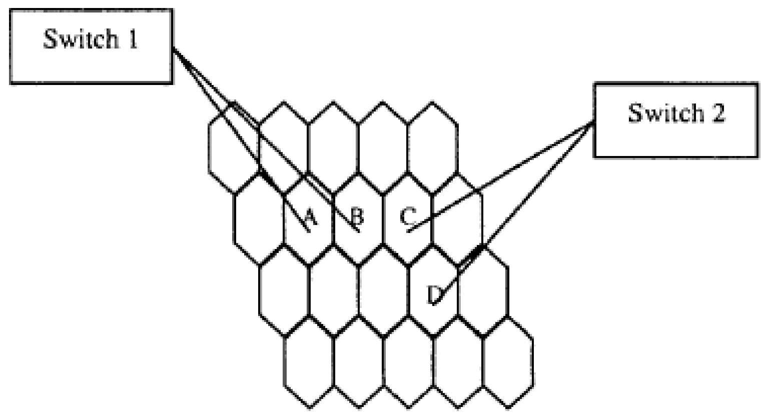

Figure 2: Geographic division in a cellular network and handoff between switches

When a handoff occurs between two cells linked to the same switch, it is called a simple handoff, because there are few necessary updates. On the other hand, a complex handoff describes a handoff between two cells related to different switches. This is because, in this case, update procedures consume more resources than in the case of a simple handoff. For example, in 2, a user who moves from cell B to cell A causes a simple handoff. The networks database that keeps in memory the switch (managing each user) does not need an update. Only Switch 1 is used for this procedure and no other network entity intervenes. However, if a user moves from cell B to cell C, we are in the presence of a complex handoff. Switches 1 and 2 have to exchange information on the user, and the database must also be updated. Furthermore, if Switch 1 is in charge of the billing, the handoff cannot simply replace Switch 1 with Switch 2. Communications between the two switches continue to be relayed through Switch 1 even after the handoff. Thus, we would have a connection to Switch 2, then to Switch 1, and finally to the network. The cost of such a complex handoff is, therefore, higher than that of a simple handoff. When the handoff frequency between cell B and cell A (2) is very high, while the handoff frequency between cell B and cell C is low, it becomes reasonable to connect cells A and B to the same switch.

Thus, the problem of cell assignment could be summarized as follows: for a set of cells and switches (whose positions are known), assign the cells to the switches in a way that minimizes the cost function. The cost function integrates a component of link cost and a component of handoff cost. The assignment must take into account the switches capacity constraints that make them capable to host only a limited number of calls.

We now give a mathematical formulation for the problem of assigning cells to switches in a cellular network.This formulation is based on so called conventional methods in cell to switch assignment problem. Only the complex handover cost and link cost between cells and switches with respect to the maximum switch capacity constraints, is considered in this formulation. With this assumption we will derive this mathematical foundation in this section.

Let n be the number of cells to be assigned to m switches. Assume that the location of cells and switches are fixed and known. Let H_{ij} be the cost per unit of time for a simple handover between cells i and j involving only one switch, and H'_{ij} the cost per time unit for a complex handover between cells i and j $(i, j = 1, 2 \ldots, n \quad with \quad i \neq j)$ involving two switches. H_{ij} and H'_{ij} are proportional to the handover frequency between cells i and j that could be measured or estimated. Let C_{ij} be the amortization cost of the link between cell i and switch $k(i = 1, 2 \ldots, n \quad and \quad k = 1, 2, \ldots, m)$ and λ_i the number of calls per time unit destined to cell i. The capacity of a switch k is denoted by M_k.

Let us define:

$$x_{ij} = \begin{cases} 1 & \textit{if cell } i \textit{ is related to switch } k \\ 0 & \textit{otherwise} \end{cases}$$

$$z_{ijk} = x_{ik}x_{jk} \qquad for \quad i,j = 1,2\ldots,n \quad and \quad k = 1,2,\ldots,m \quad with \quad i \neq j$$

$$y_{ij} = \sum_{k=1}^{m} z_{ijk} \qquad for \quad i,j = 1,2\ldots,n \quad with \quad i \neq j$$

z_{ijk} is equal to 1 if cells i and j, with $i \neq j$, are both connected to the same switch k, otherwise z_{ijk} is equal to 0. y_{ij} takes the value 1 if cells i and j are both connected to the same switches and the value 0 if cells i and j are connected to different switches.

The cost per time unit f could be calculated as:

$$f = \sum_{i=1}^{n}\sum_{k=1}^{m} c_{ik}x_{ik} + \sum_{i=1}^{n}\sum_{j=1,i\neq j}^{n} H'_{ij}(1-y_{ij}) + \sum_{i=1}^{n}\sum_{j=1,i\neq j}^{n} H_{ij}y_{ij} \qquad (1)$$

The first term of equation represents the link cost. The second term takes into account the complex handover cost, and the third, the cost of simple handover. We should keep in mind that the cost function is quadratic in x_{ik}, because y_{ik} is quadratic function of x_{ik}.

The assignment of cells to switches is subject to a certain number of constraints. Each cell must be assigned to only one switch, which is translated by:

$$\sum_{k=1}^{m} x_{ik} = 1 \qquad for \quad i = 1,2\ldots,n \qquad (2)$$

If λ_i denotes the number of calls per time unit destined to cell i, the limited capacity of switches imposes the following constraint:

$$\sum_{i=1}^{n} \lambda_i x_{ik} \leq M_k \qquad for \quad k = 1,2\ldots,m \qquad (3)$$

According to which the total load of all cells which are assigned to the switch is below the capacity of the switch. Finally, the constraints of the problem are completed by:

$$x_{ik} = \quad 0 \quad or \quad 1, \quad for \quad i = 1, 2 \ldots, n \quad and \quad k = 1, 2 \ldots, m \tag{4}$$

$$z_{ijk} = x_{ik}x_{jk} \quad and \quad i, j = 1, 2 \ldots, n \quad and \quad k = 1, 2 \ldots, m \tag{5}$$

$$y_{ij} = \sum_{k=1}^{m} z_{ijk} \qquad for \quad i, j = 1, 2 \ldots, n \tag{6}$$

The problem then is minimized to (1) under (2)-(6). When the problem is formulated as (1), it cannot be solved with a standard way such as linear programming, because constraint (5) is not linear. Merchant and Sengupta [15] [16] replaced it by the equivalent set of constraints:

$$z_{ijk} \leq x_{ik} \tag{7}$$

$$z_{ijk} \leq x_{jk} \tag{8}$$

$$z_{ijk} \geq x_{ik} + x_{jk} - 1 \tag{9}$$

$$z_{ijk} \geq 0 \tag{10}$$

We can further simplify the problem by posing:

$$h_{ij} = H'_{ij} - H_{ij} \tag{11}$$

h_{ij} refers to the reduced cost per time unit of a complex handover between cells i and j. Objective function (1) could be rewritten as follows:

$$f = \sum_{i=1}^{n} \sum_{k=1}^{m} c_{ik}x_{ik} + \sum_{i=1}^{n} \sum_{j=1, i \neq j}^{n} h_{ij}(1 - y_{ij}) + \underbrace{\sum_{i=1}^{n} \sum_{j=1, i \neq j}^{n} H_{ij}}_{constant}$$

The assignment problem takes the minimization of following cost function subject to constraints (2)-(4) and (6)-(10):

$$f = \sum_{i=1}^{n} \sum_{k=1}^{m} c_{ik}x_{ik} + \sum_{i=1}^{n} \sum_{j=1, i \neq j}^{n} h_{ij}(1 - y_{ij}) \tag{12}$$

Now this problem becomes a valid integer programming and can be solved by combination of linear programming and branch-and-bound algorithm [10].

5 Approach

5.1 Optimization Methods and Algorithms

Network topology optimization is one of the classic problems in network design and is frequently cited and discussed in the literature.The basic purpose of design is generally to minimize the cost, but the constraints vary widely according to the type of network (packets or circuits, access or transit, etc.). As a result, a number of solutions have been proposed over the years, none of which are sufficiently general.The reason is quite simple: this is a problem of combinational optimization, in which the cost function is, moreover, not linear. This is the kind of problem that is considered "difficult" in mathematical optimization theory, where they are classified as NP-hard problems. The solution of problems of this type on the scale which is normally demanded (a hundred nodes or so) generally requires the use of heuristic algorithms. These algorithms do not pretend to guarantee that the solutions provided will really be optimal, as they are intended rather to achieve reasonable execution times, and in many cases more flexible treatment of constraints.

5.2 Motivation For Mobile Network Optimization

Optimization of the transmission infrastructure (access network) used to connect base stations with the other terrestrial network elements (switches) in a mobile network can be of considerable help in reducing the overall cost of the network to a mobile telephone operator. One of the largest items of infrastructure expenditure is transmission; transmission costs are chiefly generated by the interconnection of base stations with the rest of the terrestrial network. For a mobile/cellular network, careful planning is required as it is not generally obvious how many sets of equipment are needed and where exactly they should be located for minimization of the overall network cost.

Cost reduction is not possible without addressing another aspect of crucial importance: service quality. One of the factors that most directly affect the quality perceived by the customer is availability of the service. That availability can only be kept as high as possible by avoiding over-concentration, or else equipping the network with additional capacity in terms of infrastructure and healing mechanisms to re-establish communication in the event of equipment or link failure.

In order to adopt a systematic approach to the process of planning the network that interconnects the base stations with the other elements of the terrestrial network, algorithms are used to search for lowest-cost solutions which conform to the design constraints imposed by the network planner. There is a need to employ heuristic algorithms, given that cost optimization entails solving a NP type optimization problem for which there are no known exact algorithms that can be executed in acceptable computer times.

6 Objectives

6.1 Tools For Network Planning

Planning of a mobile telephone network requires analysis of various alternative network designs in order to arrive at a compromise between the performance of each one and the cost of bringing it into service.The problem is further complicated by the fact that a mobile telephone service produces equal amounts of conversation traffic (calls) and signalling traffic (necessary for call and circuit management and exchange of information between network elements).

Planning is an extremely laborious process, especially in a large network, given the difficulty of calculation, the volume (and the variety of data to be handled) and the numerous options that have to be considered. Good planning tools are therefore essential for the different aspects of network planning, as they provide fast, simple and accurate assessment of solutions. The main purpose of these tools is to support the planner in the technical design of the network, relieving him of much of the complex calculation (frequent and repetitive in the network segments) and enabling him to concentrate on weighing up the alternatives proposed and analyzing their results. This speeds up decision-making considerably.

Unfortunately no such comprehensive tool exists which can aid in the designing of a cellular network. The main objective of this project is to come up with heuristics, mainly evolutionary and iterative heuristics, that can provide solutions to the problem of assigning cells to switches (BTSs to BSCs) of a cellular network such that the resultant cost of cabling and hand-offs between the cells is minimum. These programs can be later integrated together to form a complete software tool to aid in the designing of the cellular network.

6.2 Task Breakdown

The project will include study of present methods for solving the problems of cellular network design in general and the problem of assigning cells to switches in a cellular network. Iterative heuristics will be developed to solve the problems. Following is a task list that will be followed for this project.

Task 1: Literature review of recent work related to various methods of Mobile Cellular network Design.

Task 2: Investigation of different strategies for application of iterative heuristics in relevance to the Mobile Network Cell to Switch Assignment problem.

Task 3: Collection of data and tools for implementation, analysis and performance evaluation of the proposed Algorithms.

Task 4: Design, modelling and implementation of Simulated Annealing and Tabu Search Algorithm for the problem.

Task 5: Design, modelling and implementation of Simulated Evolution Algorithm for the problem

Task 6: Formulation of problem with the extra constraints of port capacity on switches and application of Simulated Annealing, Tabu Search and Simulated Evolution Algorithms.

Task 7: Compilation of the results and comparison of proposed Iterative Heuristic implementations in terms of their convergence rates, quality of solution as well as run-times.

7 Conclusion

Global computer network design problem is very complex and there is no general formulation of it. Complexity is generally overcome by defining simplifications. Network design problems include several OR problems, which are modelled as mathematical programming problem. The techniques used are often heuristic methods (to obtain approximate solutions) and lagrangian relaxation (to obtain lower bounds). A possible research direction consists in the use of modern heuristic techniques such as tabu search, simulated annealing and genetic algorithms.

Cost optimization is a complex task in which the planner has to carefully weigh the available alternatives to the mobile telephone operator. The saving in transmission lines must more than offset the investments in equipment with higher network capabilities and cannot be made at the expense of transmission network availability, as this would negatively affect the quality of the service offered to the customer.

To provide support for decision-making, softwares must be developed, which in addition to numerous utilities for data handling and network analysis, supplies cost-minimizing algorithms which are compatible with the design constraints imposed by the technology that mobile service provider uses. With this methodology it is possible to rapidly assess various design alternatives and carry out studies on the sensitivity of solutions to variations in demand or in the unit cost of equipment or circuits.

References

[1] Peter Kriens. Cellular network management. *http://www.aqute.biz*, October 1997.

[2] F. S. Arana Camara, A. Bartolome Santos, G. Parames Lasheras, and F. Fernandez Cuesta. Planning of the switching and control network in mobile telephony. *Telefonica Moviles:Special Issue On Mobile Services*, December 1997.

[3] S. Pierre and F. Houeto. Assigning cells to switches in cellular mobile networks using taboo search. *Systems, Man and Cybernetics, Part B, IEEE Transactions on*, 32(3):351–356, June 2002.

[4] S. Menon and R. Gupta. Assigning cells to switches in cellular networks by incorporating a pricing mechanism into simulated annealing. *Systems, Man and Cybernetics, Part B, IEEE Transactions on*, 34(1):558–565, February 2004.

[5] Sadiq M. Sait and Habib Youssef. *VLSI Physical Design Automation: Theory and Practice*. McGraw-Hill Book Company, Europe, 1995.

[6] Sadiq M. Sait and Habib Youssef. *Iterative Computer Algorithms and their Application to Engineering*. IEEE Computer Society Press, December 1999.

[7] M Grotschel. Discrete mathematics in manufacturing. *Proceedings of the Second International Conference on Industrial and Applied Mathematics, SIAM*, pages 119–145, 1992.

[8] M. R. Garey and D. S. Johnson. *Computers and Intractability: A Guide to the theory of NP-Completeness*. W. H. Freeman, San Francisco., 1979.

[9] R. M. Kling and P. Banerjee. ESP: Placement by Simulated Evolution. *IEEE Transactions on Computer-Aided Design*, 8(3):245–255, March 1989.

[10] S. Kirkpatrick, Jr. C. Gelatt, and M. Vecchi. Optimization by simulated annealing. *Science*, 220(4598):498–516, May 1983.

[11] F. J. Jariego Fente, J. A. Herrera Vicente, A. Ruiz Cantera, and R. Gomez Villagran. Planning of the base station interconexion network. *Telefonica Moviles:Special Issue On Mobile Services*, December 1997.

[12] J. Button, K. Calderhead, I. Goetz, M. Hodges, R. Patient, R. Pilkington, R. Reeveand, and T. Tattersall. Mobile network design and optimization. *BT Technol*, 14(3):29–46, 1996.

[13] B. Jabbari, G. Colombo, A. Nakajima, and J. Kulkarni. Network issues for wireless communications. *IEEE Comm. Magazine*, January 1995.

[14] V.J.M. Ferreira Filho and R.D. Galvao. A survey of computer network design problems. *Investigacio Operativa*, 4(2):183–211, 1994.

[15] A. Merchant and B. Sengupta. Assignment of cells to switches in pcs networks. *Networking, IEEE/ACM Transactions on*, 3(5):521–526, 1995.

[16] S. Pierre and A. Elgibaoui. A tabu-search approach for designing computer-network topologies with unreliable components. *Reliability, IEEE Transactions on*, 46(3):350–359, 1997.