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Optimization Methods
for UMTS Radio Network Planning

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Optimization Methods for UMTS Radio Network Planning[*,**]

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Abstract. The UMTS radio network planning problem poses the challenge of designing a cost-effective network that provides users with sufficient coverage and capacity. We describe an optimization model for this problem that is based on comprehensive planning data of the EU project MOMENTUM. We present heuristic mathematical methods for this realistic model, including computational results.

1 Introduction

Third generation (3G) telecommunication networks based on UMTS technology are currently being deployed across Europe. Network operators face planning challenges, for which experiences from 2G GSM barely carry over. The EU-funded project MOMENTUM developed models and simulation methods for UMTS radio network design. Among others, we devised network optimization methods that are based on a very detailed mathematical model.

MOMENTUM constitutes, of course, not the only effort to advance methods for UMTS radio network planning. In [1,2,3] several optimization models are suggested and heuristics methods such as tabu search or greedy are used to solve them. Integer programming methods for planning are shown in [12], power control and capacity issues are treated in [4,11]. Many technical aspects of UMTS networks and some practice-driven optimization and tuning rules are given in [10]. Optimization of certain network aspects without site selection is treated in [9].

Within this article, we focus on heuristic algorithms to solve the optimization task. Methods based directly on the mathematical mixed integer programming model presented in [5,8] will be presented in the future. The preliminary computational results obtained within MOMENTUM are very promising.

2 Optimization Approach

Our optimization approach is *snapshot based*. A snapshot is a set of users that want to use the network at the same time. We consider several snapshots at once and try

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to find a network that performs well for these snapshots and is cost-effective at the same time. Snapshots are typically drawn according to service-specific spatial traffic load distributions.

2.1 Optimization Model

The following decisions have to be made for planning a network:

Site Selection. From a set $\mathcal{S}$ of potential *sites* (roughly equivalent to roof tops where antenna masts could be placed), a subset of sites to be opened has to be chosen.

Installation Selection. At each opened site various *installations* (antenna configurations) can be employed at different antenna locations. From the set $\mathcal{I}$ of all possible installations a subset has to be selected. The number of antennas per site is limited; *three-sectorized* sites are typical.

Mobile Assignment. For each of the users, represented by the set $\mathcal{M}$ of *mobiles* that is possibly distributed over several snapshots, we have to decide which installation serves which mobile device. This is in practice often done on a best-server basis: each mobile is served by the installation whose signal is strongest at the mobile's location.

Power Assignment. Once the users are attached to installations, a feasible combination of power values has to be found. This includes transmission powers in uplink and downlink as well as the cells' pilot powers.

This is formulated as a MIP in [5,8], with binary variables corresponding to the first three decisions and fractional power variables p.

The coverage and capacity requirements are reflected in so-called *CIR* inequalities (Carrier-to-Interference-Ratio) that have to hold for each user. These inequalities at the core of our optimization model follow the pattern:

$$\frac{\text{Received Signal}}{\text{Interfering Signals} + \text{Noise}} \geq \text{Threshold}$$

Using the notation from Table 1, the CIR inequality for the uplink reads:

$$\frac{\gamma^{\uparrow}_{mj}\, p^{\uparrow}_{m}}{\bar{p}^{\uparrow}_{j} - \gamma^{\uparrow}_{mj}\, \alpha^{\uparrow}_{m}\, p^{\uparrow}_{m}} \geq \mu^{\uparrow}_{m} \tag{1a}$$

The CIR inequality for the downlink is somewhat more complicated, since code orthogonality has to be considered for signals from the same cell:

$$\frac{\gamma^{\downarrow}_{jm}\, p^{\downarrow}_{jm}}{\gamma^{\downarrow}_{jm} \left(1 - \omega_m\right) \left(\bar{p}^{\downarrow}_{j} - \alpha^{\downarrow}_{m}\, p^{\downarrow}_{jm}\right) + \sum_{i \neq j} \gamma^{\downarrow}_{im}\, \bar{p}^{\downarrow}_{i} + \eta_m} \geq \mu^{\downarrow}_{m} \tag{1b}$$

η_m	≥ 0	noise at mobile m
$\alpha_m^{\uparrow}, \alpha_m^{\downarrow}$	$\in [0,1]$	uplink/downlink activity factor of mobile m
ω_m	$\in [0,1]$	orthogonality factor for mobile m
$\mu_m^{\uparrow}, \mu_m^{\downarrow}$	≥ 0	uplink/downlink CIR target for mobile m
$\gamma_{mj}^{\uparrow}, \gamma_{jm}^{\downarrow}$	$\in [0,1]$	attenuation factors between mobile m and installation j
$p_m^{\uparrow}$	$\in \mathbb{R}_+$	uplink transmit power from mobile m
$p_{im}^{\downarrow}$	$\in \mathbb{R}_+$	downlink transmit power from installation i to mobile m
$\bar{p}_j^{\uparrow}$	$\in \mathbb{R}_+$	Total received uplink power at installation j (in the snapshot)
$\bar{p}_j^{\downarrow}$	$\in \mathbb{R}_+$	Total downlink power emitted by installation j (in the snapshot)

Table 1. Notations in CIR inequalities

2.2 Planning Data

Input data for our optimization model is derived from the planning scenarios developed within the EU project MOMENTUM. The full contents of these scenarios are described in [7], several scenarios of them are publicly available at [13]. The scenarios contain detailed data on aspects relevant to UMTS radio network planning. The data can be classified as follows:

Radio and Environment. All aspects of the “outside” world. This includes radio propagation, UMTS radio bearers, information on the terrain (such as height or clutter data), and background noise.

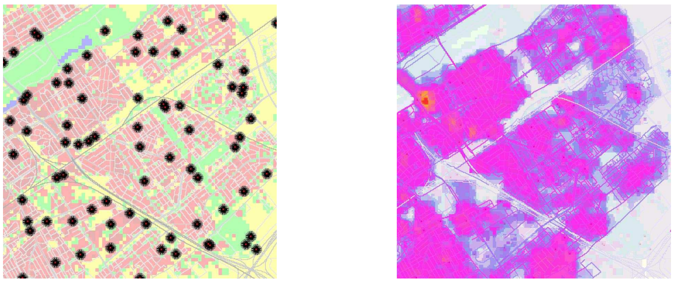
Infrastructure. All aspects that are to some extent under the control of the network operator. This includes base station hardware, antennas, potential sites and antenna locations, and radio resource management.

User Demand. All aspects related to users, such as offered services (e. g., video telephony, media streaming), user mobility, usage specifics, and traffic data.

The potential sites and installations for the planning scenario “The Hague” are shown in Fig. 1(a), the average user demand is illustrated in Fig. 1(b). Darker areas indicate higher traffic load here, the users in the snapshots are generated according to this distribution together with additional information on the used services, equipment, and mobility. The actual parameters for the optimization model [8] and the CIR inequalities (1), in particular, are derived from the information in the planning scenarios. Table 2 gives an overview.

2.3 Preprocessing: Coverage and Capacity Analysis

Before an automatic planning process can be employed, the input data is analyzed in order to detect coverage and capacity shortages. The coverage-oriented analysis is based on propagation path loss predictions for all available sites and their antenna locations. Capacity shortages are harder to detect. We use a heuristic, which is based on a tentative network design using all available sites. Employing methods similar to the ones described in [4,14], the average up- and downlink load per cell of this tentative network can be computed efficiently. If the traffic load is too high for the



(a) Potential sites and antenna configurations (installations)

(b) Traffic distribution

Fig. 1. Example of planning scenario (The Hague)

Planning Scenario	**Parameter**
Equipment loss, Connection loss Propagation loss, Antenna gain Usage loss (e. g. body)	Signal attenuation $\gamma^{\uparrow}_{mj}$,$\gamma^{\downarrow}_{jm}$
BLER requirements User speed Radio bearer	CIR targets $\mu^{\uparrow}_{m}$,$\mu^{\downarrow}_{m}$
User equipment, User mobility Radio bearer	Activity factors $\alpha^{\uparrow}_{m}$,$\alpha^{\downarrow}_{m}$
Clutter type Channel model	Orthogonality ω_m

Table 2. Derivation of parameters from the data scenarios

potential infrastructure in some regions, these can be localized as overloaded cells in the tentative network. Notice that this approach merely provides lower bounds on the achievable network up- and downlink capacity. Methods for estimating an upper bound on the network capacity are under development.

3 Heuristic Planning Methods

It turned out that solving mixed-integer program as described in its main components in Section 2.1 exactly (using for example CPLEX 8.1) takes significant time and computing resources, even for moderate sized scenarios.

Therefore, we developed various heuristic algorithms that aim at obtaining good (not necessarily optimal) solutions within reasonable running times. The explanation of *all* these methods, including greedy-type heuristics, tabu search, simulated annealing, and evolution algorithms, is beyond the scope of this document. We restrict ourselves to the most successful one, the "Set-Covering Heuristic". The interested reader may refer to [5,6] for the description of the other methods.

3.1 Set-Covering Heuristic

The idea of the Set-Covering Heuristic is to find for each installation $i \in \mathcal{I}$ a set M_i of mobiles that this installation can "cover" (we will explain this in more detail below). We assign a cost c_i to each of these sets M_i and then find a set $J = \{j_1, \dots, j_k\} \subseteq \{1, \dots, |\mathcal{I}|\}$ of indices such that each mobile $m \in \mathcal{M}$ is covered by at least one $M_j, j \in J$ and for which the cost $c_J = \sum_{j \in J} c_j$ is minimal. Each index in J corresponds to an installation, and we will simply select the installations that are given by J.

In order to compute the set M_i for a given installation $i \in \mathcal{I}$ we proceed as follows: First of all, we ignore all other installations $j \in \mathcal{I}, j \neq i$, that is, we assume they are not selected. We then consider each mobile $m \in \mathcal{M}$ and determine its distance $d_{m,i}$ to installation i. We define this distance to be $d_{m,i} = 1/(\gamma^{\uparrow}_{mi} + \gamma^{\downarrow}_{im})$ if both attenuation values are non-zero (attenuation is set to zero if the corresponding pathloss exceeds a certain threshold). If the up- or downlink attenuation between mobile m and installation i is zero, this mobile can never be served by installation i. We then set $d_{m,i} = \infty$.

Let M denote the set of mobiles for which $d_{m,i} < \infty$. We initially set $M_i = \emptyset$ and sort the mobiles in M by non-decreasing values of $d_{m,i}$. According to this list we check for each mobile m, whether installation i can serve all mobiles in $M_i \cup \{m\}$ simultaneously. In the positive case we set $M_i = M_i \cup \{m\}$. The feasibility check is based on a Power Assignment Heuristic, which basically solves two systems of linear equations that arise when inequalities (1a) and (1b) are replaced with equations, see [5,6] for details.

The Power Assignment Heuristic does not only check whether installation i can serve all mobiles in $M_i \cup \{m\}$ but also finds minimal transmission powers for each mobile/installation connection in the positive case. These transmission powers are used to compute a score c_i for the resulting set M_i:

$$c_i = \sum_{m \in M_i} \lambda^{\uparrow} p^{\uparrow} + \sum_{m \in M_i} \lambda^{\downarrow} p^{\downarrow} + C_i \tag{2}$$

where the terms $p^{\uparrow}$ and $p^{\downarrow}$ denote up- and downlink transmission powers as returned by the Power Assignment Heuristic and C_i is the cost that is associated with installing installation i. The factors $\lambda^{\uparrow}$ and $\lambda^{\downarrow}$ are used to weight the transmission powers in the cost for set M_i. From iterating over the list of mobiles with $d_{m,i} < \infty$ we obtain a set M_i together with a score (or "cost") c_i as desired; see Algorithm 1.

Algorithm 1 *Covering a set of mobiles with a given installation.*

Input: *Installation $i \in \mathcal{I}$ and mobiles $M \subseteq \mathcal{M}$ that i may potentially cover.*

1. *Determine the mobile/installation distance* $d_{m,i}$ *for each mobile in* $\mathcal{M}$.
2. *Sort* $\mathcal{M}$ *by non-decreasing distance to* i. *Denote result by* M_{sorted}.
3. *Set* $M_{return} = \emptyset$ *and* $c_{return} = C_i$.
4. *For each mobile* $m \in M_{sorted}$ *do*
   (a) *Set* $M' = M_{return} \cup \{m\}$.
   (b) *Use Power Assignment Heuristic to check whether installation* i *can serve all mobiles in* M'.
   (c) *If so, set* $M_{return} = M'$ *and update* c_{return} *according to equation* (2).
5. *Return* M_{return} *and* c_{return}.

Given the sets M_i and associated costs c_i for each installation, we define a set-covering problem. Let $A \in \mathbb{R}^{|\mathcal{M}|\times|\mathcal{I}|}$ denote the incidence matrix of $\mathcal{M}$ and the M_i (i. e., $a_{ij} = 1$ if and only if mobile i is in M_j) and introduce binary variables $x_j, j = 1, \ldots, |\mathcal{I}|$ that are set to one if set M_j is selected and to zero otherwise. The set-covering problem then reads as follows:

$$\min\Big\{\sum_{i\in\mathcal{I}} c_i x_i \mid Ax \geq 1, x \in \{0,1\}^{|\mathcal{I}|}\Big\} \tag{3}$$

Notice that in the above description we implicitly assume that $\bigcup_{i\in\mathcal{I}} M_i = \mathcal{M}$. If this is not the case we simply replace $\mathcal{M}$ by $\bigcup_{i\in I} M_i$.

As stated earlier, each set M_i is in direct correspondence with an installation $i \in \mathcal{I}$. Thus, given an optimal solution $x \in \{0,1\}^{|\mathcal{I}|}$ to (3) we simply select all installations $i \in \mathcal{I}$ for which $x_i = 1$ and install them.

The Set-Covering algorithm as described above has three problems:

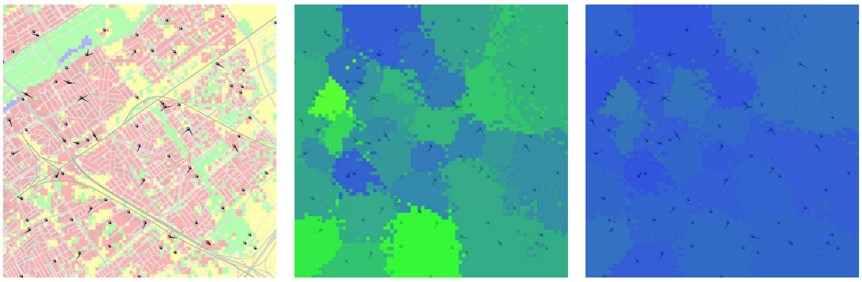
- Model (3) is too simplistic: it does, for example, not take into account that installations are hosted at sites. Opening such a site requires a certain amount of money (typically much more than the cost for a single antenna) and for each site there are minimum and maximum numbers of installations that can be simultaneously installed.
- Due to the fact that we *ignore* all other installation while computing the set M_i for installation i, we also ignore potential interference from these installations. The sets M_i tend to overestimate the coverage and capacity of the installations.
- The set-covering problem as defined in (3) may not have a feasible solution. This can especially happen if traffic is high and the number of installations that are available per site is limited.

All three problems can be resolved: In the first case, the additional constraints related to sites can easily be added to (3). In the second case, we shrink the sets M_i at the end of Algorithm 1 using a "shrinkage factor" f_{shrink}. Or we impose some heuristically determined interference via a "load factor" f_{load} and require that the installation may not use more than that percentage of its maximum load during the algorithm. We distinguish two cases if (3) is infeasible. In case f_{shrink} and f_{load} equal one we declare the input infeasible (which is true up to the assumption that we have performed an optimal mobile assignment). In case at least one of these factors is less than one we modify the factors and iterate.

3.2 Results

Using the Set-Covering Heuristic we are able to compute good solutions to large-scale real world instances. We illustrate one such result for the "The Hague" scenario mentioned in Section 2. The instance contains 76 potential sites, 912 potential installations, and 10,800 mobiles partitioned into 20 snapshots (approximately 540 mobiles per snapshot). For this instance we obtained the best result using a combination of the "heuristic interference" and "heuristic shrinking" strategies by setting $f_{\text{shrink}} = 0.7$ and $f_{\text{load}} = 0.6$.

With these modifications the Set-Covering heuristic took 66 minutes on a 1 GHz INTEL PENTIUM-III processor with 2 GB RAM to find the final installation selection. Fig. 2 depicts the solution. Fig. 2(a) shows the selected installations/antennas; the load in the network is illustrated for uplink and downlink in Fig. 2(b) and Fig. 2(c) (the light areas denote a load of about 25–30%, the darker areas have less load). Our result was evaluated using advanced static network simulation methods developed within the MOMENTUM project [14]. The methods reported at most 3% missed traffic.



(a) Selected antennas (b) Uplink load (c) Downlink load

Fig. 2. Heuristic planning solution

4 Conclusion

We presented an optimization problem of planning cost-effective UMTS radio networks. The model we use reflects many aspects of reality that are essential for planning UMTS networks. To our knowledge, this is the most detailed and comprehensive planning model in literature. Based on this model, we have described some heuristic network planning methods that work well in practice and lead to good results.

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