Global Planning of 3G Networks using Simulated Annealing

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ABSTRACT

In this paper, a simulated annealing algorithm is proposed and studied in order to find "good" feasible solution for the global topology planning problem of Universal Mobile Telecommunications System (UMTS) networks. The latter has been shown to be NP-hard as it is composed of three different subproblems (each one being NP-hard): the cell planning problem, the access network planning problem and the core network planning problem. As a result, we concentrate our effort on the development of an approximate algorithm based on simulated annealing. Numerical results show that quasi-optimal solutions (on average, within 5.26% of the optimal solution) can be found with a relatively short computation time compared to CPLEX.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication; I.2.8 [**Problem Solving, Control Methods, and Search**]: Heuristic methods

General Terms

Design, Algorithms

Keywords

Network planning, meta-heuristic, simulated annealing, 3G networks, UMTS networks.

1. INTRODUCTION

Nowadays, the Universal Mobile Telecommunications System (UMTS) takes a very important role in the wireless communication market. Serious network planning helps network operators to plan/build their network according to the required performance with long term profitability. The primary task of the overall network planning process is the topology planning, which describes the network infrastructure and the required initial investment.

IWCMC'09, June 21-24, 2009, Leipzig, Germany

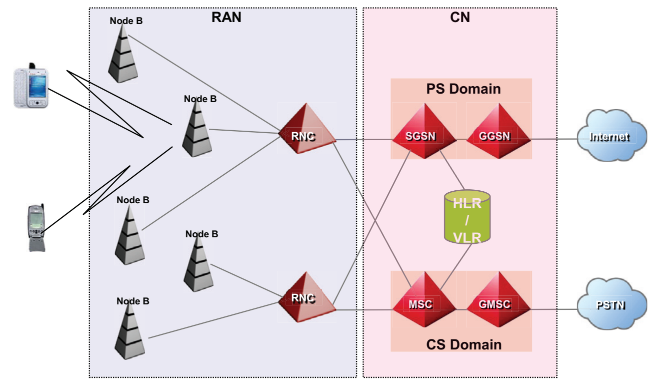

Figure 1: UMTS network architecture

From the network infrastructure point of view, UMTS networks are composed of two parts: the radio access network (RAN), also called the universal terrestrial radio access network (UTRAN), and the core network (CN). The radio access network, which is based on the wideband code division multiple access (W-CDMA) technology, is composed of node Bs and radio network controllers (RNCs). Node B, formerly known as base station in 2G networks, houses the radio transceiver and provides the interface between the radio link and the network itself. The RNC, previously known as base station controller (BSC) in 2G networks, provides connectivity between node Bs and the core network. It is also responsible for the call and mobility management and takes the full charge of radio resource management without involving the core network. The core network includes two domains: a circuit-switched (CS) domain and a packet-switched (PS) domain. On one side, the CS deals with real-time traffic, like voice, and provides connectivity to the public switched telephone network (PSTN). On the other side, the PS handles other types of traffic such as time non-sensitive services and ultimately provides a connection to the public IP network. The CN definitions are based on the 2G/2.5G network specifications. In fact, the CN is using the existing general packet radio system (GPRS) infrastructure, such as the gateway MSC (GMSC), the home location register (HLR) and the visitor location register (VLR) for the CS side and the serving GPRS support node (SGSN) and the gateway GPRS support node (GGSN) for the PS side. A typical UMTS network infrastructure is shown in Figure 1.

To plan UMTS networks, network planners must carefully select the location of all network elements, choose the optimal number and the type of equipment and interconnect them with the proper links. In fact, the planning problem of UMTS networks is very complex to solve. To reduce its complexity, a decomposition approach is usually used. The proposed decomposition breaks down the problem into three different subproblems: the cell planning subproblem, the access network planning subproblem and the core network planning subproblem. The general idea behind the cell planning subproblem is to cover all mobile users in a given region with the minimum number (or cost) of node Bs. Based on the cell planning results, the access network planning will cluster node Bs into different RNC areas [11]. Finally, the main objective for the core network planning is to build a cost-efficient network that will respect the quality of service constraints [14].

It is important to note that each of these three subproblems is NP-hard. In fact, several exact algorithms and approximate methods have been developed to solve each subproblem. Typical works on each subproblems are listed below. For more details on each subproblem and for an extensive literature review, please refer to [15] where a survey on the planning of UMTS networks is presented.

- **Cell planning problem:** [2, 3, 21].
- **Access network planning problem:** [5, 8, 11, 17].
- **Core network planning problem:** [6, 13].

One way to solve the global planning problem of UMTS network is to use a sequential approach where the three previous subproblems are solved sequentially. However, using such an approach will result in suboptimal solutions since interactions between subproblems are not taken into consideration.

A better way to solve the global planning problem is to use a global approach. Since the latter considers the three subproblems simultaneously optimal solutions can be found. In fact, a mathematical formulation has already been proposed for this problem in [16]. However, only small-size instances of the problem can be solved to optimality within a reasonable amount of computation time. To solve this issue, approximate algorithms are required.

In this paper, we propose an approximate algorithm based on simulated annealing that deals simultaneously with the three subproblems mentioned previously. The rest of this paper is organized as follows. In Section 2, we propose a heuristic based on simulated annealing to solve the global UMTS network planning problem. Then, in Section 3, the experiment design is presented followed by preliminary results and analysis in Section 4. Finally, conclusions are outlined in Section 5.

2. SIMULATED ANNEALING

In this section, we put the UMTS network topology planning problem into the framework of the simulated annealing algorithm in order to find solutions that are relatively close to the global optimal.

Simulated annealing, denoted SA, is a powerful algorithmic approach for general combinatorial minimization problems. First proposed by Kirkpatrick *et al.* [9], SA analogizes the physical annealing process in which a solid material is initially heated over the melting point to be liquified with randomly dispersed particles. Then the material is cooled

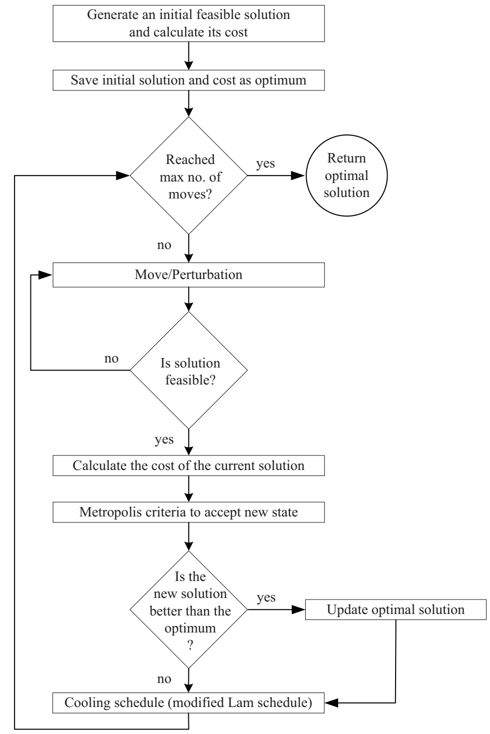

Figure 2: SA algorithm

according to a cooling schedule. At every temperature T, all particles re-crystallize to a more ordered state so as to reach the thermal equilibrium, in which, further state improvement is not expected with high probability. By gradually lowering the temperature in a well-controlled way, the material will finally reach a stable, solid state with the most ordered state and the minimum energy.

In simulated annealing, the cost function is used to evaluate the state during "annealing". The control parameter, represented by the temperature, guides the problem to its final state (also known as solution). If the temperature decreases too fast, the solution might be trapped into local optimum and lead to the final state with higher energy level (i.e. higher cost function value). A well designed cooling schedule for the temperature is the key factor to successfully find the global optimum with an acceptable computation time.

Figure 2 shows our implementation of the simulated annealing algorithm. Most implementations of simulated annealing algorithm start with a randomly generated solution. However, to improve the algorithm efficiency, it has been proposed to start the algorithm with a good quality initial solution. This strategy, called two-stage simulated annealing (TSSA), is able to improve the final solution quality as well as decrease the computation time [18]. To obtain a relatively good (and feasible) initial solution, a local search heuristic can be used. The state/quality of the initial solution will then be evaluated by the cost function, which is represented by the sum of the costs of all installed equipment (node B, RNC, MSC, SGSN) and links.

Based on the initial solution, the SA search process will transform the current state into a new state in its neighborhood. This transformation is also called Markov chain

Table 1: Features of the Node Bs

Type	1	2	3
Capacity (circuits)	100	200	400
Capacity (Mbps)	120	240	480
Number of interfaces	1	2	2
Sensitivity (dBm)	-90	-100	-110
Cost (K$)	20	30	50

Table 2: Features of the RNCs

Type	1	2	3
Switch fabric capacity (Gbps)	2	5	10
Number of node B interfaces	10	20	40
Number of MSC/SGSN interfaces	15	30	60
Cost (K$)	50	90	120

Table 3: Features of the MSCs

Type	1	2	3
Switch fabric capacity (Kcircuits)	100	200	300
Number of interfaces	50	100	150
Cost (K$)	200	350	500

Table 4: Features of the SGSNs

Type	1	2
Switch fabric capacity (Gbps)	20	40
Number of interfaces	16	32
Cost (K$)	40	60

transformation, because the current state only depends on the previous state. In order to select a new state j from the neighborhood of current state i, we used the Metropolis algorithm as proposed in [19]. The latter states that, if the cost difference between two states ($\Delta C_{ij} = C(j) - C(i)$) is smaller than or equal to zero, the acceptance probability for state j to be the next state is set to 1. On the other side, if the difference is greater than zero (i.e. a worse solution is found), then the acceptance probability of the new state will be decided according to the Metropolis criterion. The latter is a 2-step process that works as follows:

Step 1: Generate a random number (RN) between [0,1).

Step 2: If the generated RN is less than $e^{-\Delta C_{ij}/T}$, then set the acceptance probability to 1. Otherwise, reject the solution.

As mentioned above, a well designed cooling schedule is the key for a successful simulated annealing. Several aspects need to be defined for the cooling schedule [19]: initial temperature, decrement rule of temperature, termination condition and the number of iterations at each temperature (i.e. the length of the Markov chain).

Finding a suitable initial temperature is a crucial step for simulated annealing. Since only at the given fixed temperature, metropolis algorithm visits the configurations/states iteratively with a certain probability, it has a chance to miss the best state. The initial temperature has to be set high enough to be able to visit almost any neighborhood state. Meanwhile, it can not be set too high otherwise the search will become completely random and will not act as the defined simulated annealing algorithm. In our implementation, the initial temperature T is set to ten times the highest cost value among the available pieces of equipment.

Based on a series of literature review and several experiments, Swartz and Boyan modified Lam schedule is used to schedule the temperature cooling process. Detailed information about the Lam schedule can be found in [10]. For more information on Swartz and Boyan modification on Lam schedule, please refer to [20] and [4] respectively.

Usually, the stop criterion can either be a suitable final temperature or when the equilibrium is reached. However, Swartz *et al.* [20] proposed a fixed number of moves with a high probability to find the optimum solution. The number of moves is given by the following expression: $1500 \cdot N_c^{4/3}$ where N_c is the number of variables that needs to be solved, such as the total number of potential node locations in the UMTS network design problem.

To get the thermal equilibrium at each temperature T in the cooling sequence, enough perturbations should be done. Constant number of iterations at each temperature is one of the choices. Lundy and Mees, in [12], proposed to do one iteration at each temperature T. This scheme was used in our implementation.

It should be noted that the type of node installed at each site is known at each step of the search procedure. Therefore, it is possible to break the problem into four different subproblems: the TPs to node Bs assignment subproblem; the node Bs to RNCs assignment subproblem; the RNCs to MSCs assignment subproblem and the RNCs to SGSNs assignment subproblem. The first assignment subproblem consists of assigning the TPs to the node Bs while considering the power, the capacity and the signal to interference ratio (SIR) constraints. This subproblem is NP-hard (transformation from the knapsack problem) and to solve it, we use the CPLEX Mixed Integer Optimizer. The other assignment subproblems are also NP-hard and to solve them, we use the shortest augmenting path algorithm LAPJV of Jonker and Volgenant [7].

3. EXPERIMENT DESIGN

In our simulation, only the uplink direction is considered. The latter is very important when the amount of traffic is balanced between the uplink and the downlink direction. To model the traffic, we introduce the notion of test point (TP). Each TP represents a traffic demand corresponding to several co-located mobile users in a given area.

In order to simulate the behavior of the signal propagation, we use the model proposed in [1].

To design the network, three Node B types, three RNC types, three MSC types and two SGSN types are available. Their features are respectively presented in tables 1 to 4. Moreover, OC-3 and OC-12 links can be used to connect the node Bs to the RNCs, DS-3 links are used to connect the RNCs to the MSCs and gigabit ethernet (GE) links are used to connect the RNCs to the SGSNs (see Table 5). The costs of the interface (port) types are also presented in Table 5.

As mentioned in the previous section, the simulated annealing algorithm has several tunable components, which will eventually have an impact on the quality of the final solution. Our implementation of these components can be summarized as follows:

- Initial solution: 2-stage SA. We used a basic local search to find an initial solution;

Table 5: Cost of the links and interfaces

Type	Capacity	Link cost ($/km)	Interface cost
DS-3	2688 circuits	2,500	1,500
OC-3	155 Mbps	1,500	2,000
OC-12	622 Mbps	4,000	4,500
GE	1 Gbps	4,000	2,000

- Initial temperature: 5,000,000 (i.e. 10 times the value of the highest equipment cost);
- Fixed number of total moves: $1500 \cdot N_c^{4/3}$;
- Acceptance/rejection criteria: Metropolis algorithm;
- Cooling process: Swartz and Boyan modified Lam schedule, with a cooling rate of 0.999.

These parameters were selected after many trials. The best results were obtained with those values.

4. RESULTS AND ANALYSIS

In this section, we present the preliminary results to assess the performance of the simulated annealing algorithm. 24 instances of the problem were randomly generated on a $4km^2$ area. For the computing platform, we used a Linux workstation equipped with a 3 GHz CPU and 1 GB memory.

The results are presented in Table 6. The first column represents the problem number and the second column the number of TPs that need to be covered. The next four columns present respectively the number of potential node B locations, the number of potential RNC locations, the number of potential MSC locations and the number of potential SGSN locations. Columns 7 and 8 contain the results obtained by solving the mathematical model as proposed in [16]. CPLEX 10.1.1 is used to solve the model and find the optimal solutions to assess the quality of the proposed algorithm. A CPU time limit (TL) of 30 hours was set for CPLEX. This means that if CPLEX cannot find the optimal solution within 30 hours, it will return the best solution found so far. Columns 9 and 10 present the results obtained with the simulated annealing algorithm, including the value of the solution and the CPU execution time. Finally, the last column shows the gap (expressed as a percentage) between the solution value obtained with the simulated annealing algorithm and the value of the optimal solution.

As we can see from Table 6, the SA algorithm is finding solutions that are relatively close to the optimal solutions. In fact, it found the optimal solution for four different problems out of 24 (16.7% of the time). Overall, the minimum gap is 0%, the maximum gap is 24.93%, the average gap is 5.26% and the standard deviation is 6.38%. Given this, the 90% confidence interval for the average gap is $5.26 \pm 2.23\%$ percent. We can also notice that as the number of TP is increasing, the cost is also increasing. This complies with the fact that if you have more mobile users, then more equipment will be needed in order to cover all the users.

As far as the execution time is concerned, we can see that the SA algorithm can provide relatively good solutions within a reasonable amount of time. In fact, its CPU time increases at a constant rate with respect to the problem size. We can also notice that all the problems were solved within 9,000 seconds. Even if CPLEX is faster for small-size instances, its CPU time is almost increasing exponentially with respect to the problem size. It is important to note that a time limit of 30 hours was used for CPLEX. This means that the CPU time of problems 18 and 24 could have been much longer before CPLEX can find the optimal solution. This behavior is as expected since, as mentioned before, the global UMTS network planning problem is NP-hard. Finally, the small variation in the CPLEX execution time can be explained by the fact that CPLEX is using the branch and bound algorithm.

In the real world planning, UMTS networks can be very large. As a result, the proposed SA algorithm seems more appropriate for solving large size instances of the problem.

5. CONCLUSIONS

Since the global planning problem of UMTS network is NP-hard, approximate algorithms are required to find "good" solutions within a reasonable amount of time. In this paper, we proposed a simulated annealing algorithm in order to solve this problem. The proposed algorithm deals simultaneously with the cell, the access network and the core network planning subproblems.

During the simulation, 24 different problems were randomly generated and solved with the proposed SA algorithm. In order to assess the quality of the algorithm, we compared the results obtained with the exact solutions found by using a commercial solver. The results showed that the proposed algorithm can find solutions that are, on average, within $5.26 \pm 2.23\%$ (90% confidence interval) of the optimal solution. The main advantage with the proposed heuristic is the speed up in term of the CPU execution time. Therefore, larger instances of the problem can be tackled.

Future work will consist in doing more simulation in order to improve the accuracy of the gap. We are also planning to try other meta-heuristics and compare the results.

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Table 6: Simulation results

Problem	TP	Node B	RNC	MSC	SGSN	CPLEX Cost ($)	CPLEX CPU Time (s)	SA Cost ($)	SA CPU Time (s)	GAP (%)
1	5	10	5	5	5	354,045	3	355,653	338	0.45
2	5	20	5	5	5	353,922	24	355,211	64	0.36
3	5	30	5	5	5	355,880	37	383,362	1,332	7.72
4	10	10	5	5	5	381,004	12	410,351	73	7.70
5	10	20	5	5	5	410,286	29	450,386	916	9.77
6	10	30	5	5	5	389,682	66	393,500	1,815	0.98
7	15	10	5	5	5	408,705	4	408,705	393	0.00
8	15	20	5	5	5	408,274	61	408,274	1,098	0.00
9	15	30	5	5	5	407,005	149	407,005	2,655	0.00
10	20	10	5	5	5	433,388	72	444,722	525	2.62
11	20	20	5	5	5	434,191	256	444,113	1,413	2.29
12	20	30	5	5	5	426,377	313	460,405	3,289	7.98
13	25	10	5	5	5	499,261	28	521,083	657	4.37
14	25	20	5	5	5	467,535	507	558,299	2,264	19.41
15	25	30	5	5	5	449,794	20,653	500,980	4,831	11.38
16	30	10	5	5	5	505,226	856	512,300	873	1.40
17	30	20	5	5	5	481,116	6,385	514,427	2,678	6.92
18	30	30	5	5	5	TL(461,927)	108,000	480,496	5,176	4.02
19	35	10	5	5	5	514,474	74	515,185	1,204	0.14
20	35	20	5	5	5	514,925	42,731	554,631	2,367	7.71
21	35	30	5	5	5	484,759	62,458	513,477	6,249	5.92
22	40	10	5	5	5	555,559	3	555,559	987	0.00
23	40	20	5	5	5	522,172	81,681	522,906	2,782	0.14
24	40	30	5	5	5	TL(542,147)	108,000	677,322	8,369	24.93
						Mean				5.26

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