Optimization of Signal Level Thresholds in Mobile Networks

Matías Toril*, Salvador Pedraza**, Ricardo Ferrer**, Volker Wille**

*Dpt. Ingeniería de Comunicaciones. Universidad de Málaga.
mtoril@ic.uma.es, Tel: +34 952137120 , Fax:+34 952132027
Campus de Teatinos s/n 29070 Málaga (Spain)

**Nokia Networks
C/Severo Ochoa s/n. Edif. De Instit.Universitarios, Pl.3
Parque Tecnológico de Andalucía, 29590 Campanillas (Málaga), Spain
salvador.pedraza@nokia.com, Tel: +34 952028519 (Ext. 23), Fax: +34 952020044
ext-ricardo.ferrer@nokia.com, Tel: +34 952028519 (Ext. 36), Fax: +34 952020044
volker.wille@nokia.com, Tel: +44 (0)1223432447, Fax: +44 (0)1223432536

***Abstract-* The flexibility emerging from the large set of radio network parameters defined on a cell basis is not currently fully utilized because of the complexity related to their tuning processes. An automatic optimization algorithm for signal level thresholds is proposed in this paper, which is based on statistical information derived from collected measurement reports on a cell basis. Simulation results and real data are analyzed to reinforce the conclusions.**

I. INTRODUCTION

Current procedures for network design estimate the radio network performance based on mathematical propagation models, whose accuracy results largely dependent on the precision with which the environment is represented. In this design stage, adjustments related to the basic radio platform (i.e. base locations, antenna pan/tilt orientation, power) are normally performed. In the subsequent deployment stage, adjacency and frequency planning are carried out. Together with parameter planning, the actual behavior of network algorithms is thus defined. Finally, some limited further tuning, based on the feedback data obtained from drive tests or key performance statistics, is performed throughout the operational phase to keep the track of network changes.

During this optimization task, homogeneous cells are normally considered, since the large set of parameters makes the detailed tuning process on a cell-by-cell basis a time-consuming task. Operators fix parameters network wide to a common set of safe default values, even if this does not provide optimum performance in terms of quality or capacity. Clearly, the homogeneity hypothesis is normally far from reality, as propagation, interference or traffic distribution vary both in space and time across each cell in the network. A great potential gain can therefore be obtained from an automatic parameter optimization process that caters for cell peculiarities, despite the changes of existing environment both in space and time. Network performance in terms of quality, capacity and operability may thus be improved [1].

Within this parameter framework, signal level thresholds are included in access and handover algorithms for cell operational area definition [2]. Since these parameters are defined on a cell level, optimization on a cell basis may be applied if adaptation to local interference and propagation conditions is desired.

In this paper, an optimization algorithm for signal level thresholds is proposed and evaluated. The relationship between received signal level and perceived quality is extracted from real measurements, which enables pure signal (or path loss) checks to be applied to account for quality restrictions.

The remainder of the paper is organized as follows. Section II provides a brief background of the basic access algorithms used in GSM system. Section III introduces the statistical tool that the optimization algorithm is based on. Simulation and trial results are discussed in sections IV-V. Concluding remarks are finally presented in section VI.

II. SIGNAL LEVEL THRESHOLDS

In GSM/EDGE system, any user attempt to access a cell entails a check of the averaged received signal level from the beacon channel against some predefined threshold.

During idle mode, cell (re)selection algorithm is based on pathloss criterion implicit in C1 value expressed in (1) [2,3]:

$$C1 = RLA\_C - RxLevAccessMin \geq 0 \qquad (1)$$

where *RLA_C* is the averaged received signal level from the beacon, and *RxLevAccessMin* is the minimum signal level required for an MS to access a cell.

In dedicated mode, handover assures that an MS is always within the cell offering the best quality. Whenever a handover is triggered, neighbouring cells are included in the candidate list for evaluation if the condition in (2) is fulfilled,

$$AV\_RXLEV\_NCELL(n) > RxLevMinCell(n) \qquad (2)$$

where *AV_RXLEV_NCELL(n)* is the received signal level from the beacon of the neighbor cell n, and *RxLevMinCell(n)* is the minimum required signal level of the same cell.

Both signal level thresholds must ensure that connection quality is guaranteed when a cell is included in the target cell

This work has been developed as part of the agreement between Nokia and the University of Malaga, partially supported by the PROFIT Program of the Spanish Ministry of Science and Technology.

list for evaluation. The more conservative these thresholds are set, the better quality is offered by the network, but the lesser macro diversity gain is obtained, translated into risk of coverage gaps. This quality-to-coverage tradeoff, along with the variability of local interference and propagation conditions, points out the need for tuning their final settings on a cell-by-cell basis.

The gain obtained from this optimization process becomes more evident in situations where radio resource strategies other than pure radio connection quality are used in a non-homogeneous network. Traffic management strategies, such as negative power budget [4] or speed-based handover in multilayered networks [5], may send users to cells that are not optimum in terms of connection quality but in another sense (e.g. traffic congestion, expected number of handovers per call). In these cases, instabilities such as ping-pong effect may appear, unless a certain connection quality is assured by signal level thresholds when the user is handed over.

III. Description of Optimization Algorithm

A. Level-Quality statistics

As stated in GSM standards [2], Measurement Reports (MRs) from the mobile and base station are sent every SACCH multiframe period (i.e. 480 ms) to the base station controller. This piece of information comprises signal level (i.e. *RXLEV)* and signal quality (i.e. *RXQUAL)* measurements on both uplink and downlink directions for active connections.

Collection of these measurement results (named as *Level-Quality Statistics* in the following) on a cell basis provides a means to obtain the relationship between received level and perceived connection quality in any particular cell. Thus, interference and propagation peculiarities are highlighted.

An example of such statistics extracted from a typical cell in a real network is depicted in Fig. 1. This 3-D illustration shows a 2-D histogram of (*RXLEV, RXQUAL*) samples, where X-axis, Y-axis and Z-axis, represent received signal level, perceived signal quality and number of occurrences, respectively. It is worth noting that discretization over signal-level values is normally applied in order to keep the amount of information in network database to a reasonable limit. Six intervals are normally considered in real situations, whose limits are unequally distributed on the level axis in order to obtain higher resolution in the region of interest.

From this plot, it is clearly seen that the relationship between signal level and connection quality in a cell is not deterministic, but rather probabilistic (i.e. different connection quality values are possible for a certain signal level value, depending on interference and propagation). Nonetheless, the logical rule that predicts that higher received signal values result in higher probability of good connection quality is still evident.

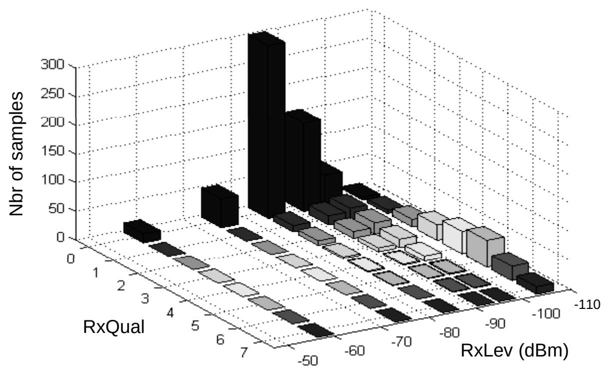

Fig. 1. *Level-Quality Statistics* of a cell in a real network.

B. Optimization process

Fig.2 summarizes the basic structure of the optimization process under study. After preliminary MR collection, the histogram of jointly distributed random variables *RxLev* and *RxQual* is estimated in each cell. The subsequent process builds the relationship between received signal level and predicted connection quality, by means of which operator quality constraints are mapped into signal level thresholds.

First, the 2-D joint p.d.f. (probability density function) of *RxLev* and *RxQual* random variables declared in (3) is estimated through normalization by the total number of samples in the table. The p.d.f. of *RxQual* conditioned to *RxLev* in (4) may easily be obtained through normallization by the number of MRs in every level band. By means of this function, the probability of perceiving a certain connection quality, given that a certain level is received, is determined. Finally, the c.d.f. (cumulative probability density function) of *RxQual* conditioned to *RxLev* in (5), which is the core of the optimization process, is extracted by the cumulative sum in the quality axis.

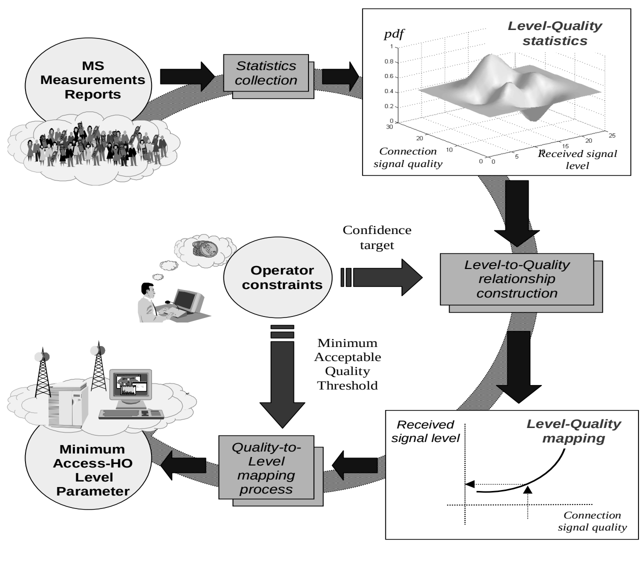

Fig. 2. Basic steps of the optimization algorithm.

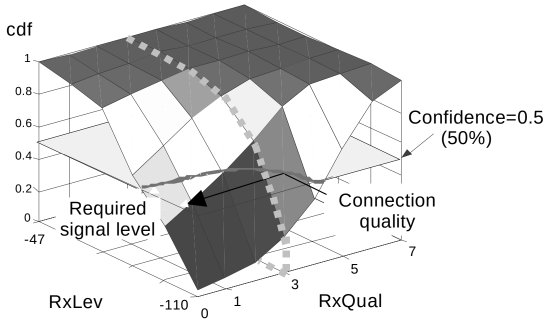

Fig.3. Representation of $c.d.f._{RxQual/RxLev}$ surface.

$$p.d.f._{RxLev,\, RxQual} = P\,(RxLev = RXLEV,\, RxQual = RXQUAL) \quad (3)$$

$$p.d.f._{RxQual\,/\,RxLev} = P\,(RxQual = RXQUAL\,/\,RxLev = RXLEV) \quad (4)$$

$$c.d.f._{RxQual\,/\,RxLev} = P\,(RxQual \le RXQUAL\,/\,RxLev = RXLEV) \quad (5)$$

Fig.3 depicts an example of $c.d.f._{RxQual/RxLev}$ surface that represents the probability to perceive a connection quality better than *RxQual* given a certain level *RxLev*. When a certain connection quality value is fixed as a requirement, a vertical plane parallel to the XZ plane is defined (e.g. *RxQual*=3 in Fig. 3). The dotted line formed by the intersection between the previous plane and the surface under study represents the probability (or confidence) of reaching the predefined quality target for every level band. On the other hand, whenever a certain confidence is desired in the decision, a horizontal plane parallel to the XY plane is defined (e.g. $c.d.f._{RxQual/RxLev}$=0.5 in Fig. 3). In this case, the curve represents the quality that is assured for every level band with a certain confidence.

Fig. 4 represents several examples of *Level-Confidence* and *Level-Quality* curves. Obviously, the definition of different confidence or minimum quality targets leads to different mapping curves. Hence, these constraints may be used by the operator to tailor the behavior of the algorithm.

In the previous explanation, possible existence of multiple tables in a cell (i.e. one for each TRX and link direction) has not been considered. In these situations, merging of several tables must be considered if a unique value must be finally suggested for the whole cell. Tables from several TRXs in a cell may be easily combined, since the probability of user assignment is implicit in the number of samples. Unfortunately, combination of link directions is not straight forward, due to the shift in received level caused mainly by their different transmitted power. The proposed solution is based on the separate calculation of minimum levels for both directions $RXLEV_{ul}\,|_{Q,C}$ and $RXLEV_{dl}\,|_{Q,C}$. Later post-processing will estimate the downlink level $RXLEV_{dl\leftarrow ul}|_{Q,C}$ corresponding to the uplink level $RXLEV_{ul}\,|_{Q,C}$ by means of the mapping function expressed in (6). The most stringent value of both directions is suggested as the final optimized value $RXLEV_{opt}$.

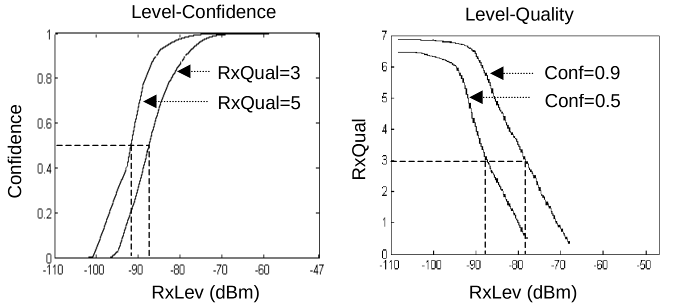

Fig.4. *Level-Confidence* and *Level-Quality* mapping curves.

$$RXLEV_{dl\leftarrow ul} = \left\{ RXLEV_{dl} \,/\, P(RxLev_{dl} \le RXLEV_{dl}) = P(RxLev_{ul} \le RXLEV_{ul}) \right\} \quad (6)$$

$$RXLEV_{opt}\Big|_{Q,C} = \max\left(RXLEV_{dl\leftarrow ul}\Big|_{Q,C},\, RXLEV_{dl}\Big|_{Q,C}\right) \quad (7)$$

IV. SIMULATION

A. Simulation scenarios

The simulation tool used in this study has been a GSM/EDGE network simulator developed by Nokia Research Center (NRC) [6]. The initial macrocell scenario consists of 75 hexagonal cells (tri-sector sites), as depicted in Fig. 5. Table I shows its main configuration parameters.

Minor changes were progressively introduced so as to build two irregular scenarios where adaptability of the proposed algorithm could be tested. In the first scenario, the original 4/12-reuse frequency plan was slightly modified in order to create interfered cells (*I* cells). In such a situation, avoidance of the connection quality problems is the aim of the tuning process. The analysis is focused on the level thresholds related to handover, since the expected quality experimented by the end user is mainly controlled by mechanisms in connected mode (e.g. handover). For the second scenario, several cells in the border were barred (B cells) so that coverage gaps were added locally. In this case, increase of global carried traffic in the network is the main goal of the tuning process, so level thresholds related to access are subject to optimization.

As a reference case for both scenarios, homogeneous threshold settings were chosen for access and handover. A value equal to –85dBm was first selected as a trade-off between coverage and quality network wide, based on the analysis of global indicators. A rough coverage estimation of some cells is superimposed on Fig.5, where *RxLev*≥-85dBm and no shadowing have been considered.

TABLE I
SIMULATION PARAMETERS

Scenario	MACRO trisector 65º, Cell radius 1km 1TRX/cell , 4/12 Frequency reuse
Propagation model	Okumura Hata, Path loss slope 3.76
Fading model	Correlated slow fading, Std. 6 dB
Features	FH/PC/ DTX/ UL diversity off
Parameters	HO Thresholds: RXQUAL=4 HO Margins: Pbgt=3dB, Qual=0dB
Average Fractional Load	30%
Time resolution	SACCH frame (480ms)
Simulated network time	90h

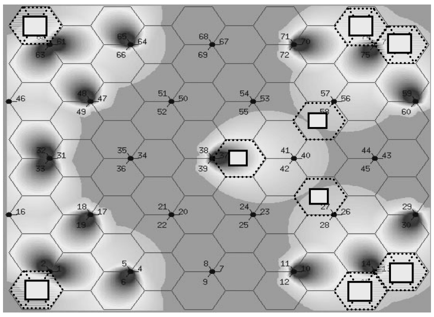

Fig.5. Scenario with interfered (*I*) and barred (*B*) cells.

B. *Scenario 1: Optimization of handover constraints*

Handover optimization in the scenario suffering from local interference problems is first considered. Fig. 8 depicts the minimum signal levels proposed by the algorithm on a cell basis. It is clearly observed how the restriction degree may be regulated by means of the c*onfidence* parameter. Once selected, different thresholds are suggested for every individual cell, where their corresponding interference- or noise-limited nature may be identified. In this particular case, the cost related to signalling and call dropping probability in handover recommends the selection of a high confidence value for the algorithm (e.g. 99%).

After optimization, the raise of handover constraints to interfered cells relieves quality problems, as discerned over the share of good quality samples (i.e. *RXQUAL* 0-5) depicted in Fig. 7. A deeper analysis reveals that the quality gain is mainly obtained by the rejection of users from adjacent cells in shadow conditions, which could otherwise establish connection to the interfered cell from unacceptable distance ranges. Of course, the improvement in those bad cells is achieved at the expense of adjacent ones.

Meanwhile, cells apart from the interference hotspot in the scenario also restrict their operational area compared to the initial situation, but in a lesser degree due to their smaller interference. The consequence is a decrease of macro diversity gain, originated by a candidate list curtailing. Such quality degradation is not detected in the results, since enough cell overlapping is still assured in the considered scenario. Nonetheless, gentle restriction is recommended for real networks where overlapping is difficult to estimate, so smaller confidence values should be selected for these cases.

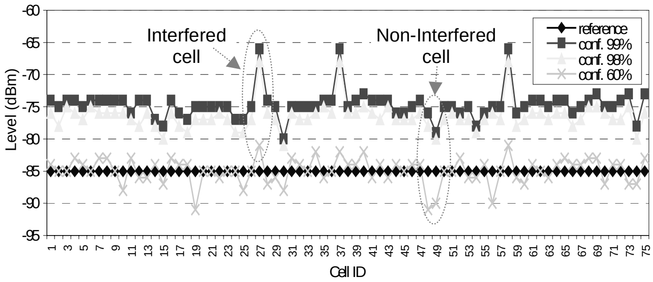

Fig.6. Signal level thresholds before/after optimization.

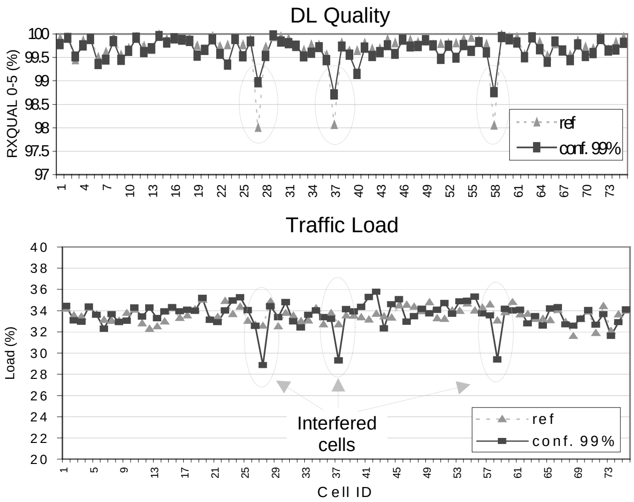

Fig.7. Quality and traffic network simulation statistics.

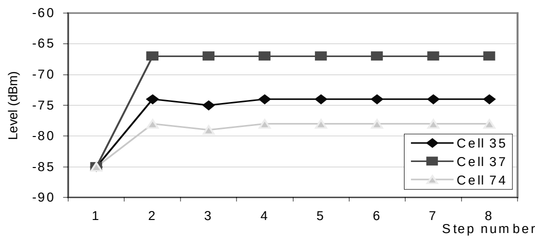

Fig.8. Evolution of values along several optimization steps.

This enlargement and shrinking of cell service area may unavoidably influence the user distribution in the network, which is observed in the traffic load profile depicted in Fig. 7. This fact should be taken into account in cells with neighbors close to suffer from unacceptable blocking values (which is not the case in the example), since radio connection quality is strongly influenced by handover failure ratio. Hence, combination of this quality assurance strategy with other traffic balance features is strongly recommended.

Finally, several consecutive optimization steps were performed in order to verify network stability. Fig. 8 represents the evolution of the suggested signal level thresholds for some representative cells (e.g. interference and coverage limited cells). Departing from the initial –85dBm setting, it is evident that the steady state in the network is reached after few optimization steps.

C. *Scenario 2: Optimization of access/handover constraints*

Border effect in the previous simulation scenario was instrumental in adding coverage gaps by means of selective cell barring. Simultaneous optimization of both access and handover thresholds is targeted.

Several reasons point out the need to configure lower (i.e. less restrictive) confidence values in the algorithm for the access parameter optimization. First, the importance of traffic revenues yields that soft (or even null) restrictions are usually preferred by the operators, since careless adjustment of this parameter may prevent users to access the network in coverage-limited areas. In addition, cell (re)selection algorithm already gives a mechanism to prioritize (and not only restrict) cells through the comparison against level thresholds. Thus, unnecessary restriction of the access to every cell in the network is not justified if the differences between cells may be transferred into the C1 evaluation by means of differences in thresholds. For both reasons, a confidence value of 50-60% seems a better option, since lower minimum signal levels are suggested while differences among cells are still maintained, as observed in Fig. 6.

Relaxation of access constraints in non-interfered (i.e. coverage limited) cells yields that fewer users are lost in their first attempt in this region, without any major drawback. As a consequence from this local constraint relief, the number of uncovered users in the network is decreased by 65% from the reference situation, which is translated into a slight increment of the global carried traffic.

At the same time, interfered cells will undergo restriction of user access. This fact does not lead to coverage problems in the considered scenario since surrounding cells occupy the gaps left by limited cells. If so desired, additional constraints may be included in the optimization procedure to avoid coverage gaps caused by simultaneous restriction of adjacent cells.

V. THE ALGORITHM IN A REAL NETWORK

The described algorithm was tested in a rural environment, where coverage limitations should dominate. Optimization of thresholds in connection set-up was performed over 115 cells on a daily basis. During the trial, maximum deviation from initial setting of –104dBm was constrained to ±4dB for safety reasons. The distribution of parameter values suggested by the algorithm is presented in Table II.

Trial results showed that local increased cell catchment may be obtained without degradation of network quality. Unfortunately, the small anticipated traffic increase (1%) was masked by statistical fluctuations. Nonetheless, the trial was instrumental in checking the stability of suggested values against time. Fig. 9 depicts the standard deviation of suggested parameter values over a 4-week period, where it is seen that more than 80% of all cells experience a deviation value below 3dB, despite weekly traffic variations.

TABLE II
DISTRIBUTION OF SUGGESTED LEVELS IN TRIAL

Suggested Level [dBm]	*Count*	*Ratio of cells [%]*	*Cum Ratio of cells[%]*
-108	33	29.2	29.2
-107	4	3.5	32.7
-106	4	3.5	36.3
-105	10	8.8	45.1
-104	8	7.1	52.2
-103	18	15.9	68.1
-102	10	8.8	77.0
-101	8	7.1	84.1
-100	18	15.9	100.0

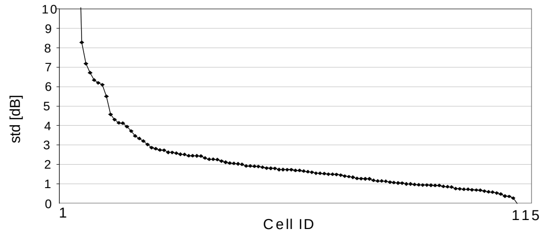

Fig. 9. Variation of suggested values over 4-week period.

VI. CONCLUSION

Automatic optimization of radio network parameters in a cell basis will be crucial to enhance both operability and performance of complex future mobile networks. Within this framework, an optimization algorithm for signal level thresholds has been here proposed. Its main contribution is the development of a mathematical tool that is able to extract propagation and interference conditions in a cell level. Homogeneous parameter settings may then be upgraded to cater for local differences.

Simulation results show that the proposed optimization procedure is instrumental in scenarios where severe local quality or coverage problems are found, whenever enough overlapping is ensured. Operability is guaranteed through few simple parameters that are easily understood by the operator. Trial results confirm the stability of the approach.

Further work is now focused on the application of this mathematical tool in the optimization of handover margins, since prioritization strategies may be preferred over restriction policies.

ACKNOWLEDGMENT

The authors would like to thank SMART developers in the NRC Helsinki for their support.

REFERENCES

[1] S. Pedraza, "Identifying & overcoming the challenges of migrating towards self-configuring networks". *Cell Planning Technical Forum*, July 2001 – Dublin.

[2] 3GPP TS 45.008 v5.4.0, "Radio subsystem link control", November 2001.

[3] 3GPP TS 43.022 v4.3.0, "Functions related to Mobile Station in idle mode and group receive mode". June 2001.

[4] C. Chandra, T. Jeanes, W. H. Leung. "Determination of optimal handover boundaries in a cellular network based on traffic distribution analysis of mobile measurement reports". *IEEE Veh. Technol. Conf.*, Vol.1 pp.305-309, May 1997.

[5] K.L. Yeung, S. Nanda. "Channel Management in microcell/macrocell cellular radio systems". *IEEE Trans. Veh. Technol.*, vol. 45, no. 4. November 1996.

[6] M.Moisio, T.Kojo, S.Nikkarinen, E.Pernilä, A.Sevon and J.Sipola, "SMART GSM Network Simulator. Functional Description", NRC 2000.