UMTS Radio Network Multiparameter Control

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Abstract— **Five key UMTS radio network parameters are simultaneously optimized with an automatic control method. The parameters relate to admission control, power control, handover control, and coverage. The optimization is guided by heuristic expert-defined rules, which apply specific trade-off policies and statistics of poor quality calls, blocking rates, power and interference levels, and terminal measurements to qualify the parameter values. The method was validated using a dynamic WCDMA system simulator with a deployment of 17 cells in Helsinki city center. The same parameter value was applied in each cell as the network formed of a uniform cell structure. The method was shown to produce convergence of parameters and stable operation. The obtained results showed that the method improved overall network performance in comparison to fixed planned default values. The capacity of network was improved close to 20% with slightly decreased but still acceptable quality of calls.**

Keywords— **UMTS, radio network planning, optimzsation, call quality, congestion, admission control, power control, handover control, coverage, system simulation**

I. INTRODUCTION

The radio interface of UMTS networks can carry voice and data services with various data rates, traffic requirements, and quality-of-service targets [1]. Moreover, the operating environments vary considerably from indoor cells to large macro cells. Efficient use of a limited frequency spectrum in diverse conditions requires careful setting of numerous vital network and cell parameters such as maximum load levels and allocated channel powers. The parameter setting is referred to as radio network planning and optimization. Once a UMTS network is built and launched, its operation and maintenance largely consists of monitoring the performance or quality characteristics and changing parameter values in order to improve performance. The operability of the network would considerably benefit from automated monitoring and parameter changing. UMTS network autotuning and advanced monitoring are discussed in [2]. Previously, we have described one-parameter control algorithms for UMTS radio networks [3-6]. In the present study, we control multiple parameters simultaneously with a set of heuristic rules. Adequate call success and quality are defined together with costs of diverting from them. The parameters are controlled to minimize the total cost. Simulations are carried out to show that the parameter control converges, is stable, and improves overall network performance.

We use automatic control of five key UMTS radio network parameters: admission control parameters *PrxTarget* and *PtxTarget* [3,4], power control parameter *CPICHToRefRABOffset* [4], handover control parameter *AdditionWindow* [5], and pilot power *PtxPrimaryCPICH* that determines the cell coverage [6]. The parameters are controlled to eliminate poor connection quality and congestion or, if elimination is not possible, to find an optimum balance between them. The optimum balance is defined by the following policies:

- The cost of poor quality is two times the cost of blocking the connection.

- The cost of blocking due to uplink congestion is equal to the cost of blocking due to downlink congestion.

- The maximum allowed ratio of poor quality connections is 5%.

- The maximum allowed blocking ratio is 5%.

- 95% of the pilot Ec/Io measurements that the terminals report to the network must be above –15 dB.

The same parameter value is applied in each cell of the simulated network as the base stations share similar properties and form an isolated and uniform cell structure.

The proposed control method is not compared to other optimization approaches. Presumably, similar results are obtained with any valid approach. However, the approaches differ in their practicability and adoption by the network operator. The advantage of our method lies in the explicated operation that supports understanding of regularities in the network.

II. NETWORK PERFORMANCE AND CONTROL RULES

A. Performance measures

Uplink poor call quality: The cell is regarded as having a condition of poor uplink quality if significantly over 5% of the connections, sampled every 10 seconds, had excessive frame error rates in the samplings of past 100 seconds. A frame error rate significantly higher than 2% is regarded as excessive. The sampled connections are limited to those, for which the cell is the strongest one in the terminal active set. With moving terminals, the frame error rate of a connection in a particular cell is thus likely measured over a short period of time and the variance of rate can be high. The number of sampled connections can also vary considerably from cell to cell and time period to another. The uplink quality measures are

normalized to remove the effect of varying sample size making them commensurate. In formal terms, define R be the ratio of connection samples with excessive frame error rate, T be the limit ratio set to 5%, N be the total number of call samples, and

$$Q = \frac{R - T}{\sqrt{T(1-T)/N}} \cdot \quad (1)$$

Then, the cell has poor uplink quality if

$$N \cdot R \geq 5 \quad (2)$$

and

$$Q > 2 \cdot \quad (3)$$

Formula (1) checks that the sample size is sufficiently large for assuming the estimate of R normally distributed. Formula (2) checks that the ratio of connections with excessive frame error rate is significantly higher than T (i.e. 5%). Constant 5 in (2) is a rule-of-thumb value suggested by statistical literature. Constant 2 in (2) is the 98% point in the cumulative normal distribution leaving a 2% change of error in regarding the cell as having poor uplink quality.

1) Downlink poor call quality: Poor downlink quality is measured in the same way as poor uplink quality. However, the cell lacks information about the frame errors in downlink. Thus, we define that an erroneous frame is received in downlink if the link power hits the maximum link power allocated to the connection.

2) Congestion: The cell is regarded as having a condition of excessive uplink or downlink congestion if significantly over 5% of the admission requests of real-time services were blocked during the past 100 seconds due to insufficient uplink or downlink power resources. Formally, the excessive congestion is detected with formulas similar to (1) to (3) by substituting blocking ratio and the number of admission requests for R and N:

$$B = \frac{R - T}{\sqrt{T(1-T)/N}} \cdot \quad (4)$$

The cell has increased congestion if (2) holds and $B > 2$.

3) Pilot sufficiency: The received pilot signal of a terminal is regarded as sufficient if the received pilot Ec/Io is over –15 dB. The cell is regarded as having a too low (or high) pilot power if significantly under (or over) 95% of the pilot Ec/Io levels are sufficient. Formulas similar to (1) to (3) are used to detect significant deviations.

4) Uplink noise rise: The average, *PrxTotalAve*, and the deviation, *PrxTotalDev*, of the logarithm of uplink noise rise, sampled once a second, are computed over the past 100 seconds for each cell. The statistics are used to indicate that an uplink congestion problem is likely due to an insufficient uplink power allocation and not due to insufficient hardware or logical resources.

5) Downlink total transmission power: The average, *PtxTotalAve*, and the deviation, *PtxTotalDev*, of the logarithm

of downlink total transmission power are used to indicate an increased probability of downlink power exhaust or wideband power amplifier overload.

B. Controlled parameters

1) PrxTarget determines the optimum planned uplink load level measured as the received total interference power. Admission Control, Packet Scheduler, and Load Control apply the parameter to the allocation of uplink power resources. If *PrxTarget* is low, the system can show unnecessary congestion, as the uplink power resources are not fully utilized. If *PrxTarget* is high, the system can show poor uplink call quality as exceedingly high power resources are granted to the users.

2) CPICHToRefRABoffset determines the maximum downlink link power allocated to a radio access bearer. The maximum power of the reference radio access bearer, typically a low-bit-rate speech service, is the pilot power divided by *CPICHToRefRABoffset*. The maximum power of other radio access bearers is obtained by scaling the reference maximum power to match the bit rate and Eb/No requirement of the particular service. If *CPICHToRefRABOffset* is too low, the system can show congestion as unnecessarily high power allocations are made and the downlink power resources are not fully utilized. If *CPICHToRefRABOffset* is too high, the system can show poor downlink call quality due to insufficient power allocation and resulting link power outage.

3) PtxTarget determines the optimum planned downlink load level measured as the total transmitted cell power. If *PtxTarget* is low, the system can show unnecessary congestion, as the downlink power capacity is not fully utilized. If *PtxTarget* is high, the system can show poor downlink call quality, for instance, due to an overloaded wideband power amplifier.

4) PtxPrimaryCPICH determines the power of the primary common pilot channel, or simply the pilot power, in the cell. The pilot power is an indication to the mobile of its ability to use the signals from the cell transmitting that pilot. If *PtxPrimaryCPICH* is low, the call setup success and soft-handover performance can deteriorate. If *PtxPrimaryCPICH* is high, the system can show unnecessary downlink congestion as the pilot consumes power from the transport channels.

5) AdditionWindow determines the addition of a cell to the active set of the terminal. If the active set is not full and the received pilot signal is higher than that of the strongest cell in the active set minus *AdditionWindow* then the addition is performed. *AdditionWindow* has an effect on the average size of the terminal active sets and on the average level of the soft-handover overhead. If *AdditionWindow* is set to a too high value, the active set sizes of the terminals are too large on the average, which can cause a) increased downlink congestion due to insufficient physical (channel elements) and logical (codes) resources, and b) increased base station total transmission powers due to many links. If *AdditionWindow* is set to a too low value, the active set sizes of terminals are too small on the average, which can cause increased uplink

interference and congestion. The calls from terminals on the cell border can show increased poor quality due to power outage.

DropWindow is a similar parameter to *AdditionWindow* but for dropping cells from the active set. In the parameter control, *DropWindow* was always just set 2 dB higher than *AdditionWindow*.

C. Control rules

The optimization is performed for a group of cells so that the performance measures are collected for each cell separately but the cells share the same values of *PrxTarget*, *CPICHToRefRABOffset*, *PtxTarget*, and *AdditionWindow*. The performance in each cell of the group is evaluated. Basically, if the number of cells with congestion is larger than the number of cells with poor call quality, the appropriate power parameter in all cells is increased. If the poor call quality is the major problem in the cell group, the power parameter is decreased. The optimization rules can be given in the following general way.

If the number of users in cells with uplink power-based congestion is higher (or lower) than the number of users in cells with uplink poor call quality then *PrxTarget* is increased (or decreased) by 1 dB. *PrxTarget* is limited between 3 and 16 dB over the system noise level.

If the number of users in cells with downlink congestion is higher (or lower) than the number users in cells with downlink poor call quality then *CPICHToRefRABOffset* is increased (or decreased) by 1 dB. *CPICHToRefRABOffset* is limited between *PtxPrimaryCPICH* / *PtxLinkMax* and *PtxPrimaryCPICH* / *PtxLinkMin*, when the allocated link power for the reference bearer is between *PtxLinkMin* and *PtxLinkMax*.

If the number of users in cells with an increased probability of base station power exhaust is higher (or lower) than the number of users in cells with downlink poor call quality then *PtxTarget* is decreased (or increased) by 1 dB. *PtxTarget* is limited between two times *PtxPrimaryCPICH* and the maximum base station total power.

If the number of users in cells with uplink congestion is higher (or lower) than the number of users in cells with downlink congestion then *AdditionWindow* is increased (or decreased) by 1 dB. *AdditionWindow* is limited between 1 and 10 dB.

If the number of users in cells with unsatisfactory pilot reception is higher (or lower) than the number of users in cells with satisfactory reception then *PtxPrimaryCPICH* is increased (or decreased) by 1 dB. The reception is unsatisfactory if significantly fewer than 95% of the terminal-reported pilot Ec/Io levels exceed –15 dB. *PtxPrimaryCPICH* is limited below 10% of the maximum base station total power.

The following sections describe the details of determining cells having poor connection quality or congestion, the information of which is used in the aforementioned voting.

1) Uplink poor quality and congestion: A cell can simultaneously suffer from both excessive poor connection quality and congestion. In order to determine which is more severe and requires more urgent attention, cost needs to be considered. Let the poor connection quality be two times more costly than congestion. With the quality measure of (1) and the congestion measure of (4), we can define a balance measure *W*

$$W = 2 \cdot \max(0, Q - 2) - \max(0, B - 2) . \qquad (5)$$

The maximum function and subtraction with 2, the 98% point in the cumulative normal distribution, cancel insignificant increases of the performance measure. Now,

a) if *W* is positive then the cell suffers principally from poor uplink connection quality.

b) If *W* is negative and *PrxTotalAve* + 2·*PrxTotalDev* > *PrxTarget* then the cell suffers principally from uplink power-based congestion. The latter condition checks that the noise rise is close to *PrxTarget*, which supports the interpretation that the congestion is due to too low *PrxTarget*.

2) Downlink poor quality and congestion: As in the uplink case, the downlink poor quality and the congestion are weighted with cost factors and balance measure *W* similar to (5) is defined.

a) If *W* is positive then the cell suffers principally from poor downlink connection quality.

b) If *W* is negative and then the cell suffers principally from downlink power-based congestion.

3) Base station power exhaust: If *PtxTotalAve* + 2·*PtxTotalDev* is larger than the base station maximum power then the cell is considered as having an increased probability of base station power exhaust.

III. Simulation Environment

The multiparameter control was verified with an advanced WCDMA radio network simulator [7]. The simulator implements many advanced features such as admission control, closed-loop and outer-loop power controls, soft and hard handover controls, packet scheduler, load control, and quality manager. For this analysis, the simulator modeled 17 cells deployed over an area of Helsinki center. The mobile stations were uniformly distributed along the streets of simulated area. They moved with constant speed and made new calls according to a Poisson interarrival distribution. The simulation step was one frame or 10 ms, at which the transmission powers, received interferences, and signal-to-interference ratios were recalculated for each connection in uplink and downlink.

Fig. 1 shows the general view of the simulated network. The cells were numbered from 13 to 26 and 30 to 32. The cells are indicated in Fig. 1 by bars pointing to the principal direction of antenna pattern. The antenna of easternmost sector was omnidirectional, however. The channel multipath profile was that of ITU Vehicular A [8] with 5-path propagation. The path gains are shown in Table 1. One half of the signal power came along the line of sight and the other half was a sum of powers from four reflected signals. In downlink, signals from the same base station propagating along the same path were totally orthogonal, that is, they did not interfere with each other's

signal. Thus, the downlink orthogonality factor [1] computed from the path gains was 60%. The propagation loss was calculated using the Okumura-Hata model with average correction factor of –6.2 dB. The shadow fading process conformed to the buildings, streets, and water areas, Fig. 1. Short-term fading with 7-dB deviation was added to the process.
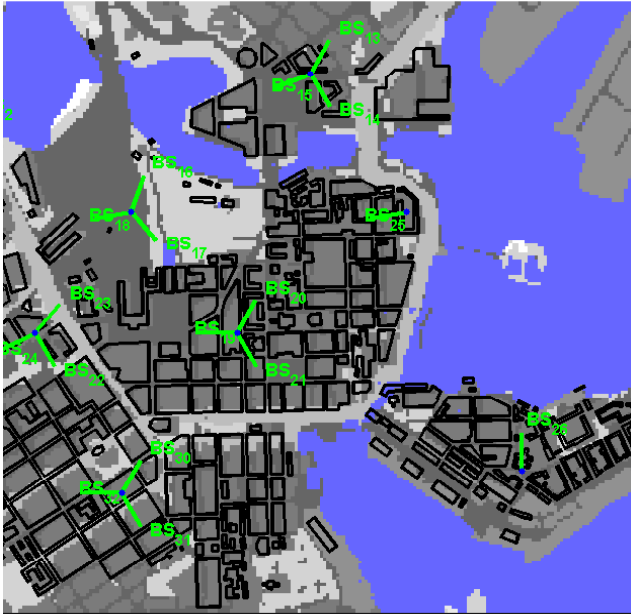

Figure 1. Deployment of five three-sector and two one-sector sites in Helsinki center area. Water appears as wide uniform areas.

All cells shared the same values of the controlled parameters. Their initial values were:

- *PrxTarget*: 6 dB over the system noise

- *CPICHToRefRABOffset*: 7 dB

- *PtxTarget*: 10 W

- *AdditionWindow*: 1 dB

- *PtxPrimaryCPICH*: 1 W

The simulations were carried out with four different loadings that were produced with 1,000, 2,000, 3,000, or 4,000 subscribers in the network. Each subscriber made 11 calls or call attempts in an hour on the average, and 70% of the calls used 8-kbps speech service and 30% used 64-kbps circuit-switched-data service. The average length of speech calls was 30 seconds and that of circuit-switched-data calls 20 seconds. With 1,000 subscribers, the average number of simultaneous calls in a cell was about five, assuming that no calls were blocked. The simulated time was two hours. The parameter control was performed every 100 seconds. For each load level, a simulation was performed both with the fixed parameter values and with the parameter control and the obtained results were compared.

To validate the control of *PtxPrimaryCPICH*, call setups and handovers were made impossible if the pilot Ec/Io level to the

terminal was below –21 dB. Thus, the network performance deteriorated if *PtxPrimaryCPICH* was controlled to a too low value.

TABLE I.   SOME NETWORK PARAMETERS

Parameter	Value
Chip rate	3.84 MHz
Frequency	2.0 GHz
Bandwidth	5.0 MHz
Base station maximum transmission power	20 W
Mobile station maximum transmission power	125 mW
Power control dynamic range	65 dB in UL, 20 dB in DL
Base station antenna sector and gain	65°, 17.5 dBi Omni, 11.0 dBi
Mobile station antenna sector and gain	Omni, 0.0 dBi
Uplink system noise	–102.9 dBm
Downlink system noise	–99.9 dBm
Minimum coupling loss	–50 dB
Average antenna height	18 m
Multipath propagation gains	50, 30, 11, 6, 3 %
Mobile station speed	3 km/h
Outer loop frame error rate target	1 %

IV.   RESULTS AND DISCUSSION

The general performance in the network with and without control is given in Table 2. The upper number in each row is the result obtained with the initial parameters and the lower number is that with control. The first and second row shows that the number of started calls was increased significantly with control (subject to sufficient traffic). The next four rows show that the ratio of poor quality calls was at most 1.0% with the initial parameters and 2.2% with control. Call quality was regarded as poor if over 2% of the frames were received incorrectly during the whole converse time. The last two rows show that the blocking ratio was significantly reduced with control. Requiring that at most 5% of the calls are either blocked or suffer from poor quality then the number of subscribers that the network tolerated was between 1,000 and 2,000 with the initial parameters. With control, the number was increased to between 2,000 and 3,000. The quality of calls was too good by the standard of defined policy with the initial parameters, which was reflected in high blocking. The capacity was much improved by trading off quality for reduced blocking. Taking into an account a 2.5-dB difference in signal level requirements between the 8 and 64-kbps services, the combined improvement of capacity was 9% with 2,000, 17% with 3,000, and 19% with 4,000 subscribers.

The 4,000-subscriber case was selected to exemplify the adjustment of parameters because it best revealed the control dynamics due to high traffic density. Fig. 2 shows the results with the control of *PrxTarget*. No cell showed significant deterioration of uplink quality. There were similar uplink blocking problems in some cells, which are typified in Fig. 2 with the blocking in cell 20 in the middle of the simulated area. As the quality was not a problem, *PrxTarget* was gradually increased, with which the blocking clearly decreased until *PrxTarget* reached its upper limit.

TABLE II. GENERAL NETWORK PERFORMANCE

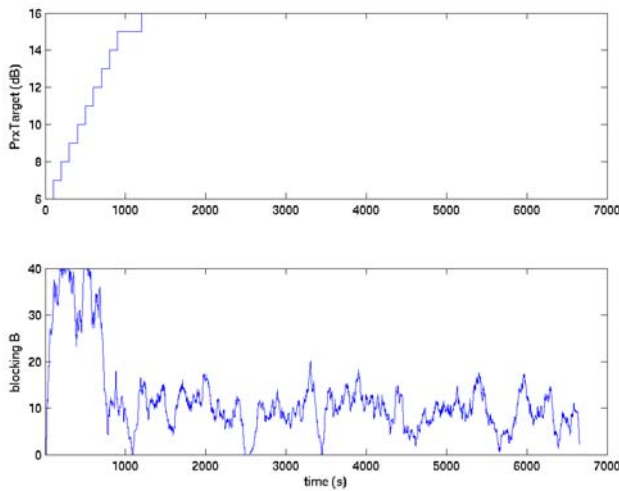| Indicator	Number of Subscribers			
	1,000	2,000	3,000	4,000
Started speech calls	14,000 14,000	26,000 28,000	33,000 40,000	39,000 52,000
Started CS calls	5,800 5,800	11,000 12,000	14,000 16,000	17,000 19,000
Poor quality speech calls UL (%)	0.2 0.2	0.2 0.3	0.3 0.6	0.2 0.9
Poor quality speech calls DL (%)	0.1 0.3	0.2 0.2	0.2 1.2	0.4 1.9
Poor quality CS calls UL (%)	0.3 0.5	0.7 1.2	1.0 2.1	0.9 2.2
Poor quality CS calls DL (%)	0.1 1.8	0.1 0.9	0.0 1.0	0.0 1.0
Blocked speech calls (%)	0.6 0.5	8.2 0.8	20 3.8	30 6.9
Blocked CS calls (%)	0.6 0.4	8.0 1.7	21 10	31 21

CS: circuit-switch data.

Figure 2. *PrxTarget* and uplink blocking *B* in cell 20. The blocking is indicated as the value of statistic (4), not as a ratio.

In downlink, there were some cells with quality problems. However, most of the problems occurred in cell 20. Fig. 3 shows that *PtxPrimaryCPICH* was decreased from its initial value stabilizing at the level of 250 mW. The obtained low pilot power was justified as no failed call setups or handovers were detected. The quality in cell 20 deteriorated with the decreasing pilot power. This is explained with the fact that *CPICHToRefRABOffset* is linked with *PtxPrimaryCPICH*. *CPICHToRefRABOffset* must be decreased with *PtxPrimaryCPICH* in order to keep allocated link powers similar. Fig. 3 shows that the control appropriately decreased *CPICHToRefRABOffset*, which stabilized at 0 dB. The allocated power with the stable values was 250 mW for a speech-service link. After the levels stabilized, *CPICHToRefRABOffset* responded to increased quality problems by decrease. Once the situation was corrected, *CPICHToRefRABOffset* was increased to alleviate the blocking. Thus, *CPICHToRefRABOffset* modestly fluctuated around the optimum level.
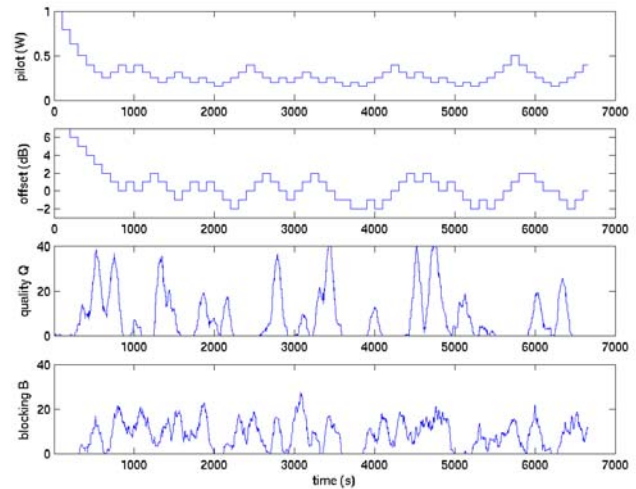

Figure 3. *PtxPrimaryCPICH*, *CPICHToRefRABOffset*, downlink quality *Q* and downlink blocking *B* in cell 20. The quality and blocking are indicated as statistics (1) and (4). Higher *Q* corresponds to lower quality.

Fig. 4 shows the control of *AdditionWindow*, whose value was rapidly increased in the beginning to reduce excessive uplink blocking. The uplink blocking problem was mainly corrected with *CPICHToRefRABOffset* as described above. Thus, once the transient phase was over, *AdditionWindow* decreased and started fluctuating, with a 3-dB median level, keeping the uplink and downlink blocking indicators similar. For instance, the downlink blocking ceased for a long period after 3,500 seconds while the uplink blocking remained significant. *AdditionWindow* responded with notable increase until the blockings were balanced.

PtxTarget was also changed from its initial level. The median level was 12.6 W, around which *PtxTarget* fluctuated from –1 dB to 1 dB.
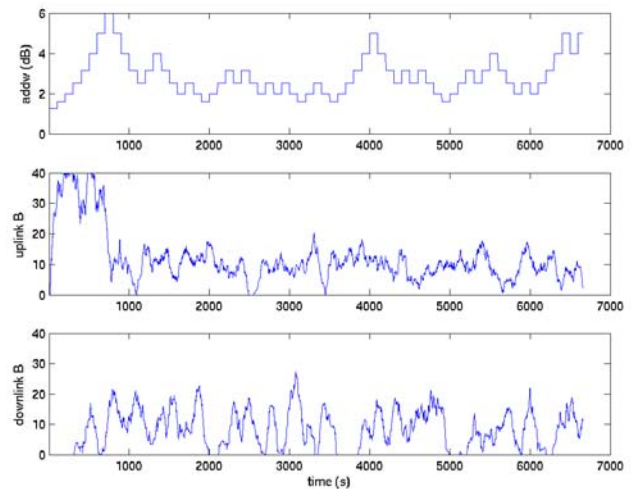

Figure 4. *AdditionWindow*, uplink blocking *B* and downlink blocking *B* in cell 20. The blockings are indicated as statistic (4).

The obtained increase of close to 20% in capacity is highly specific to the described case and generalizing the result to real networks is not straightforward. The benefit of control depends on the choice of the initial parameters, traffic characteristics, defined policies, and the availability of performance measures. Our study case omitted packet traffic. Implementing quality measures and defining policies for packet users is not much different from those for conversational users. The described rules do not need revising. Only the balance measure (5) requires adding terms quantifying the costs of packet traffic quality and congestion.

In this study, the same parameter value was applied in each cell since the cells were considered to form a homogeneous cluster. Although it would be possible to have separate parameter values for each cell, we suggest optimization on a per-cluster basis for improved stability. In a network of diverse cell properties and many layers, the clustering of cells is thus an additional task. The clustering can be based on performance measures and parameters with conventional methods such as the k-means algorithm or the self-organizing map [9].

The rule-based approach is not necessarily superior to conventional optimization methods, such as the gradient-descent minimization [5,10] in terms of convergence speed, stability, or robustness. The gradient-descent algorithm utilizes stochastic search, that is, random perturbations of parameters to find the optimum values. The benefit of stochastic search is that minimum knowledge is required about the dependence of performance on the parameters. On the other hand, the choices that the algorithm makes in the parameter adjustments may remain obscure to the network operator. The rule-based control is based on expert knowledge, according to which the rules are constructed. The rules likely require revision of details in the beginning of operation. However, the approach offers to the network operator a good insight into the regularities of system, which may prove valuable in solving problem situations.

To conclude, the automatic optimization of multiple UMTS radio network parameters was described. The optimization was guided by heuristic rules, commensurate performance indicators, and trade-off policies. The method was shown to produce convergence of parameters, stable operation, and a significant increase of capacity.

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