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On the Design of Large-scale Cellular Mobile Networks Using Tabu Search

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1. Introduction

The design of UMTS networks involves optimizing a number of network configuration parameters in order to meet various service and performance requirements. Universal Mobile Telecommunications Service (UMTS) can be viewed as an evolution of the Global System for Mobile communication (GSM) that supports 3G services [18][22]. Generally, a UMTS network is divided into an access network and a core network (Figure 1). The former is dependent upon access technology, while the latter can theoretically handle different access networks. The access network is known as the UMTS Terrestrial Radio Access Network (UTRAN) and comprises two types of nodes: the Radio Network Controller (RNC) and the Node B, which is a base station (BS) [18][22]. It controls the radio resources within the network and can interface with one or more stations (Node Bs).

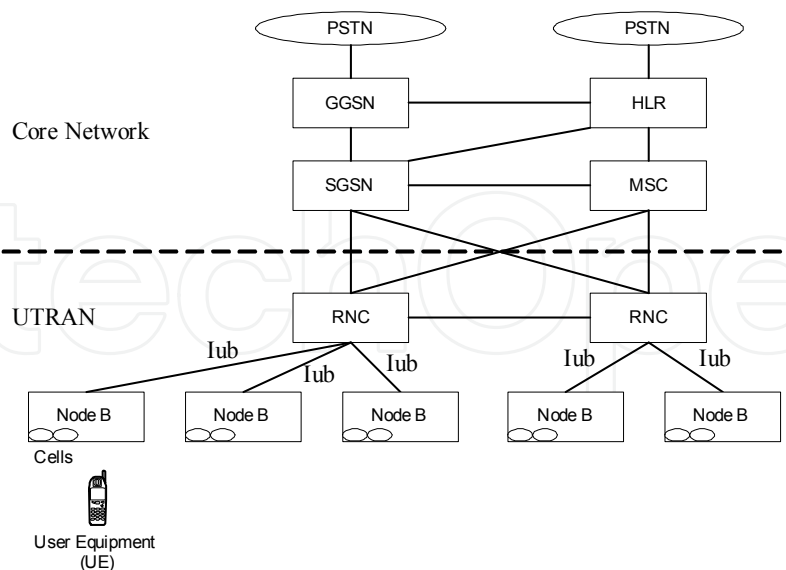


Figure 1. UMTS network architecture

The air interface used between the User Equipment (UE) and the UTRAN is Wideband Code-Division Multiple Access (WCDMA.) The UTRAN communicates with the core network over the Iu interface, which comprises two components: the Iu-CS interface,

Source: Local Search Techniques: Focus on Tabu Search, Book edited by: Wassim Jaziri, ISBN 978-3-902613-34-9, pp. 278, October 2008, I-Tech, Vienna, Austria

supporting Circuit-Switched (CS) services and the Iu-PS interface for Packet-Switched (PS) services [18][22].

In the core network, Mobile Switching Centers (MSCs) are responsible for the circuit-switched location management, while Serving GPRS Support Nodes (SGSNs) assume the packet-switched location management. Both domains are linked through certain interfaces, but the information is kept in separate network entities: the circuit-switched location information remains in the MSC, while the packet-switched location information stays in the SGSN. The Home Location Register (HLR), a common location information database for both domains, contains the network's subscriber profiles. The Gateway GPRS Support Node (GGSN) links a UMTS network and a Public Switched Telephone Network (PSTN).

A Personal Communication Service (PCS) network, such as a UMTS, is a wireless communication network that integrates various services such as voice, video and electronic mail, which are accessible from a single mobile terminal and for which subscribers obtain a single invoice. These various services are offered in a cover zone area that is divided into Node Bs, which manage all the communications within the cell. In the cover zone, Node Bs are connected to special units called Radio Network Controllers (RNCs).

When a user's communication switches from one Node B to another, the new Node B becomes responsible for relaying this communication through the allocation of a new radio channel for the user. Supporting the transfer of the communication from one Node B to another is called a handover. This mechanism, which primarily involves the RNCs, occurs when the level of signal received by the user reaches a certain threshold. There are two types of handovers. In the case of Figure 2 for example, a movement where a user moves from Node B_i to Node B_j is referred to as a soft handover because these two nodes are connected to the same RNC. The RNC which supervises the two nodes remains the same and the cost is low in terms of system resources. On the other hand, a case where the user moves from Node B_i to Node B_k is considered a complex handover. The cost associated to this concept is superior as both RNC 1 and 2 remain active during the handover procedure and the database that contains subscribers' information requires an update.

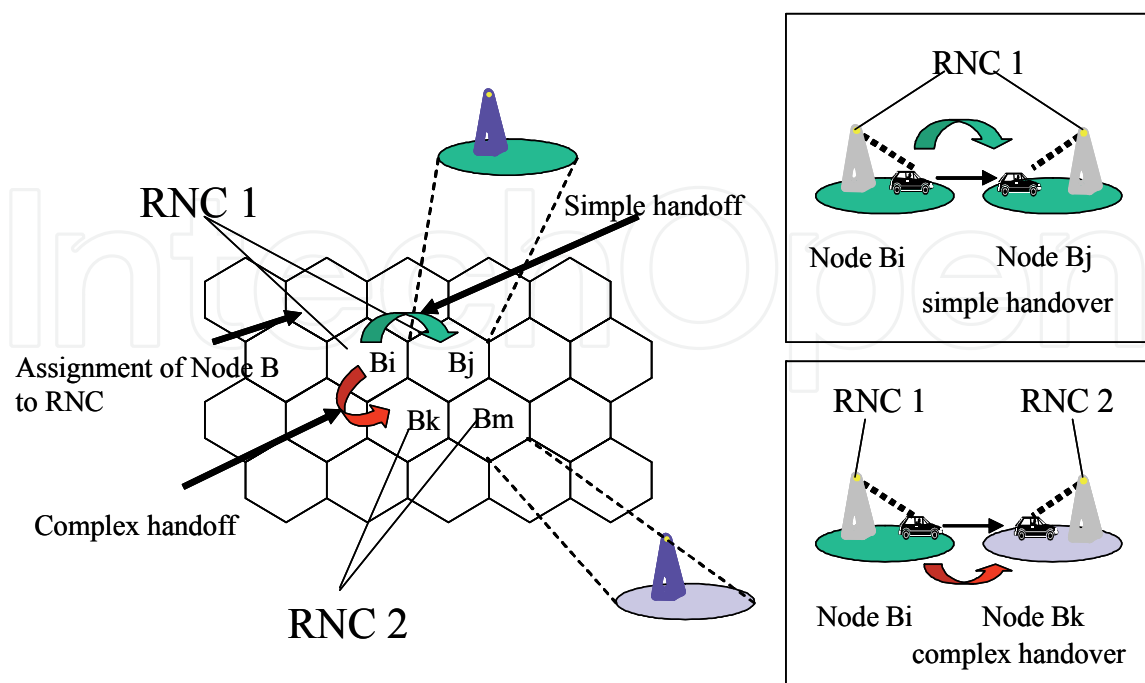


Figure 2. Geographic division in a cellular network

The total operating cost of a cellular network includes three components: the cost of the links between the Node Bs and the RNC to which they are joined, the monthly amortization cost of installed RNCs and the cost generated by the handovers between Node Bs. Therefore, intuitively, it seems more discriminating to join Nodes B_i and B_k to the same RNC, if their handover frequency is high. The problem of assigning Node Bs to RNCs consists essentially of finding the configuration that minimizes the total network operating costs. This problem can be solved by way of an exhaustive search method that would entail a combinatorial explosion and, therefore, an exponential augmentation of execution times [1][14].

This paper proposes a tabu search method to efficiently solve the problem of assigning Node Bs to RNCs in cellular mobile networks. Section 2 provides background and related work. Section 3 describes tabu search method. Section 4 presents some adaptation and implementation details. Finally, Section 5 elaborates on experimental results and compares them to other methods which are well documented in the literature.

2. Formulation of the problem and related work

The assignment problem consists of determining a Node Bs assignment pattern which minimizes a certain cost function, while respecting particular constraints, especially those related to limited RNC capacity [26][27].

Let n represent the number of Node Bs to be assigned to m RNCs. The location of Node Bs and RNCs is fixed and known.

Let H_{ij} depict the cost per time unit for a simple handover between Node B_i and Node B_j , involving only one RNC, and H'_{ij} the cost per unit of time for a complex handover between Node B_i and node B_j ($i, j = 1, \dots, n$ with $i \neq j$), involving two different RNCs. H_{ij} and H'_{ij} are proportional to the handover frequency between Node B_i and Node B_j .

Let c_{ik} denote the amortization cost associated to the link between Node B_i and RNC k ($i = 1, \dots, n; k=1, \dots, m$).

Let INS_k express the monthly amortization cost for each installed RNC k ($k=1, \dots, m$).

Let x_{ik} illustrate a binary variable, equal to 1 if Bs i is related to RNC k ; otherwise x_{ik} is equal to 0.

The assignment of Bs to RNCs is subject to a number of constraints. In fact, each Node B must be assigned to a single RNC, which can be expressed as follows:

$$\sum_{k=1}^m x_{ik} = 1 \quad \text{for } i = 1, \dots, n. \quad (1)$$

Let z_{ijk} and y_{ij} be defined as:

$$z_{ijk} = x_{ik} x_{jk} \quad \text{for } i, j = 1, \dots, n \text{ and } k = 1, \dots, m, \text{ with } i \neq j.$$

$$y_{ij} = \sum_{k=1}^m z_{ijk} \quad \text{for } i, j = 1, \dots, n, \text{ and } i \neq j.$$

z_{ijk} is equal to 1 if B_i and B_j , with $i \neq j$, are both connected to the same RNC k ; otherwise z_{ijk} is equal to 0. Thus, y_{ij} takes the value of 1 if B_i and B_j are both connected to the same RNC and the value 0 if B_i and B_j are connected to different RNCs.

The cost per unit of time f of the assignment is expressed as follows:

Minimize:

$$f = \sum_{i=1}^n \sum_{k=1}^m c_{ik} x_{ik} + \sum_{k=1}^m INS_k + \sum_{i=1}^n \sum_{j=1, j \neq i}^n H'_{ij} (1 - y_{ij}) + \sum_{i=1}^n \sum_{j=1, j \neq i}^n H_{ij} y_{ij} \quad (2)$$

The first term of the equation represents the link cost. The second term takes into account the amortization cost of the installed RNC. The third term deals with the complex handover cost and the last, the cost of simple handovers. We must keep in mind that the cost function is quadratic in x_{ik} , as y_{ij} is a quadratic function of x_{ik} . It also bears mentioning that an eventual weighting could be taken into account, specifically in the link and handover cost definitions.

The capacity (calls per unit of time) of an RNC k is denoted M_k . If λ_i depicts the number of calls per unit of time directed to B_i , the limited capacity of RNCs imposes the following constraint:

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

according to which the total load of all Node Bs that are assigned to the RNC k , is less than the capacity M_k of the RNC. Finally, the problem constraints are completed as follows:

$$x_{ik} = 0 \text{ or } 1 \text{ for } i=1, \dots, n \text{ and } k = 1, \dots, m. \quad (4)$$

$$z_{ijk} = x_{ij} x_{ik} \text{ and } i, j = 1, \dots, n \text{ and } k = 1, \dots, m. \quad (5)$$

$$y_{ij} = \sum_{k=1}^m z_{ijk} \quad \text{for } i, j = 1, \dots, n \quad i \neq j \quad (6)$$

Constraints (1), (3) and (4) pertain to transport problems. In fact, each Node B_i could be likened to a factory that produces a call volume λ_i . The RNCs are then considered as warehouses of M_k capacity where Node Bs production could be stored.

The assignment problem consists of minimizing (2) under (1), and (3) to (6). When formulated that way, the problem cannot be solved with a standard method such as linear programming as Constraint (5) is not linear.

The total cost comprises three components, namely the handover cost between two adjacent Node Bs, installation cost of the RNC, and the cost of the link between Node Bs and RNCs. The design is to be optimized subject to the constraint that the call volume of each RNC must not exceed its call handling capacity. This kind of problem is an NP-hard problem [15], so enumerative searches are practically inappropriate for moderate- and large-sized cellular mobile networks [2][4][15][16]. Since they examine the entire search space in an exhaustive manner to find the optimal solution, they are only efficient for spaces which are relatively small, corresponding to small-sized instances of the problem. For example, for a network composed of m RNC and n Node Bs, m^n solutions must be examined.

Optimization problems arising during the various phases of a network life cycle differ, not only in their objectives, but also in the set of design parameters and the level of detail with which they deal. Mean site-to-site distances, site locations, sectorization, antenna types and average antenna heights are usually addressed in the dimensioning phase [2][25][28].

In [21], an engineering cost model is being proposed to estimate the cost for providing personal communications services in a new residential development. It estimates the expenses of building and operating a new Personal Communication Service (PCS) using existing infrastructures such as the telephone, cable television and cellular networks. In [8], the economic aspects of configuring cellular networks are presented. Major components of costs and revenues as well as the major stakeholders are identified and a model is developed to determine the system configuration (e.g., cell sizes, number of channels, link costs, etc.). For example, in a large cellular network, it is impossible for a Node B located in eastern United States to be assigned to an RNC located in western United States. In this case, the variable link cost is ∞ . The geographical relationships between nodes and RNCs are considered in the link cost value, so that the Node Bs are generally assigned to neighboring RNCs and not to remote RNCs. In [9], various methods are suggested to estimate the handover rate in mobile networks and the economic impacts of mobility on system configuration decisions (e.g., annual maintenance and operations, channel costs, etc.) are addressed. The cost model proposed in this paper is based on [8][9][21].

Wu & Pierre [26][27] propose a strategy designed to solve this problem. The proposed hybrid search strategy is composed of three phases: a constraint satisfaction method with an embedded problem-specific goal to guide the search for an acceptable initial solution, an optimization phase using local search algorithms, such as tabu search [10] and a post optimization phase to improve the solutions generated by the second phase through a constraint optimization procedure. Merchant & Sengupta [15][16] studied this assignment problem. Their algorithm starts from an initial solution, which is improved through a series of greedy moves, while avoiding being stranded in a local minimum. The moves used to escape a local minimum explore only a very limited set of options. Such moves rely on the initial solution and do not necessarily generate an acceptable final solution. Beaubrun et al. [3] use simulated annealing to solve this problem in 2G. *Simulated Annealing* (SA), a stochastic algorithm, introduced by Metropolis et al. [17], is used to estimate the solution of very large combinatorial optimization problems. It represents an effective solution to certain combinatorial optimization problems. Other heuristic approaches have been developed for this kind of problem in 2G networks [6][7][19][20][23][25].

3. Tabu search, simulated annealing and genetic algorithm approaches

Different approaches can be used for assigning of Node Bs to RNC. One can mention heuristic approaches like tabu search, genetic algorithms and simulated annealing.

3.1 Tabu search approach

A *tabu search* method is an adaptive technique used in combinatorial optimization to solve NP problems [7][10]. Nevertheless, it is particularly the local search neighborhood and the way the tabu list is built and exploited that are subject to many variations, which accords tabu its meta-heuristic nature. The tabu list is not always a list of solutions: it can be a list of forbidden moves/perturbations [7]. However, accepting solutions that are not necessary the best introduce a cycle risk, i.e., a return to the solutions that have already been considered, hence the idea of keeping a *tabu list* T of solutions that have already been considered. Thus, during the generation of the set V of neighbour candidates, the solutions in the tabu list are not considered.

On one side, keeping a tabu list allows for avoiding the cycle risk; on the other side, the storage of the solutions that have already been found could require large amount of memory. Moreover, it proves useful to be able to return to a solution that has already been considered, in order to continue the search in another direction. A compromise is reached by keeping a tabu list, which avoids cycles with a length that is less or equal to k . However, a cycle with a length higher than k could always occur.

To minimize the objective function, the tabu search method starts from an initial solution and attempts to reach a global optimum by applying moves that allow the passage from a solution s_i to another solution s_{i+1} chosen in the neighborhood $N(s_i)$ of s_i (the $N(s_i)$ of a solution s_i is defined as the set of solutions that are accessible by applying one move to s_i). At each iteration i , the neighborhood where solutions are selected is redefined as the neighborhood of the current solution s_i . The tabu conditions change and the admissible solutions are no longer the same.

The exploration of the search domain could be represented by a graph $G=(X,A)$ where X refers to the set of solutions and A the set of arcs $(x, m(x))$, where $m(x)$ is the solution obtained by applying the move m to x . Then, a given move will be equivalent to a set of arcs $\{(x, m(x)), x \in X\}$. The graph G is symmetrical because for each arc $(x, m(x))$, there exists an arc $(m(x), x)$ obtained by applying the reverse move m^{-1} to $m(x)$. The tabu search method starts from an initial solution x_0 , node of the graph G , and will search in G a path x_0, x_1, \dots, x_k , where $x_i = m(x_{i-1})$ with $i=1, \dots, k$. Each intermediary solution of the path is obtained by applying a move to the precedent solution. The arcs (x_i, x_{i+1}) of the path are chosen by solving the optimization problem:

$$f(x_{i+1}) = \min f(x_i) \text{ with } x_i \in V - T \quad (7)$$

where V in this case is the whole neighborhood $N(x_i)$ of x_i .

If the set $V-T$ of solutions to be explored is too large, the cost induced by the algorithm could become prohibitive. Conversely, a too small set has the adverse effect on the quality of solutions found. The tabu search method could be distinguished from the general descending method, mainly by the use of a shorter-term memory structure, which allows for accepting less good solutions in order to exit local optima, while avoiding cycles. For more details on the tabu method, one can refer to [7].

To solve the assignment problem with a tabu search method, a search domain free from capacity constraints on the RNC was selected, while respecting the constraints of unique assignment of Node Bs to RNC. Two values are associated with each solution: the first one indicates the intrinsic cost of the solution, calculated from the objective function (equation 2) and the second expresses the solution evaluation, taking into account the costs and penalties for not respecting the capacity constraints. At each step, the solution associated with the best evaluation is chosen. Once an initial solution is built from the problem data, the short term memory component attempts to improve it, while avoiding cycles and the middle-term memory component seeks to intensify the search in specified neighborhoods.

The neighborhood $N(S)$ of a solution S is defined by all solutions accessible from S by applying a move $a \rightarrow b$ to S . Indeed, $a \rightarrow b$ is defined as the re-assignment of node a to RNC b . To evaluate this neighborhood $N(S)$ solution, the gain $G_S(a,b)$ is associated with the move $a \rightarrow b$ and the solution S is defined by :

$$G_S(a, b) = \begin{cases} \sum_{i=1, i \neq a}^n (h_{ai} + h_{ia})x_{ib_0} - \sum_{i=1, i \neq a}^n (h_{ai} + h_{ia})x_{ib} + c_{ab} - c_{ab_0} & \text{if } b \neq b_0 \\ M & \text{if not} \end{cases} \quad (8)$$

where:

- h_{ij} refers to the cost of the handover between node i and j ;
- b_0 denotes the RNC of node a in solution S , that is, before the application of an $a \rightarrow b$ move;
- x_{ik} takes value 1 if node i is assigned to RNC k , 0 otherwise;
- c_{ik} depicts the cost of linking node i to RNC k ;
- M consists of a large arbitrary number.

The short-term memory moves iteratively from one solution to another, applying certain moves and prohibiting a return to the k latest visited solutions. It starts with an initial solution, obtained simply by assigning each node to the closest RNC, according to an Euclidean distance metric. The rationale for this memory component consists of improving the current solution, by decreasing either its cost or penalties.

The middle-term memory component tries to intensify the search in promising regions. It is introduced after the end of the short-term memory component and allows returning to solutions that may have been omitted. It consists mainly of defining intensively searched regions before choosing the types of moves to be applied.

To diversify the search, we use a long-term memory structure in order to guide the search towards regions that have not been explored. This is often done by generating new initial solutions. In this case, a table $n \times m$ (where n is the number of cells and m the number of RNC) counts, for each arc (a, b) , the number of times this arc appears in the visited solutions. A new initial solution is generated by choosing, for each cell a , the least visited arc (a, b) . Solutions visited during the intensification phase are not taken into account because they result from different types of moves than those applied in short and long-term memory components. From the new initial solution, we start a new search with short and middle term memory mechanisms.

3.2 Simulated annealing approach

Simulated annealing (SA) was introduced by Metropolis et al. [17] and is used to approximate the solution of very large combinatorial optimization problems [13]. Besides the traditional greedy local search techniques, the stochastic properties of the SA algorithm prevent it to get stuck to local minima. On the other hand, in traditional greedy local search, the quality of the final result heavily depends on the initial solution. In contrast, the idea behind SA is to adequately explore the whole solution space early on so that the final solution is insensitive to the starting state [13].

Conversely to a local search algorithm, SA allows for a given optimization problem to accept solutions which deteriorate the cost, even if later, these solutions will be abandoned if they generate no improvements. SA uses randomness to decide whether to reject or accept a solution which deteriorates the cost.

The algorithm starts with an initial feasible solution, which is set as the current solution. Randomly, a neighboring solution from the solution space is chosen, and its cost is compared to that of the current solution. If the cost is improved, this neighbor solution is kept and set as the current solution. Otherwise, this solution is accepted with a probability that is calculated according to the stage the algorithm is in [13].

3.3 Genetic algorithm

Genetic Algorithms (GA) are based on the Darwin's concept of natural selection. They essentially consist of creating a population of candidates and applying probabilistic rules to simulate the evolution of the population. GAs are robust search techniques based on natural selection and genetic mechanisms [6][11][12].

Genetic algorithms (GA) are robust search techniques based on natural selection and genetic production mechanisms [11]. GAs perform a search by evolving a population of candidate solutions through non-deterministic operators and by incrementally improving the individual solutions forming the population using mechanisms inspired from natural genetics and heredity (e.g., selection, crossover and mutation). In many cases, especially with problems characterized by many local optima (graph coloring, travelling salesman, network design problems, etc.), traditional optimization techniques fail to find high quality solutions. GAs can be considered as an efficient and interesting option [11].

GAs [11] are composed of three phases: a phase of creation of an initial population, a phase of alteration of this population by applying various genetic operators on its elements, and finally a phase of evaluation of this population during a certain number of generations. Each generation is supposed to provide new elements better than those of the preceding generation. Intuitively, the more larger is the number of generations, the more refined is the solution. It is hoped that the last generation will contain a good solution, but this solution is not necessarily the optimum.

We have introduced a simple notation to represent cells and switches, and to encode chromosomes and genes. We opted for a non-binary representation of the chromosomes. In this representation, the genes (squares) represent the cells, and the integers they contain represent the switch to which the cell of row i (gene of the i^{th} position) is assigned. Our chromosomes have therefore a length equal to the number of cells in the network n , and the maximal value that a gene can take is equal to the maximal number of switches m . A chromosome represents the set of cells in the cellular mobile network, and the length is the number of cells.

Crossover is a process by which two chosen string genes are interchanged. The crossover of a string pair of length l is performed as follows: a position i is chosen uniformly between 1 and $(l-1)$, then two new strings are created by exchanging all values between positions $(i+1)$ and l of each string of the pair considered.

Mutation is the process by which a randomly chosen gene in a chromosome is changed. It is employed to introduce new information into the population and also to prevent the population from becoming saturated with similar chromosomes.

The next generation of chromosomes is generated from present population by selection and reproduction. The *selection* process is based on the fitness of the present population, such that the fitter chromosome contributes more to the reproductive pool; typically this is also done probabilistically.

4. Performance evaluation and numerical results

We submitted our tabu search approach to a series of tests in order to determine its efficiency and sensitivity to different parameters. Thus, we will present a few results, which we compare to those provided by other known heuristics. The most important measurement criterion is the objective function value f (equation 2).

4.1 Experimental settings

This approach was subjected to a series of tests in order to determine its efficiency and sensitivity to different parameters. In the first step, the experiments are executed by supposing that Node Bs are arranged on an hexagonal grid whose length and width are almost equal. The cost of a link between a node and an RNC is proportional to the distance separating both [7]. The call rate γ_i of a node, B_i , follows a gamma probability distribution with variance equal to one. The call duration at any Node B is exponentially distributed with parameter equal to one [5]. If a node j has k neighbors, the $[0,1]$ interval is divided into $k+1$ sub-intervals by choosing k random numbers distributed evenly between 0 and 1. At the end of the service period in node j , the call could be either transferred to the i^{th} neighbor ($i=1, \dots, k$) with a handover probability r_{ij} equal to the length of the i^{th} interval, or ended with a probability equal to the length of the $k+1^{\text{th}}$ interval. To find the call volumes and the rates of coherent handovers, the nodes are considered as $M/M/1$ queues that form a Jackson network. The incoming rates α_i in Node Bs are obtained by solving the following system:

$$\alpha_i - \sum_{j=1}^n \alpha_j r_{ji} = \gamma_i \quad \text{with } i = 1, \dots, n \quad (9)$$

If the incoming rate α_i is greater than the service rate, the distribution is rejected and chosen over. The handover rate h_{ij} is defined by:

$$h_{ij} = \lambda_i \cdot r_{ij} \quad (10)$$

All the RNCs have the same capacity M calculated as follows:

$$M = \frac{1}{m} \left(1 + \frac{K}{100}\right) \sum_{i=1}^n \lambda_i \quad (11)$$

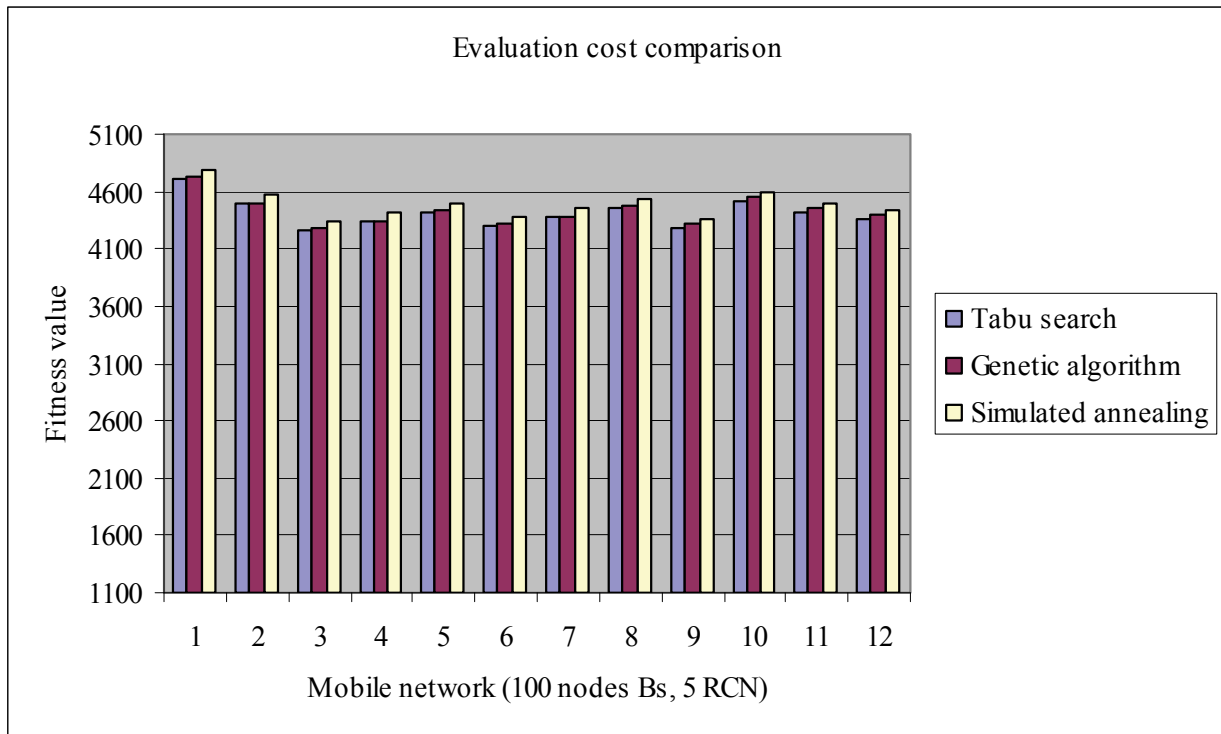
where K is uniformly chosen between 10 and 50, which insures a global excess of 10 to 50% of the RNCs' capacity compared to the nodes' call volume.

5.1 Comparison with other heuristics

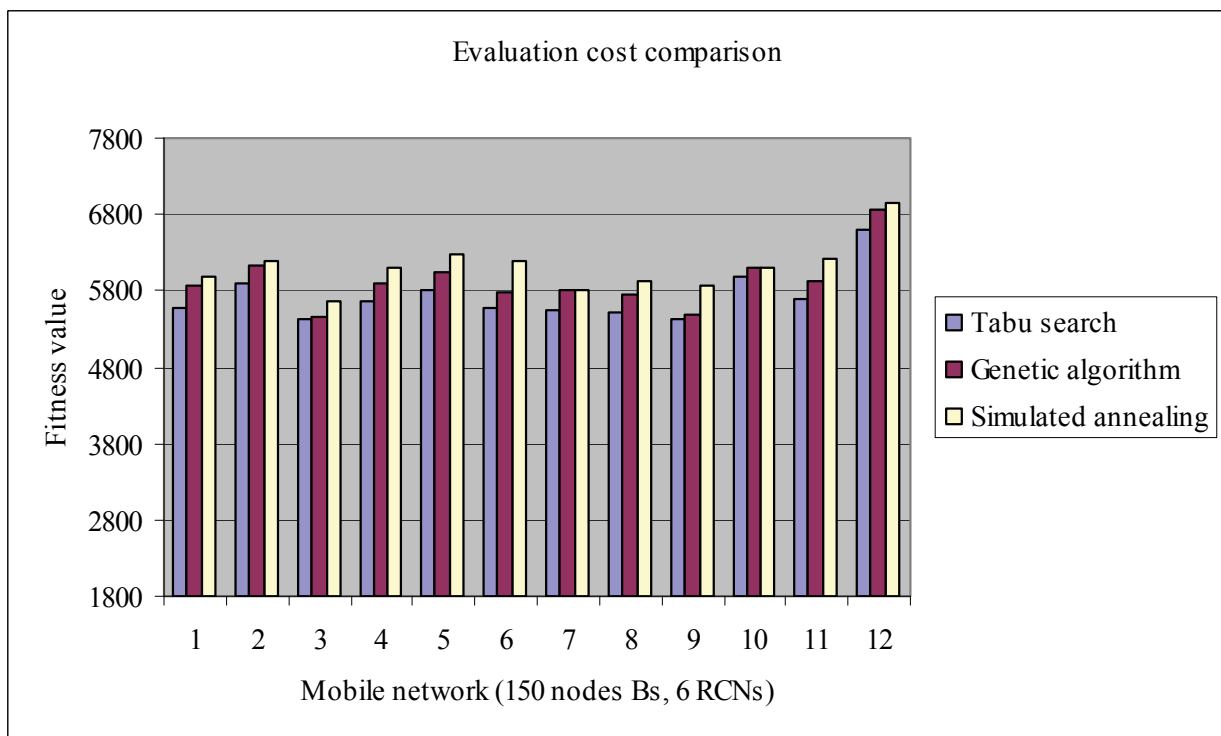
Genetic algorithm (GA) and simulated annealing (SA) are compared with our tabu search solution. In this investigation, a number of Node Bs, varying between 100 and 400, and a number of RNCs fluctuating from 5 to 8 are used, meaning that the search space size spans from 5^{100} to 8^{400} .

The three heuristics consistently find feasible solutions. However, these results inform only about the feasibility of obtained results, without demonstrating whether or not these solutions are among the best. Figure 7 shows the results obtained for 5 different scenarios instances of problems: 5 RNCs and 100 Node Bs, 6 RNCs and 150 Node Bs, 7 RNCs and 200 Node Bs, and 8 RNCs and 400 Node Bs. For each instance, the results of 12 different cases tested show that the evaluation costs represent the average over 100 runs for each algorithm. In each of all the considered series of tests, the tabu search yields an improvement in terms of $f(2)$ compared with the other two heuristics. For example, with 7 RNCs and 200 Node Bs, the tabu search solution costs are 3.3% and 4.6% lower than the results generated by GA and SA respectively. Table 2 summarizes the results. Nevertheless, given the initial link, the handover and the annual maintenance costs for large-sized cellular mobile networks this small improvement, in terms of $f(2)$, represents a large reduction in costs in the order of millions of dollars over a five-year period. For example, in a cellular network composed of

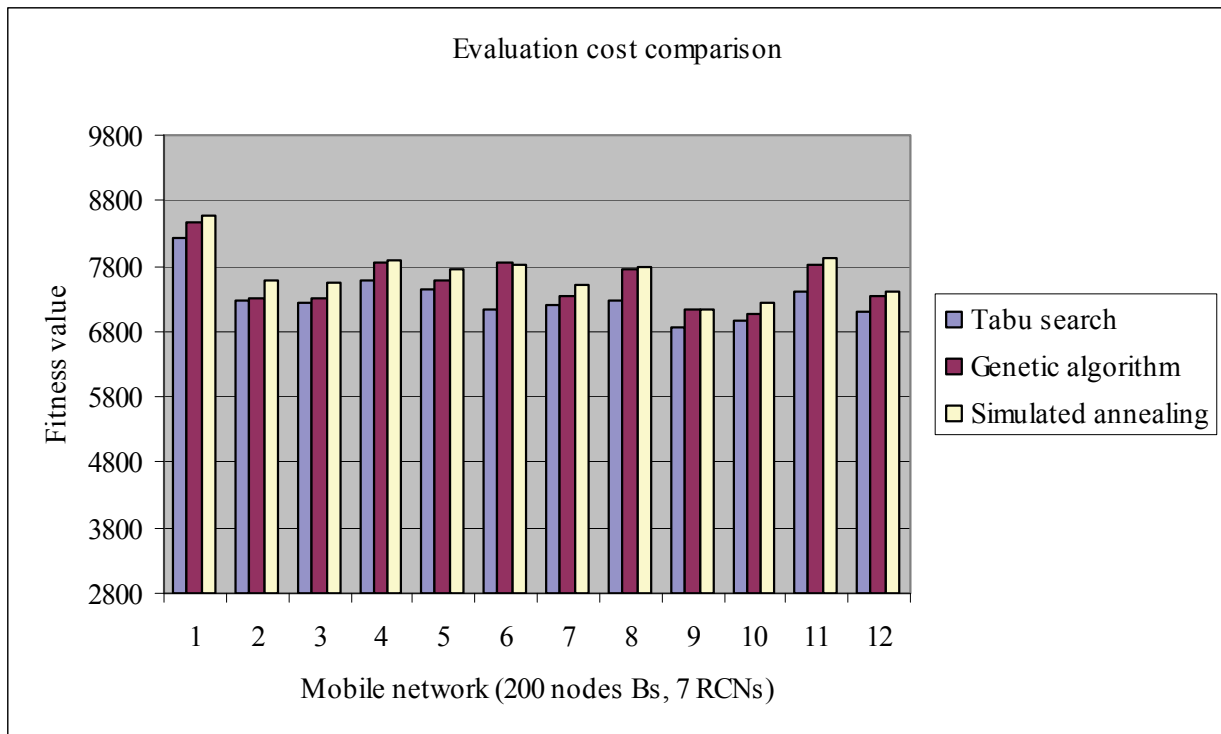
100 Node Bs, with an initial link and handover cost of \$ 500,000 for each cell, an improvement of 2% in the cost function represents an approximate saving of \$1M over five years. In the case of 500 Node Bs, and an improvement of 5% in the cost function, represents an approximate saving of \$12M over 5 years.



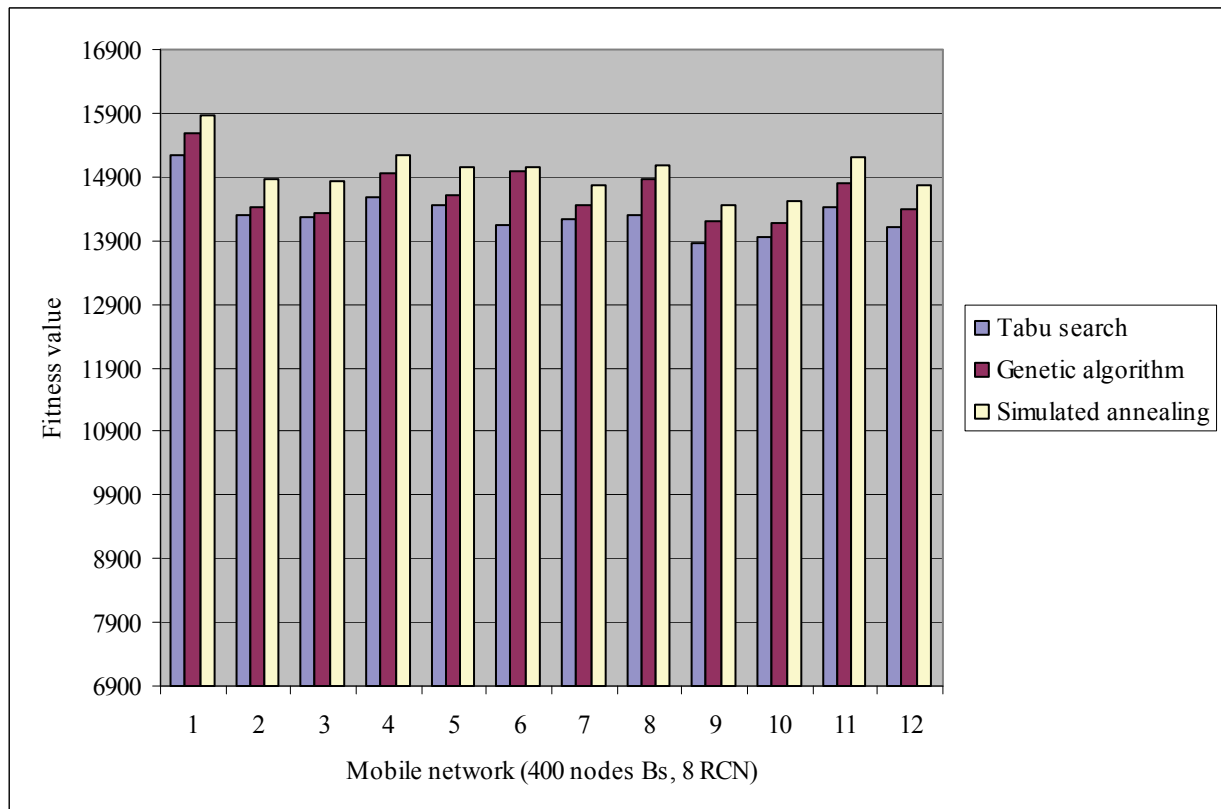
(a) Scenario composed of 5 RNCs and 100 Node Bs



(b) Scenario composed of 6 RNCs, 150 Node Bs



(c) Scenario composed of 7 RNCs, 200 Node Bs



(d) Scenario composed of 8 RNCs, 400 Node Bs

Figure 7. Comparison between tabu search, genetic algorithm and simulated annealing.

	5 RNCs 100 Node Bs	6 RNCs 150 Node Bs	7 RNCs 200 Node Bs	8 RNCs 400 Node Bs
Genetic algorithm	1.6%	2.9%	3.3%	4.3%
Simulated annealing	2.8%	4.1%	4.6%	6.8%

Table 2. Tabu search average improvement rates in terms of $f(2)$.

6. Conclusion

In this paper, we proposed a tabu search approach to design large-scale UMTS mobile networks and to specifically solve the problem of assigning Node Bs to RNCs in cellular mobile networks. Experiments were conducted to measure the quality of solutions provided by this algorithm. This approach was compared against genetic algorithm and simulated annealing.

Computational results obtained confirm the efficiency and the effectiveness of the tabu search to provide better solutions than genetic algorithm and simulated annealing, especially for large-scale cellular mobile networks with a number of Node Bs varying between 100 and 400, and a number of RNCs oscillating between 5 and 8, meaning that the search space size ranges between 5^{100} and 8^{400} and that the average improvement rates are in the order of 2% and 7% respectively. This improvement represents a substantial reduction in maintenance and operations costs, which, for a 5 year period, amount to millions of dollars.

7. References

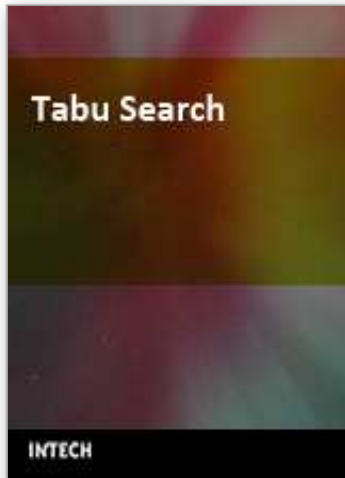
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The goal of this book is to report original researches on algorithms and applications of Tabu Search to real-world problems as well as recent improvements and extensions on its concepts and algorithms. The book's Chapters identify useful new implementations and ways to integrate and apply the principles of Tabu Search, to hybrid it with others optimization methods, to prove new theoretical results, and to describe the successful application of optimization methods to real world problems. Chapters were selected after a careful review process by reviewers, based on the originality, relevance and their contribution to local search techniques and more precisely to Tabu Search.

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