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Multi-level Tabu Search for 3G Network Dimensioning

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***Abstract*— We investigate the dimensioning of 3G wireless networks with a CDMA2000 radio interface technology. These networks offer a range of multimedia services that require different end-to-end QoS. In order to meet this QoS, dimensioning of a 3G network must include an handshake between the radio and the core networks and therefore involve the three networks (radio, core, access).**

In this paper we primarily address the problem of optimizing the base station locations and the core network link capacity with different multimedia traffic scenarios and different QoS and GoS requirements. The dimensioning problem is formulated as a Mixed Integer Program (MIP) problem and solved by a Tabu Search (TS) algorithm that relies on the Signal to Noise plus Interference Ratio (SNIR) to guide its search strategy. In order to improve the efficiency of the Tabu Search, we study extensively various of its key features: *(i) Search Intensification* through dynamic Tabu lists and aspiration criteria; *(ii) Search Diversification* through restarts using new base station locations.

We next conduct experiments with the resulting Tabu Search (TS) on quite large instances. The MIP formulation can be used to evaluate the quality of those solutions. It is then showed that the TS solutions are almost optimal on small instances and requires much less resources than the approximated solutions obtained with the MIP formulations, even for larger instances.

I. Introduction

Dimensioning of 3G radio networks involves determining the minimum number of base stations with their UL/DL capacities and their locations that would provide the necessary coverage in order to meet the required quality of service (QoS) and the targeted grade of service (GoS) for each type of multimedia services. This implies the establishment of a Bearer Service with clearly defined characteristics from the source to the destination for each type of services. Moreover, in order to take into account the end-to-end QoS requirements, components of the core network (CN) must also be considered in the planning process, especially with respect to the handshake for the downlink connections with multimedia traffic.

The 3G dimensioning problem that is discussed in this paper provides tools to determine the necessary number of base stations with their location and coverage area capacity as well as the wired link capacity in the core network.

Most of the published articles on the dimensioning of 3G networks focus on the design of methods and algorithms for the planning of a CDMA2000/UMTS radio network (RN) with optimization tools dedicated to some aspects of the radio network, e.g., the optimal location of the base stations. But no study has yet taken care of the handshake between the core network and the radio network except for a preliminary study in [1], this is one of the contributions of the current paper.

Basic references for radio network and cell planning include Laiho *et al.* [2], Holma and Toskala [3]. Many studies deal with the optimization of the location of the base stations (BS). Molina et al. [4] proposed and compared three different algorithms to solve the BS location problem with a model that includes no power control mechanism. Ibbetson and Lopes [5] developed two iterative algorithms based on the cell coverage radius with QoS constraint expressed in terms of GoS. Another study is due to Tutschku [6] where the demand node concept is used to maximize uncapacitated covering location of base stations while minimizing co-channel interference. More recently, Almadi *et al.* [7] proposed methods based on the Signal-to-Interference Ratio (SIR) as quality measurement. However, they focused on the uplink in the restricted case of voice calls and developed Monte-Carlo greedy-type heuristics. Eisenblatter *et al.* [8] includes a refined modeling for the configuration problem, but no solution tool is provided.

In the sequel, we propose a multi-hour dimensioning method of a 3G network with a multi-service traffic demand, associated with different QoS requirements for different user priorities. We include the "handshake" between the radio and the core networks taking into account the cost of the base station location and the wired link capacity of both the radio and the core networks.

The paper is organized as follows. In Section II, we present the mathematical model for the dimensioning problem. Section III presents a Tabu Search procedure to solve the problem; construction of initial solutions, intensification and diversification strategies are examined. The performance of various Tabu operators and the efficiency of the proposed Tabu search procedure are presented and compared with a mixed integer programming algorithm using CPLEX [9] in Section IV. Finally, we conclude the paper in Section V.

II. Statement of the Dimensioning Problem

We propose a dimensioning model with the objective of minimizing the cost, defined as proportional to the number of base stations and the overall capacity of the wired links of the core and radio networks.

We consider a multi-service traffic described by a set S of sessions. Each session s, if granted, is associated with a set F_s of 4 flows : $F_s = \{f^{\text{UL\_RL}}, f^{\text{UL\_WL}}, f^{\text{DL\_RL}}, f^{\text{DL\_WL}}\}$ where we distinguish the uplink (UL)/downlink (DL) flows and the radio (RL)/wired (WL) link network flows.

For each wired link flow f, the throughput can take any value between $\overline{\rho}_f$ and $\underline{\rho}_f$, i.e., the maximum/minimum bandwidth. For each radio link flow f, the throughput values t are defined by a set T of discrete values which might differ on the uplink/downlink, and which depend on the services. Again, each throughput t is bounded: $\underline{t} \leq t \leq \overline{t}$. Each radio throughput value is coupled with a frame error rate (FER), leading to a Radio Access Bearer (RAB) for each radio flow: $r_f = \text{RAB}_f = (t_f, \text{FER}_f) \in R$.

We consider a multi-period network dimensioning scheme model, in which network traffic is considered for different periods (denoted h) during, e.g., the day to reflect the load variation.

Let us introduce the following routing parameter:

$$b_{ihf} = \begin{cases} 1 & \text{if } \text{BS}_i \in L_s^{\text{BS}} \text{ during period } h \\ 0 & \text{otherwise.} \end{cases}$$

where L_s^{BS} is the list of potential base stations that are able to serve s.

We now describe the set of constraints.

A. Call Admission Control Constraints

A given session can be granted if and only if all of its 4 associated flows can be accepted. Therefore, for each of the flow f of s, we have:

$$\underline{\rho}_f y_s \leq x_f \leq y_s \overline{\rho}_f \qquad f \in \{f^{\text{UL\_WL}}, f^{\text{DL\_WL}}\} \tag{1}$$

$$\underline{t}_f y_s \leq x_f \leq y_s \overline{t}_f \qquad f \in \{f^{\text{UL\_RL}}, f^{\text{DL\_RL}}\} \tag{2}$$

where the variables are defined as follows:

- x_f is the bandwidth of flow f where $x_{f_s^{\text{UL\_WL}}}$ defines the bandwidth of the uplink flow on the wired link, and $x_{f_s^{\text{DL\_WL}}}$, $x_{f_s^{\text{UL\_RL}}}$, $x_{f_s^{\text{DL\_RL}}}$ are defined similarly.
- y_s is the call admission decision variable of session s: it is equal to 1 if session s is accepted, and to 0 otherwise.

B. Grade of Service

We impose a differentiated grade of service for each user priority and for each service. It is defined for the overall planning period.

$$\frac{\sum_{s \in S^{a,p}} y_s}{|\mathcal{S}^{a,p}|} \geq 1 - \text{Br}^{a,p} \qquad a \in A \quad p \in P \tag{3}$$

where the parameters are defined as follows:

- $S^{a,p}$ is the set of sessions associated with service a and priority p,
- $\text{Br}^{a,p}$ is the blocking rate for flows associated with service a and priority p.

C. Constraints on the Radio Links

Given a session s, if it is accepted, one or two base stations (two in the case of soft handoff) are activated, the same one(s) for the uplink and the downlink flows.

We first define the α_{irf} decision variables such that:

$$\alpha_{irf} = \begin{cases} 1 & \text{if RAB } r \text{ is used to serve } f_s \text{ by } \text{BS}_i, \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

and the soft handoff (SH) variable z_{fr}

$$\sum_{r \in R} z_{fr} \leq 1 \qquad f \in F_s^{\text{RL}} \qquad s \in S \tag{5}$$

where, for each session s, variable z_{fr} is equal to 1 if session s (and each of its radio flow) is in soft handoff with RAB r, and to 0 otherwise.

In case of SH, we assume that the MS receive the same service (RAB) on the two air interface channels, both on the uplink and the downlink flows. Therefore the equation defining the throughput of a radio flow is written as follows:

$$x_f = \sum_{r=(t,.) \in R} t\Big(\sum_{i \in L_s^{\text{BS}}} \alpha_{irf} - z_{fr} \Big) \qquad f \in F_s^{\text{RL}} \quad s \in S. \tag{6}$$

The selection made at the RNC - Radio Network Controller - is based on the CRC - Cyclic Redundancy Check - (on the basis of the best FER), and the flow entering the RNC node (x_f^i) must be equal to the flow leaving it (x_f).

$$x_f^i \leq x_f \leq \sum_{i \in L_s^{\text{BS}}} x_f^i \qquad i \in L_s^{\text{BS}}, f \in F_s^{\text{RL}}, s \in S. \tag{7}$$

D. Uplink Cell Capacity Constraint.

The uplink capacity calculation is based on the CDMA $\frac{E_b}{N_t}$ equation :

$$\frac{W}{r_t} \frac{P^{\text{UL}}}{(1+\lambda) P_T^{\text{UL}} - \nu_s P_s^{\text{UL}} + W N_o} \geq \left(\frac{E_b}{N_t}\right)^{\text{UL}}_{s,r,Min}$$

where λ is the fraction of the overall power P_T received at the BS, that defines the inter-cell interferences, W is the modulation bandwidth of the CDMA system and N_o is the power spectral density of the thermal noise.

Estimation of the transmitted gain as a function of the difference in the power level of the involved links is presented in [10] [11] for the UL link. We mapped these results to our case by applying a reduction equal to the SH gain in the $\frac{E_b}{N_t}$ target.

$$\frac{1+\lambda}{W} \sum_{s \in S} \sum_{r=(t,.) \in R^{\text{UL}}} \frac{\gamma_{st}^{\text{UL}} \, \nu_s \, b_{ihf^s_{\text{UL\_RL}}} \, (\alpha_{irf_s^{\text{UL\_RL}}} - z_{f^s_{\text{UL\_RL}}})}{\frac{1}{t} + \frac{\gamma_{st}^{\text{UL}} \, \nu_s}{W}} + \frac{\gamma_{st}^{\text{UL-SH}} \, \nu_s \, b_{ihf^s_{\text{UL\_RL}}} \, z_{f^s_{\text{UL\_RL}}}}{\frac{1}{t} + \frac{\gamma_{st}^{\text{UL-SH}} \, \nu_s}{W}} < LF_{\text{UL}}$$

$$i \in L_s^{\text{BS}}, \quad h = 1, 2, \ldots, H \tag{8}$$

where γ_{st}^{UL} $\gamma_{st}^{\text{UL-SH}}$ are the $\frac{E_b}{N_t}$ target in NSH and SH respectively, ν_s is the activity factor related to session s; LF_{UL} is an upper bound on the uplink load factor.

E. Downlink Cell Capacity

The downlink capacity can be expressed as described below in the case of no soft handoff. For each base station i and for each period h, we have:

$$\sum_{s \in S} \sum_{r=(t,.) \in R^{\mathrm{DL}}} \frac{\gamma_{st}^{\mathrm{DL}} \ \nu_s \ P_{is} \ b_{ihf_s^{\mathrm{DL\_RL}}} \ \alpha_{itf_s^{\mathrm{DL\_RL}}}}{\dfrac{1}{t} + \dfrac{\gamma_{st}^{\mathrm{DL}} \nu_s \, \omega}{W}} \leq P_{\mathrm{BS}} - P_{\mathrm{cont}} \quad (9)$$

where

$$P_{i,s} = (N_0 \psi_{si} + \frac{P_{\mathrm{BS}}}{W} (\sum_{i': \mathrm{BS}_{i'} \in \mathrm{Ring1}(\mathrm{BS}_i)} \frac{\psi_{si}}{\psi_{si'}} + \omega)) \qquad (10)$$

with ω being the cell orthogonality factor and P_{BS} the maximum output power of one base station (we assume that it is the same for all base stations). P_{cont} is the power allocated to the pilot and the control channels (CCH). ψ_{si} is an attenuation coefficient proportional to the fourth power of the distance between the mobile station associated with session s and its home base station BS_i. $\psi_{si'}$ is an attenuation coefficient proportional to the fourth power of the distance between the mobile station associated with session s and one of its neighboring base stations $\mathrm{BS}_{i'}$.

Reduction of the inter-cell interference is the main reason for employing power control in the DL direction. In the case of soft handoff, both the $\frac{E_b}{N_t}$ reduction and the capacity formula are modified in a similar way than for DL. We generalized the results in SH gain in DL as presented in [11] for the multi service traffic demand.

F. Quality of Service

We consider the following four traffic classes: conversational (voice and video-conferencing), streaming (video), interactive (web browsing) and background (email) with two user priorities: gold and silver. For each application, and for each priority, we provide the following QoS constraints that define the distribution of sessions with respect to the various RAB values, aiming at providing reasonable bandwidth even during the congestion periods

$$\begin{aligned} -\frac{1}{2} \sum_{\substack{r \in T_{a,p}^d: \\ r' \preceq r}} Q_{r'ap}^d \leq Q_{rap}^d \sum_{s \in S^{a,p}} \sum_{\substack{r' \in T_{a,p}^d: \\ r' \prec r}} \alpha_{r's}^d \\ - \left(\sum_{\substack{r' \in T_{a,p}^d: \\ r' \prec r}} Q_{r'ap}^d \right) \sum_{s \in S^{a,p}} \alpha_{rs}^d \leq \frac{1}{2} \sum_{\substack{r' \in T_{a,p}^d: \\ r' \preceq r}} Q_{r'ap}^d \\ a \in A, \quad p \in P, \quad r \in R, \quad (11) \end{aligned}$$

where $T_{a,p}^d$ is the set of RABs for service a with priority p and direction d (i.e., uplink or downlink). Constraints (11) ensure that: $\sum_{r \in R} QoS_r^{a,p} = 1$

G. Objective Function

Our objective is to minimize the deployed number of BSs and the capacity on the wired link in both the CN and the RN.

$$\sum_{s \in S} \sum_{f \in F_s^{\mathrm{WL}}} a_{\ell hf} x_f \leq C_\ell \quad h = 1, \ldots, H; \ell = 1, \ldots, m \quad (12)$$

where C_ℓ is a variable measuring the capacity of wired link ℓ and $a_{\ell hf}$ is a routing variable equal to 1 if link ℓ is on the routing path of flow f during period h. We can now express the objective function as :

$$\mathrm{Cost} = w_c \sum_{\ell=1}^{m} d_\ell \, C_\ell + w_{\mathrm{BS}} \sum_{i=1}^{n_{\mathrm{BS}}} x_i^{\mathrm{BS}}$$

where C_ℓ corresponds to the capacity of link ℓ:

$$C_\ell = \max_{h \in H} \sum_f a_{\ell hf} \, x_f$$

and where w_c and w_{BS} are normalized cost coefficients.

III. A Tabu Search for 3G Network Dimensioning

Tabu Search (TS) is an extension of the classical Local Search (LS) methods. It can be seen as an LS provided with memories and search strategies (intensifications and diversifications) to explore the solution space more thoroughly [12]. There are two types of memory in TS: short-term memory and long-term memory.

We implemented the Short-term memory by means of four Tabu lists: *(i)* TABU_ADD_MS_LIST and TABU_DROP_MS_LIST which record the tabu attributes of the different MSs moves. Each MS move is recorded with the following data: (BS_j, Td_MS, $AIter$) where BS_j is the covering BS, Td_MS is the time during the opposite move is labeled Tabu (Tenure duration) and $AIter$ is the iteration index at which the move occurred. *(ii)* TABU_ADD_BS_LIST and TABU_DROP_BS_LIST record respectively the set of non active and active BSs with their Tabu status as in the MS Tabu lists.

Long term memory is implemented by means of an array of n lists NBR_ITER_MS_LISTS, each dedicated to a given MS_i. Entry j in NBR_ITER_MS_LISTS(i) records the number of moves carried out on MS_i from the potential BS_j.

Short-term memory is used through an intensification strategy that focuses on searching for an improved solution within a restricted promising region. In our study, intensifications are performed combining going back to a promising region and some aspiration criteria. Diversification strategies, which are typically based on a long-term memory function, guide the search to unexplored regions of the solution space. The number of moves performed on each MS_i is the base information for diversification in the proposed Tabu Search.

A. The Tabu Search Algorithm

The behavior of the TS we propose is based on the Signal to Noise plus Interference Ratio (SNIR) (SNIR = Signal Power / (Noise Power + Interference Power)). Only interferences caused by external phenomenons are considered, inter-cell and intra-cell attenuation are not taken into account in the TS behavior. The flowchart on Fig. 1 describes the different sequential levels of the proposed TS

1) Initial Solution: Depending on its position, each MS_i has two lists of BSs : $L^{\mathrm{SH}}_{\mathrm{MS}_i}$ and $L^{\mathrm{NSH}}_{\mathrm{MS}_i}$ which can serve it either in soft handover (SH) or in non soft handover (NSH). To construct an initial solution, we first activate each MS_i by attaching it either to a single BS_j where $\mathrm{BS}_j \in L^{\mathrm{NSH}}_{\mathrm{MS}_i}$ or to a pair BS_k, BS_ℓ where $\mathrm{BS}_k, \mathrm{BS}_\ell \in L^{\mathrm{SH}}_{\mathrm{MS}_i}$ with the highest SNIR. A solution S can be seen as a *n*-uplet

$$S = \{\ldots(\mathrm{MS}_{i_1}, \mathrm{BS}_j), (\mathrm{MS}_{i_2}, \mathrm{BS}_k, \mathrm{BS}_\ell)\ldots\}$$

where $\mathrm{BS}_j \in L^{\mathrm{NSH}}_{\mathrm{MS}_{i_1}}$, BS_k, $\mathrm{BS}_\ell \in L^{\mathrm{SH}}_{\mathrm{MS}_{i_2}}$. BSs are initially considered with unlimited capacity and are activated as they are selected to serve a first MS. The BS activation process stops when all MSs are associated with at least one servicing BS. The construction of the first solution influences the speed at which the TS finds good solutions. Different strategies were built and experienced: activate all MSs in NSH state, activate all MSs in SH state and activate half MSs in NSH state and the other half in SH state. We retained the last one for the quality of its corresponding initial solution, i.e., almost feasible, and helpful for finding good solutions.

2) Moves: Operating moves on BSs are of two types: ADD or DROP moves. When it is possible to perform an ADD/DROP move on a BS_i (check the entry BS_i in TABU_ADD_BS_LIST/TABU_DROP_BS_LIST whether the current iteration index $> AIter + Td\_\mathrm{BS}$), an ADD/DROP move makes the current BS_i available/non-available for servicing some MSs. Such a move is implemented by moving BS_i from the TABU_ADD_BS_LIST/TABU_DROP_BS_LIST to the TABU_DROP_BS_LIST/TABU_ADD_BS_LIST. To prevent moving back to previously investigated solutions and in order to search the solution space thoroughly, we define two different Tabu tenure durations $Td\_\mathrm{BS}_{\mathrm{ADD}}$ and $Td\_\mathrm{BS}_{\mathrm{DROP}}$ as the time that must elapse before the BS_i is allowed to move to TABU_ADD_BS_LIST or TABU_DROP_BS_LIST list.

We define two elementary and four composite types of moves operating on MSs. These are: ADD, DROP, NSH-to-SH/NSH, and SH-to-NSH/SH.

The ADD and DROP moves are slightly different from those operating on BSs as they may not change the active/non-active status of MSs. The ADD move may operate on an active or non active MS_i : on an active MS_i linked to BS_j by adding to it another servicing BS_k; on a non active MS_i by linking it to a new BS_ℓ. The DROP move is the opposite to the ADD move. Regardless of the previous cases, each time a MS_i is added/dropped to/from a BS_j, a new entry *Tabu_(Drop/Add)* = (BS_j,Td_MS_(drop/add), AIter) is created and added to the TABU_DROP_MS_LISTS(i)/TABU_ADD_MS_LISTS(i) list.

The NSH-to-SH/NSH and SH-to-NSH/SH moves are compositions of a given number of ADD/DROP MOVES.

As for BS moves, to prevent cycling in solution investigation, we define two different Tabu tenure durations $Td\_\mathrm{MS}_{\mathrm{ADD}}$ and $Td\_\mathrm{MS}_{\mathrm{DROP}}$ as the time that must elapse before the MS_i can be added/dropped to/from BS_j or the time a BS_j

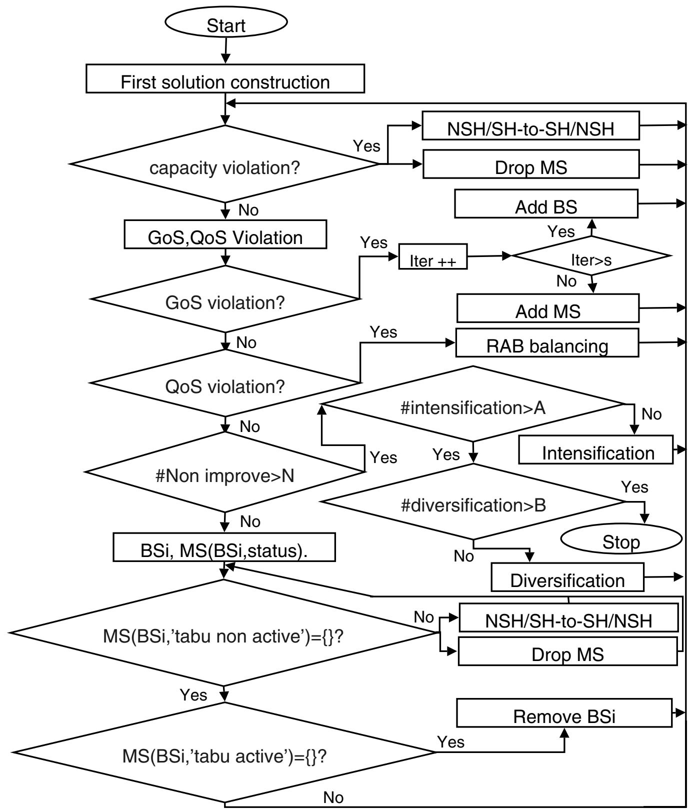

Fig. 1. Tabu Search Algorithm

cannot be dropped/added from/to TABU_ADD_MS_LIST(i) / TABU_DROP_MS_LIST(i). The choice of Tabu tenure duration is a key parameter in a TS algorithm. In Section IV, experiments have been conducted to empirically select the Tabu duration and propose a dynamic one to compare the effects of this parameter on the convergence to a good solution.

3) Feasibility Recovery: Composed of the first three sequential strategies (see Fig. 1) which are dedicated to eliminate the capacity, GoS and QoS constraint violations:

The strategy for capacity violation recovery operates on the most BS violated capacity, say BS_j, by selecting the active MS_i during the most violated period with the lowest SNIR. Depending on the Tabu remove status of the MS_i from BS_j, three moves may be applied to reduce the capacity violation : *(i)* a SH-to-NSH move by removing the link (MS_i,BS_j) if the second servicing BS_ℓ can handle the MS_i in a NSH state or by removing both of the two links (MS_i,BS_j) (MS_i,BS_ℓ) and searching for another BS_k $(k \neq j, \ell)$ which can serve the MS_i in NSH. *(ii)* a NSH-to-SH move by adding another link (MS_i, BS_k) to the existing link (MS_i,BS_j) if the two BS_j, BS_k can serve the MS_i in SH or by removing the link (MS_i,BS_j) and searching for two other BS_k and BS_ℓ $(k, \ell \neq j)$ which can serve the MS_i in SH. *(ii)* a DROP move. However, because it induces more violation in the GoS constraint, this move is only performed when none of the previous moves is possible.

In the recovery strategy for GoS violation, a MS_i of the same type than the most violated application is selected for an ADD move. As an execution of this strategy is directly followed by the previous one (see the flowchart on Fig 1), cycling on ADD and DROP moves may occur if the current radio capacity is not large enough to contain all the MSs. To prevent this to happen, we apply an ADD move on a given BS only after a given number of MS ADD moves without GoS violation recovery. The BS_j to be added is selected by evaluating the following equation

$$\min_{j \in L_{\mathrm{BS}}^{\neg\mathrm{active}}} \Big(\sum_{s \in L_{\mathrm{BS}_j}^{\mathrm{MS}-\neg\mathrm{active}}} (P_{j,s}/|L_{\mathrm{BS}_j}^{\mathrm{MS}-\neg\mathrm{active}}|) \Big)$$

where $P_{j,s}$ is defined in equation (10), $L_{BS}^{\neg\mathrm{active}}$ is the set of non active BSs, and $L_{\mathrm{BS}_j}^{MS-\neg\mathrm{active}}$ is the set of inactive MSs that are covered by BS_j. The selected BS_j guarantees, for a given number of newly granted MSs, the least attenuation factor, thus, the highest SNIR.

In the recovery strategy for QoS violation, in order to meet the QoS requirements, i.e., to satisfy equation (11), a RAB balancing strategy is used to distribute the activated MSs over the dedicated RAB.

4) Minimize the number of Base stations: This strategy aims at minimizing the necessary number of BSs in order to cover the traffic demand. Before removing a BS_j from the active set, we need to remove all its MSs. This step operates (capacity violation recovery) with an objective to reduce the BS_j capacity occupancy to zero before dropping it. Selection is made according to the least loaded active BS.

5) Intensification with Short Term Memory: Intensifications are performed when no solution improvement is observed after N iterations. They are executed by a restart procedure from the current best solution i (S_i^{best}) combined with an aspiration criterion in order to cancel the Tabu active status of MSs and BSs of the S_i^{best}. Tabu status overrides are accomplished on some of the BSs and their linked MSs. The next equation

$$\sum_{s \in L_{\mathrm{BS}_j}^{\mathrm{MS}-\mathrm{active}}} (P_{j,s}/|L_{\mathrm{BS}_j}^{\mathrm{MS}-\mathrm{active}}|) \qquad j \in L_{\mathrm{BS}}^{\mathrm{active}}$$

gives the average $P_{j,s}$ from $L_{\mathrm{BS}_j}^{\mathrm{MS}-\mathrm{active}}$ to each BS_j. We calculate a median (M) for the measured $P_{j,s}$'s and apply an override on BSs with an average $P_{j,s}$ greater than αM. This way, we make the TS focus on BSs servicing more attenuated MSs by allowing moves on them and their linked MSs.

Aspiration criteria is applied only for the first intensification close to the S_i^{best}, the next intensifications on the same solution are carried out only by the restart procedure. The iteration after the intensification j on S_i^{best} links the solution S_i^{best} to another solution $S_i^{\mathrm{after\_best}}$ by an oriented path $P_j^{S_i} = (S_i^{\mathrm{best}}, S_i^{\mathrm{after\_best}})$. To stimulate the next-intensification iterations to follow different outgoing paths $P_k^{S_i} (k = 1 \ldots A$, and $\neq$ all previous $j)$ from S_i, we close the door of the leading path $P_j^{S_i}$ by setting up the Tabu status of the corresponding moves in S_i^{best}.

6) Diversification with Long Term Memory: Diversifications are applied when no solution improvement is observed during a consecutive number, say A, of iterations in the intensification process. The NBR_ITER_MS_LISTS records for each MS_i the number of Add/Drop moves performed on each potential BS_j. The diversification process starts by deactivating all the active MSs and BSs after canceling all the Tabu active status; after that, each MS_i is activated by linking it to its potential BS(s) (whether SH or NSH) with the least operated one(s) with respect to ADD/DROP moves.

IV. Computational Results

We generated 3G multi-service traffic patterns based on realistic traffic profiles presented in [13] and the forecasted one in [14] to test the efficiency of the TS proposed in the previous section. Initially, we deployed a large number of BSs with an extended coverage area (large overlapping areas) uniformly over the global space. MSs are assumed uniformly distributed over the covered space and planning period.

Before solving the test instances, we evaluate the best values of the Tabu parameters: Td_BS_{add}, Td_BS_{drop}, Td_MS_{add} Td_MS_{drop}. Test evaluation shows that $Td\_\mathrm{MS}_{\mathrm{ADD}}$, $Td\_\mathrm{MS}_{\mathrm{DROP}}$ are dependent on the number of MSs and the potential number of BSs for each MS_i ($L_{\mathrm{MS}_i}^{\mathrm{SH/NSH}}$)(set to 15 in our study). $Td\_\mathrm{BS}_{\mathrm{ADD}}$, $Td\_\mathrm{BS}_{\mathrm{DROP}}$ are dependent on the $|L_{\mathrm{BS}}^{\mathrm{active}}|$ and $|L_{\mathrm{BS}}^{\neg\mathrm{active}}|$. In the test, since the number of non active potential BSs for each MS is larger than the number of active ones, and $|L_{\mathrm{BS}}^{\neg\mathrm{active}}|$ than that of $|L_{\mathrm{BS}}^{\mathrm{active}}|$, it becomes evident that $Td\_\mathrm{MS}_{\mathrm{ADD}}$ and $Td\_\mathrm{BS}_{\mathrm{ADD}}$ will be respectively greater than $Td\_\mathrm{BS}_{\mathrm{DROP}}$ and Td_MS_{drop}.

To find the best values of the Tabu tenure duration parameters, the TS is tested with 3 different instances of traffic. The average values and the parameters are reported in Figure 2.

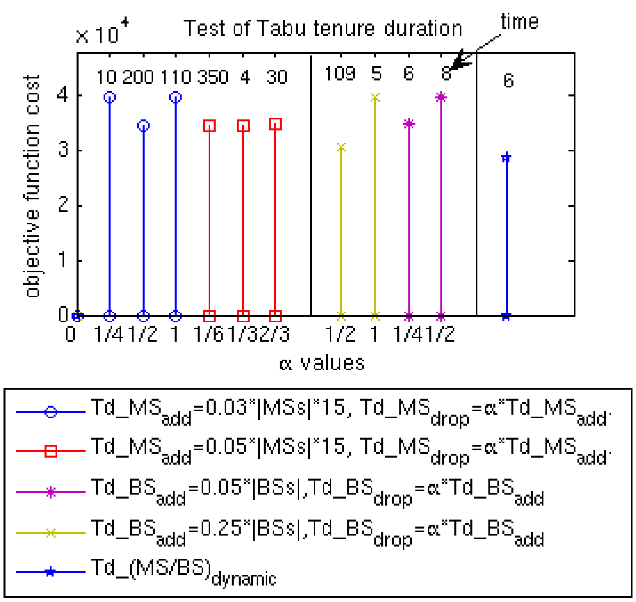

Fig. 2. Test of Tabu Tenure Duration parameters

The first part of the graph shows the variation of the *objective* (cost) as a function of the $Td\_\mathrm{MS}_{\mathrm{ADD/DROP}}$ of MSs and the elapsed time, this comparison is done without considering the Tabu tenure parameters related to the BSs. The

TABLE I

SOLUTION QUALITY COMPARISON

Pb_i	TS				CPLEX						TS → CPLEX					
80X50	30464	136s	30464	300s	30485	164s	10%	30218	233s	1%	30218	19s	5%	30218	82s	1%
160X50	82580	1670s	82516	3129s	83075	2831s	10%	77505	7458s	1%	80075	452s	5%	77505	890s	1%
320X50	100754	2769s	100690	24560s	107800	44676s	20%	-	89h	10%	99745	937s	10%	84632	4312s	5%
500X50	160802	5421s	121802	89245s	179794	64956s	20%	-	89h	10%	118623	4592s	10%	98525	89038s	5%
800X50	201566	14306s	191566	106350s	-	89h	30%	-	89h	20%	201566	520s	15%	175420	19050s	10%

second part of the graph shows the best values obtained for all Tabu tenure parameters by applying various variations on the $Td\_\mathrm{BS}_{\mathrm{ADD/DROP}}$ while the $Td\_\mathrm{MS}_{\mathrm{ADD/DROP}}$ were fixed according to the best results of the previous experiences. The best parameters are those resulting from combining the best MSs parameters $Td\_\mathrm{MS}_{\mathrm{ADD}} = 0.05 \times |\mathrm{MS}s| \times 15$ and $Td\_\mathrm{MS}_{\mathrm{DROP}} = (1/3) \times Td\_\mathrm{MS}_{\mathrm{ADD}}$. This leads to the best cost with the shortest time (4 seconds) with the BSs parameters $Td\_\mathrm{BS}_{\mathrm{ADD}} = 0.25 \times |\mathrm{BS}s|$ and $Td\_\mathrm{BS}_{\mathrm{DROP}} = (1/2) \times Td\_\mathrm{BS}_{\mathrm{ADD}}$. We conducted similar experiments to compare the best empirical Tabu tenure values with a dynamic Tabu tenure one. We observed, see part 3 of the graph in Fig. 2, that the latter is more efficient than the former one.

The previous experimentations are repeated again to show the effects on the solution quality, of applying dynamic/static Tabu tenure duration combined with/without intensification and diversifications strategies. The experimentations show the efficiency of both the dynamic Tabu tenure duration and the intensification-diversification strategies in the TS process.

TABLE II

EFFECT OF APPLYING INTENSIFICATIONS AND DIVERSIFICATIONS ON STATIC AND DYNAMIC TS

Static Tabu		Dynamic Tabu	
¬ (Ints∧ Divr)	(Ints∧ Divr)	¬ (Ints∧ Divr)	(Ints ∧ Divr)
32620(109s)	29720 (347s)	29720(6s)	29608(68s)

Next, we evaluate the quality of the solutions provided by the TS heuristic. Depending on the size of the problem instances, solutions are evaluated with different precision using the MIP library of the CPLEX package, see Tab. I. TS → CPLEX denotes a running instance with the MIP-CPLEX algorithm where the initial solution is generated by TS.

The best solutions are those corresponding to TS → CPLEX composition obtained in the two last columns (Tab. I). As the size of the instances increases, the MIP-CPLEX algorithm fails to find good solutions even with a large precision (20%, 30%) and longer processing time.

The solutions found with the TS algorithm are also sensitive to the size of the instances, with a precision smaller than 10% for relatively small instances (80 × 50, 160 × 50), precision is over 10% (but still less than 15%) for larger instances (320 × 50, 500 × 50, 800 × 50). We observe that for all the instances, the solutions provided by the TS are not only better, but obtained much faster than those obtained with the MIP-CPLEX algorithm.

V. CONCLUSION

The proposed Tabu Search is one of the first complete studies dealing simultaneously with the BS locations and the wired link capacity of large 3G network instances. The quality of the solutions are assessed using a MIP (Mix-Integer program) model solved by the CPLEX package. Search strategies of the TS approach are based on the Signal to Noise plus Interference Ratio and composed of two alternate phases, the feasibility recovery phase (capacity, GoS, QoS) and the minimization of the number of base stations phase.

Computational experiments of the proposed TS are performed for different instance sizes and show outstanding performance in terms of quality (cost and execution time).

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