A Rule-Based Algorithm for Common Pilot Channel and Antenna Tilt Optimization in UMTS FDD Networks

Alexander Gerdenitsch, Stefan Jakl, Yee Yang Chong, and Martin Toeltsch

In this paper we address the problem of capacity optimization in a Universal Mobile Telecommunication System (UMTS) radio network. We present an optimization algorithm for finding the best settings of the antenna tilt and common pilot channel power of the base stations. This algorithm is a parametric method, based on a set of rules. We evaluated our optimization technique on a virtual network scenario with 75 cells. For this scenario we show an increase in capacity compared to the initial settings of about 60 percent.

Keywords: UMTS optimization, common pilot channel (CPICH) power, antenna tilt.

I. Introduction

The Universal Mobile Telecommunication System (UMTS) radio interface can carry voice and data services with various data rates, traffic requirements and quality of service (QoS) targets. Careful configuration of the many network and cell parameters is required and is crucial to a network operator because they determine the capability to provide services, influence the QoS, and account for a major portion of the total network deployment and maintenance costs. Optimization is needed, both in the planning stage to optimize the network configuration for investment saving as well as after the deployment of the network, to satisfy the growing service demand [1], [2]. However, there are numerous configurable parameters which are multi-dimensional and interdependent, and their influence on the network is highly non-linear. Hence, finding the optimum network configuration is a very complex and time-consuming task. Automated optimization algorithms are needed to perform the optimization process quickly and efficiently, with minimal contribution from the operational expenditure. The content of this paper is based on [3], and the presented algorithm in this publication is an extension of the rule-based approach presented in [4]. The new algorithm achieves a higher capacity gain. Furthermore, it needs fewer iterations and thus saves computation time.

Our algorithm optimizes common pilot channel (CPICH) power and antenna tilt settings. These cell parameters have the most significant influence on network capacity [5], [6]. For the evaluation of the network configuration, we use a static UMTS frequency division duplex (FDD) network simulator. The simulator is provided by SYMENA, Software & Consulting GmbH, Austria (http://www.symena.com). Coverage, capacity,

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and quality of service related issues can be analyzed with this tool. The network configuration and user distribution are input into the simulator. The uplink and downlink are jointly analyzed, and the simulation results comprise coverage and capacity information, traffic statistics, outage reasons for the unserved users, and soft handover (SHO) statistics.

The paper is organized as follows. In section II, the influence of the configuration parameters is described in more detail. The description of the optimization process with the rule-based algorithm is presented in section III. In section IV, results of the optimization are given. Finally, some conclusions are drawn in section V.

II. Optimization Parameters

There are numerous configurable base station parameters which influence and determine the capacity of the network, for example:

- antenna settings (tilt, azimuth, height, antenna pattern),
- CPICH power, and
- soft handover parameters.

All these parameters have a strong influence on the interference in the system and therefore on the amount of served mobile terminals. In this paper, we focus on optimizing CPICH power and antenna tilt only.

1. CPICH Power

The CPICH is used by mobile phones to obtain an initial system synchronization and to aid the channel estimation for the dedicated channel. After turning on the power and while roaming in the network, a mobile phone determines its serving cell by choosing the best CPICH signal. Thus, CPICH power determines the cell coverage area. Increasing or decreasing the CPICH power will enlarge or shrink the cell coverage area. Therefore, by appropriately adjusting the CPICH power of the base stations, the number of users per cell can be balanced among neighboring cells, which reduces the inter-cell interference, stabilizes network operation and facilitates radio resource management [7].

On the other hand, there are some constraints on setting the CPICH power: values too high will create interference called “pilot pollution” to the neighboring cells, which will decrease the network capacity [8]. Setting CPICH power too low will cause uncovered areas between cells. In an uncovered area, the CPICH power is too weak for the mobile phone to decode the signal, so network access is impossible.

2. Antenna Tilt

Antenna tilt is defined as the elevation angle of the main beam of the antenna relative to the azimuth plane. Antenna downtilt is often used in mobile wireless systems, particularly in the UMTS network, where traffic in all cells is simultaneously supported using the same carrier frequency. The desired effect is a reduction of the other-to-own-cell interference ratio i, which is defined according to [5] as,

$$i = \frac{I_{oth}}{I_{own}}. \tag{1}$$

In (1), I_{oth} denotes the inter-cell interference and I_{own} is the intra-cell interference. By downtilting the antennas, the other-to-own-cell interference ratio i can be reduced: The antenna main beam delivers less power towards the neighboring base stations, and therefore most of the radiated power goes to the area that is intended to be served by this particular base station [9]. Additionally, an antenna tilt adjustment also affects the cell coverage area, which limits the tilt to reasonable values.

3. Influence of CPICH Power and Antenna Tilt

Adjusting the CPICH power and antenna tilt can increase the network capacity by

i) reducing inter-cell interference and pilot pollution,
ii) optimizing base station transmit power resources,
iii) load sharing and balancing between cells, and
iv) optimizing SHO areas.

III. Optimization Technique

In this section, the developed algorithm is described. The rule-based optimization algorithm, which is presented in this paper, is an extension of the approach introduced in [4]. The optimization of the base station parameters, in our case CPICH power and tilt, begins with a first evaluation of the network. After analyzing the results of the first evaluation, the iterative optimization process is started. Each loop includes two steps. In the first step, the parameters are changed according to a rule-based optimization technique, described in subsection 3 of this section. This new technique changes CPICH power and antenna tilt together. In contrast to [4], an increase of CPICH power and antenna uptilting is also possible. After changing the parameters, in the second step, the network is evaluated. Then, the next iteration of the optimization loop is started and the parameters are changed again. Figure 1 shows the flow chart of the optimization process.

1. Grade of Service

During the optimization process, an indicator is used to

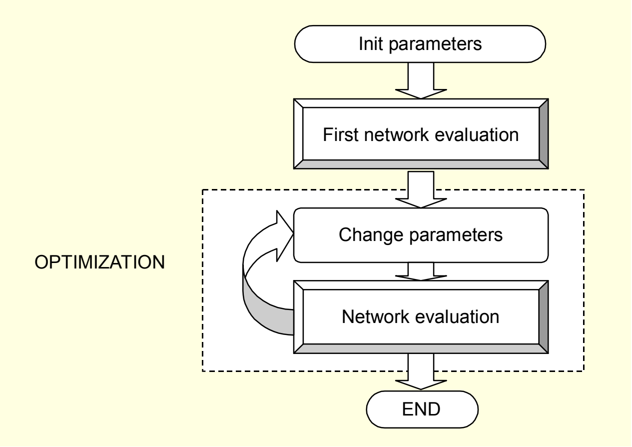

Fig. 1. Structure of optimization process.

characterize how many users can be provided with a service. This value is called *Grade of Service* (GoS) and describes the ratio of served users over all existing users.[1] We define the GoS as

$$GoS = \frac{served\_users}{existing\_users}. \tag{2}$$

In (2), *served_users* denotes the total number of served users in a defined area (e.g. the whole simulation area), and *existing_users* is the total number of simulated users in the same area. During the optimization process, the GoS increases from its initial value of 95 percent until it has reached 100 percent. Then all users are served and the optimization algorithm cannot proceed any further. Now, however, the network can accept more users. Thus, our optimization algorithm applies the following approach: When the GoS reaches a threshold value of 97 percent, new users are added to the network until the initially defined GoS of 95 percent is reached again. In the following, this function is referred to as *add_users*.

For the evaluation of the network, a *fitness function* has to be defined. The fitness function represents the optimization goal. In this paper, we want to maximize the capacity of the network; therefore we consider the number of served users as the goal of the optimization. As GoS reflects this amount of served users, it is used as our fitness function.

2. Quality Factor *QF*

To describe the quality of a cell in the network, a performance indicator denoted as *quality factor* (*QF*) is introduced. The *QF* indicates whether a cell is heavy loaded or not, and it is determined by the following three values:

i) f_{load}
ii) f_{pwr}
iii) f_{OVSF}

The parameter, $f_{load,}$ is a measure of the uplink cell loading condition and is defined as

$$f_{load} = \frac{\eta}{\eta_{thres}}. \tag{3}$$

In (3), η_{thres} denotes the planned uplink cell load, and η is the actual cell loading. The second value, f_{pwr}, is a measure of base station (BS) transmit power utilization in the downlink and is defined as

$$f_{pwr} = \frac{P_{transmit}}{P_{max}}. \tag{4}$$

In (4), P_{max} denotes the maximum transmit power of a cell, while $P_{transmit}$ represents the current total transmit power of that cell. The third value, f_{OVSF}, is a measure of the orthogonal variable spreading factor (OVSF) code utilization in the downlink and is defined as

$$f_{OVSF} = \frac{ovsf_{used}}{ovsf_{limit}}. \tag{5}$$

In (5), $ovsf_{limit}$ is the maximum available number of OVSF codes, which is 512; $ovsf_{used}$ is the number of used OVSF codes. With the three values, f_{load}, f_{pwr} and f_{OVSF}, the *QF* is defined as

$$QF = 1 - \max(f_{load}, f_{pwr}, f_{OVSF}). \tag{6}$$

The range of the *QF* is between zero and one. A low value *QF* describes a heavily loaded cell, and a high value *QF* describes a weakly loaded cell. Therefore, by using the QF as the performance indicator, CPICH power and antenna tilt settings can be adjusted adaptively according to the loading condition in the uplink and downlink of a cell.

3. Changing CPICH Power and Antenna Tilt

In each iteration of the optimization loop, illustrated in Fig. 1, the *QF* is computed for each cell, while the CPICH power and antenna tilt are changed according to the developed rules, as shown in Table 1.

The rules are designed in such a way that a highly loaded cell (QF < 0.5) having outaged users is required to shrink its

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[1] Note that some literature defines GoS as the probability of a call being blocked or delayed for more than a specified interval.

coverage area by decreasing the CPICH power and increasing the antenna downtilt. Conversely, if the cell has a low user density ($QF > 0.7$), it has to expand its coverage area to cover more users by increasing the CPICH power and antenna uptilt. With this approach, load balancing within the cells in a network can be achieved, resulting in higher network capacity.

Table 1. CPICH power and antenna tilt adjustment.

QF	CPICH power and antenna tilt change
$QF < 0.5$	Decrease CPICH power and tilt antenna down
$0.5 \le QF \le 0.7$	No change
$QF > 0.7$	Increase CPICJ power and tilt antenna up

CPICH power and antenna tilt modifications are controlled by a set of rules with different step size and limitation settings, as shown in Table 2 below. One rule consists of one instruction for the CPICH power and one instruction for antenna tilt.

Table 2. An example of CPICH power and antenna tilt step size and limitation settings.

rule	param	stepsize	limit	iter
0	CPICH	3 dB	25 dBm	50
	tilt	1.5°	4°	
1	CPICH	0.5 dB	10 dBm	50
	tilt	0.25°	7°	

In Table 2, *param* specifies the modified parameter; *stepsize* denotes the maximum allowed adjustment of CPICH power and antenna tilt settings per iteration; *limit* describes the lower or upper limit of the parameter, and *iter* specifies how often the rule can be applied at most.

When the QF of a cell is greater than 0.7, both its CPICH power and antenna uptilt will be increased by

$$stepsize \cdot \left| \frac{QF - 0.7}{0.3} \right| . \tag{7}$$

On the other hand, if the cell's QF is less than 0.5, the CPICH power will be reduced, and antenna downtilt will be increased by

$$stepsize \cdot (1 - QF) . \tag{8}$$

Consequently, the adjustments of CPICH power and antenna tilt depend on the cell's actual QF. With this strategy, CPICH power and antenna tilt are adjusted adaptively according to the loading condition of a cell.

The modification of antenna downtilt and CPICH power has to be limited (lower limit for CPICH power and upper limit for antenna downtilt) in each rule by the parameter *limit* in order to avoid changes that are too big in a particular cell, which can be seen in Table 2. There are no limitations set for the maximum CPICH power and maximum antenna uptilt, so a larger service coverage area is allowed in regions where the user density is low. Furthermore, the developed algorithm is biased toward reducing the initial CPICH power and increasing the antenna downtilt. When the optimization process is launched, the algorithm starts with the first rule of the used rule set (e.g. from Table 2). For each rule, several iterations are performed. According to Table 2, we can see that in this case the algorithm proceeds to rule number 2 after the first 50 iterations. If the GoS after one of the iterations within any one rule is lower than 95 percent and lower than the GoS from the previous iteration, the new result is not accepted. In this case, the same iteration is performed again, but only in two-thirds of the previously modified cells (priority according QF) are the CPICH power and tilt settings changed (*Cell Reduction*). The algorithm terminates when either all rules of the rule set have been processed or if the QF in each cell is between 0.5 and 0.7, which can be seen in Table 1. This means the network is balanced, or that the algorithm cannot process further due to the limits for CPICH power and tilt. Figure 2 shows a detailed flowchart of the optimization loop.

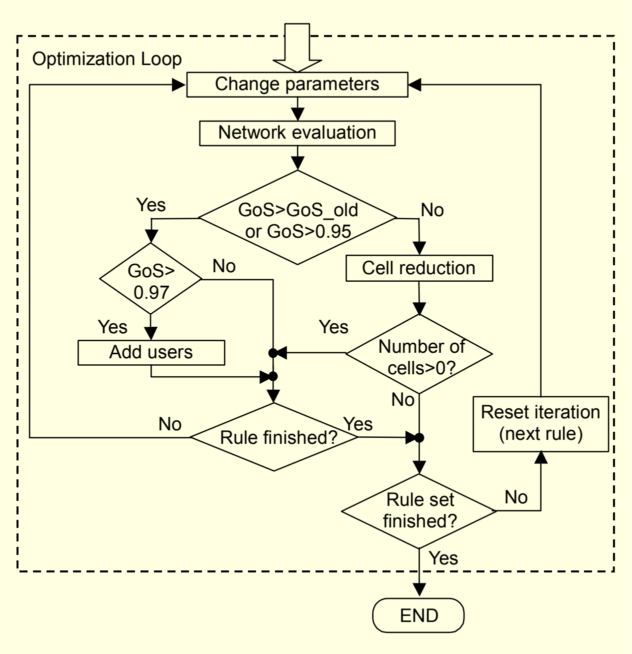

Fig. 2. Detailed flowchart of the optimization loop.

IV. Optimization Results

In the network scenario, we used 25 base stations equipped with 3-sector antennas, thus comprising 75 cells. The distribution of the mobile terminals was assumed according to the population density, with a service mix of 40 percent speech users and 60 percent two-way 64 kb/s data users. The initial number of users in the whole network is 1057. The distribution of the base stations as well as the distribution of the users is shown in Fig. 3. The arrows in the figure represent the sectors of a base station, and the dots symbolize the users in the system.

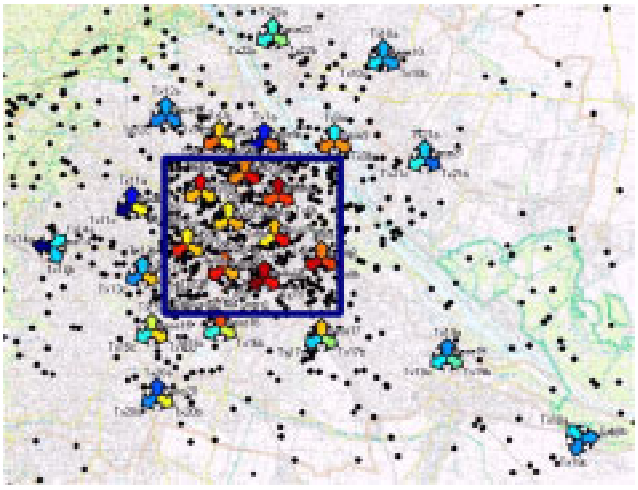

Fig. 3. Base station locations and user distribution of the network.

Table 3. Simulation parameters.

Number of sites	25
Number of sectors per site	3
Number of sites in optimization area	9
Total number of initial users	1057
Service mix	40% 12.2 kb/s speech user 60% 64 kb/s data user
Activity factor	0.5 (speech);1.0 (data)
Max. BS TX power	43 dBm
Max. MS TX power	21 dBm
Antenna height	30 m
BS antennas	65°/16 dBi
MS antennas	Omni/0 dBi
Active set size	2
Active set window	3 dB
Initial CPICH power	33 dBm
Initial tilt[2]	0°

The area inside the rectangle is defined as the optimization area. This is the area of interest, and the GoS is evaluated over this part. The initial value of the GoS in this optimization area is 95.11 percent. The most important parameters used in the simulation scenario are introduced in Table 3.

Table 4 shows the results of the optimization. Before and after optimization, 50 snapshots with different user distributions are simulated. The optimization process itself is performed with one fixed user distribution. Before optimization, the mean number of served users in the optimization area is 511.

After the optimization, with our rule based approach, 831 users are served in average. This increase in served users leads to a capacity gain of 62.6 percent. It is noticeable that the standard deviation of served users with respect to different user distributions after the optimization is much higher than before. This means that the optimized network is less stable regarding the user distribution. A possible approach for reducing this dependence would be to use different user distributions during the optimization process.

Table 4. Optimization results.

Simulation	Before optimization	After optimization
Mean number of served user in target area	511	831
Standard deviation (number of served users)	7.54 (1.48%)	31 (3.7%)
Capacity gain (%)		62.6

V. Conclusion

In this paper, we presented a rule-based algorithm for optimizing the two most important parameters of a UMTS base station, CPICH power and antenna tilt. The main difference to the algorithm presented in [4] is that with the new algorithm, CPICH power and antenna tilt are changed together, and that an increase of CPICH power and antenna uptilting is possible during the optimization process. The new algorithm gives a higher capacity gain. Furthermore, it needs fewer iterations and thus saves computation time. The evaluation of our rule-based algorithm was done on a virtual network scenario with 75 cells using SYMENA's static UMTS FDD network simulator. For this scenario, we have shown an increase in capacity of 62.6 percent.

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[2] The antenna pattern has a predefined tilt of 3°.

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