WIRELESS WORLD
RESEARCH FORUM

Self-configuration, -optimisation and -healing in wireless networks

L.C. SCHMELZ (Nokia Siemens Networks, Munich, Germany)
J.L. VAN DEN BERG, R. LITJENS (TNO ICT, Delft, The Netherlands)
A. EISENBLÄTTER (Atesio, Berlin, Germany)
M. AMIRIJOO, O. LINNELL (Ericsson, Linköping, Sweden)
C. BLONDIA (IBBT, Gent-Ledeberg, Belgium)
T. KÜRNER (TU Braunschweig, Braunschweig, Germany)
N. SCULLY (Vodafone, Newbury, United Kingdom)
J. OSZMIANSKI (Nokia Siemens Networks, Wroclaw, Poland)

***Abstract*— This paper presents a vision on the use of self-organisation methods (self-optimisation, self-configuration, and self-healing) as a promising concept to automate wireless access network planning, deployment and optimisation. The major intentions are to improve network coverage, resource utilisation and service quality, and to substantially reduce operational expenditure. The fundamental drivers for the deployment of self-organisation methods are discussed, considering both the technology and the market perspective. The distinction and interactions between the different components of self-organisation are outlined and the expected gains are discussed. An overview of the current state of the art in this field is followed by a formulation of the main challenges in the development of effective and reliable methods for self-organisation. Finally, a brief overview of the European SOCRATES project is given, which recently started to overcome these challenges.**

***Index terms* — Self-organisation, self-optimisation, self-configuration, self-healing,**

Introduction

FUTURE wireless access networks will exhibit a significant degree of self-organisation, as also recognised by standardisation body 3rd Generation Partnership Project (3GPP) [1] and operators lobby Next Generation Mobile Networks (NGMN) [2]. The principal objectives of introducing self-organisation into wireless access networks are (i) to effectuate substantial operational and capital expenditure (O/CAPEX) reductions by diminishing human involvement in network operational tasks; and (ii) to optimise network capacity, coverage and service quality. The general idea is to integrate network planning, configuration, and optimisation into a single, mostly automated process requiring minimal manual intervention.

The goal of this paper is to present a vision regarding the use of self-organisation methods, comprising self-optimisation, self-configuration, and self-healing, as a promising opportunity to automate wireless access network planning and operation. In the next section, we discuss the key drivers for the development of self-organisation methods, covering both the technological and market perspectives. Subsequently, in Section 3 we formulate a vision about future self-organising wireless access networks and describe the relations between the self-optimisation, self-configuration and self-healing components. Section 4 then describes and illustrates the expected gains in terms of O/CAPEX reductions and performance enhancement. An overview of the state of the art is given in Section 5, followed by a discussion of the key challenges in the development of methods for self-organisation in Section 6. The paper ends with some concluding remarks.

Drivers

The need for self-organisation and hence the on-going developments in this field within e.g. 3GPP, NGMN, and several (inter)national R&D projects, are driven by a number of technological and market developments.

On the *technological* side, the complexity of large scale contemporary/future radio access technologies imposes significant operational challenges, primarily due to the multitude of tuneable parameters and the intricate dependencies among them. Although this complexity is unavoidable when providing the desired potential and flexibility to offer diverse services with enhanced resource efficiency and quality, it aggravates the network operations. The great multitude of sites/cells required to provide coverage with future high frequency technologies and the coexistence and coordinated exploitation of (cooperative) multiple heterogeneous access networks complicate this task even more. Due to these technological complexities, currently the key operational tasks of radio network planning and optimisation are largely separated tasks. Intrinsic shortcomings of methodologies currently applied for these tasks include (i) the 'over-abstraction' of access technologies for network planning purposes; (ii) the consideration of performance indicators that are of limited relevance to the end user's service perception; (iii) the time-intensive experiments with limited operational scope (confined to a limited area and/or a subset of radio parameters/mechanisms); and (iv) delayed, manual and poor handling of cell/site failures.

As such, the current approaches can certainly benefit from advanced solutions that reduce labour-intensity and enhance network performance at the same time. At the same time, the increasing technical capabilities of both base stations and user terminals to perform, store, process, and act upon measurements increases sharply. This is a key enabler to support self-organisation objectives.

On the *market* side, the ever increasing demand for and diversity of offered services, each with their own traffic characteristics and high service quality requirements, and the need to reduce the time to market of innovative services, further add to the operational complexity. A final market-oriented driver is the pressure to remain competitive by effectuating cost reductions, eventually enabling lower prices.

As a bottom line, the introduction of self-organisation in the wireless access network, offers a great potential for network operators to reduce operational (and hardware) costs and enhance resource efficiency, for users to experience high quality services with enhanced availability and at lower prices, and for service providers to introduce new services more swiftly and with fewer operational hurdles.

Vision

In our vision, which is in line with the views of 3GPP [1] and the NGMN group [2], future networks will require minimal human involvement in the network planning and optimisation tasks. Newly added base stations are self-configured in a 'plug-and-play' fashion, while existing base stations continuously self-optimise their operational algorithms and parameters in response to changes in network, traffic and environmental conditions.

The adaptations are performed in order to provide the targeted service availability and quality as efficiently as possible. In the event of a cell or site failure, self-healing methods are triggered to resolve the resulting coverage/capacity gap to the extent possible. The envisioned operational process applied in self-organising radio access networks and the distinct components of self-organisation are illustrated by Figure 1.

Let us consider a fully configured and operational radio access network and, somewhat arbitrarily, start at the depicted '*measurements*' phase. This phase indicates a continuous activity where a multitude of measurements are collected via various sources, including network counters and probes. These raw measurements of e.g. radio channel characteristics, traffic and user mobility aspects, are processed in order to provide relevant information for the various related self-optimisation tasks. The required format, accuracy and periodicity of the delivered information depend on the specific mechanism that is to be self-optimised.

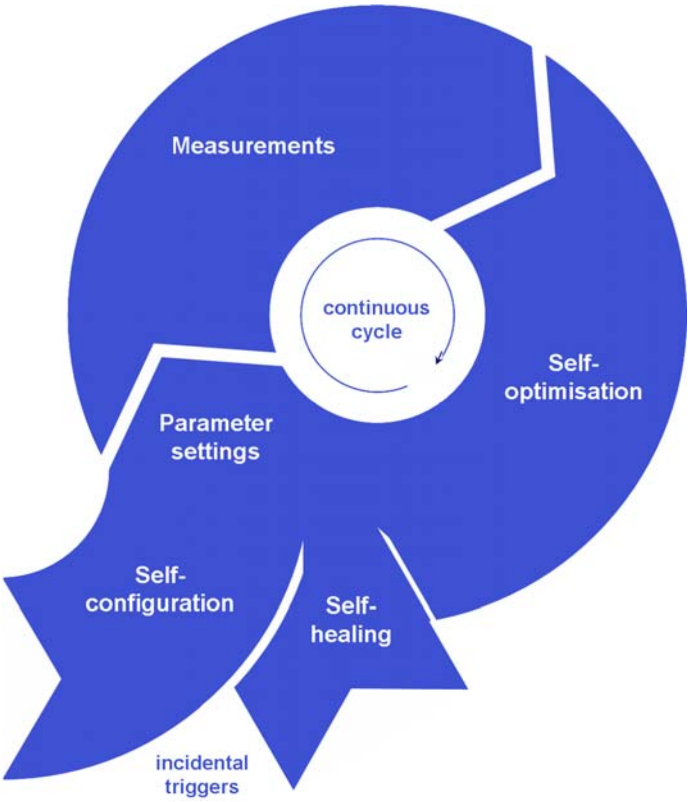


FIGURE 1: SELF-OPTIMISATION IN FUTURE WIRELESS NETWORKS

In the '*self-optimisation*' phase intelligent methods apply the processed measurements to derive an updated set of radio (resource management) parameters, including e.g. antenna parameters (tilt, azimuth), power settings (incl. pilot, control and traffic channels), neighbour lists (cell IDs and associated weights), and a range of radio resource management parameters (admission/congestion/handover control and packet scheduling). In case the self-optimisation methods appear to be incapable to meet the performance objectives, capacity expansion is indispensable and timely triggers with accompanying suggestions for human intervention are delivered, e.g. in terms of a recommended location for a new site.

The '*self-configuration*' phase, depicted as an external arm reaching into the continuous self-optimisation cycle, is triggered by 'incidental events' of an 'intentional nature'. Examples are the addition of a new site and the introduction of a service or new network feature. These upgrades generally require an initial (re)configuration of a number of radio parameters or resource management algorithms, e.g. pilot powers and neighbour lists. These have to be set prior to operations and before they can be optimised as part of the continuous self-optimisation process.

Triggered by 'incidental events' of a 'non-intentional nature', such as the failure of a cell or site, '*self-healing*' methods aim to resolve the loss of coverage/capacity induced by such events to the extent possible. This is done by appropriately adjusting the parameters and algorithms in surrounding cells. Once the actual failure has been repaired, all parameters are restored to their original settings.

The degree of self-organisation that is deployed determines the residual tasks that remain for network operators. In an ideal case, the operator merely needs to feed the self-organisation methods with a number of policy aspects, e.g. its desired balance in the apparent trade-offs that exist between the conflicting coverage, capacity, quality and cost targets. The self-organisation methods then feed the operator with (i) timely triggers for capacity expansion in the form of new sites, intelligently suggesting a good location, or other hardware issues e.g. new channel boards, a more powerful amplifier, a change in mechanical tilt (note that electrical tilt can be done automatically); and (ii) immediate alarms in case of network element failures. Until (if ever) such an ideal setting is achieved, we foresee a gradual introduction of self-organisation in radio access networks, characterised by different incremental upgrades which are implemented and monitored.

This way, the implemented measures can be adequately assessed; the impact of potential 'teething troubles' can be limited and the operators' confidence to hand over its control to automated algorithms increases.

Expected Gains

The key operational gains from employing self-organisation in wireless access networks are in the form of O/CAPEX reductions and performance enhancements.

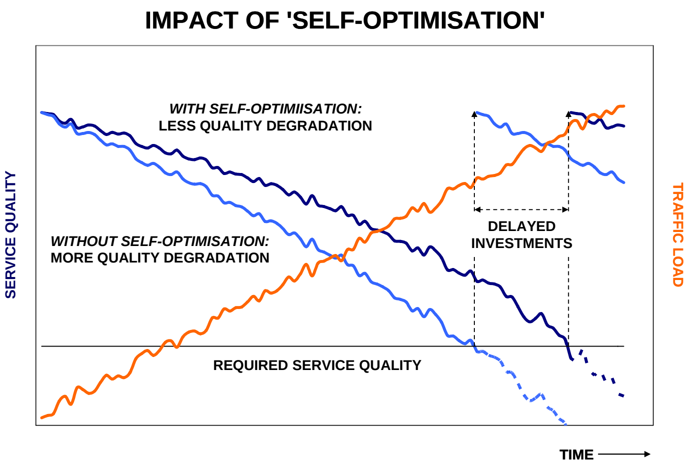
The primary anticipated *OPEX reductions* are expected by reducing human involvement in the areas of drive testing, network planning, monitoring and optimisation. Drive tests are currently performed to check the performance of the network. This labour-intensive task can be replaced by measurements from user terminals and base stations. Using measurements from user terminals also has the advantage that measurements are obtained from additional locations, such as inside buildings. The manual effort involved in network planning, configuration, monitoring and optimisation is currently very large, also considering the large number of cells that need to be considered. The application of self-organisation methods can reduce this effort significantly. The foreseen large-scale deployment of femto-cells to move substantial amounts of traffic away from the expensive macro-cellular network layer, requires that some key integration issues with the macro layer are resolved, e.g. by means of self-organisation [3]. With regard to network monitoring, if a network or cell is not performing as desired, considerable manual effort is invested to identify the problem.

To give an indication of the potential for OPEX savings, it was recently noted in [4] that as much as 25% of OPEX is related to costs for network operations and maintenance (with remainder spent a.o. on marketing & sales, customer care and interconnection/roaming). For an operator such as Vodafone UK, this amounts to about €1250 million [5].

Besides these key advantages related to OPEX reductions, the application of self-organisation also enhances *network performance* and the experienced *service quality*, by better adapting to specific characteristics and requirements. As will be illustrated, such performance enhancements may be exploited to effectuate *CAPEX reductions* (even if the self-organising network elements themselves may be more costly). Associated improvements can be expected in different areas. For instance, by optimally tuning radio (resource management) parameters to the actual traffic, mobility and propagation conditions, the network capacity is maximised and an optimal number of sessions can be served at the desired service quality level. Regarding coverage provisioning, it is noted to be traditionally hard for network operators to provide adequate coverage for high data rate applications at indoor locations such as home and offices. Furthermore, the use of self-configuration techniques enable operators to install new (femto/micro/macro-)sites and technological features swiftly with near-immediate operation, which speeds up upgrades and extensions, while still ensuring network reliability.

Figure 2 (top) illustrates the performance enhancement that is due to self-optimisation: as the traffic load grows over time, a network applying self-optimisation techniques manages to deliver better service quality than a network not utilising self-optimisation.

Given a minimum target on the experienced service quality, the use of self-optimisation consequently allows for a delayed investment for additional network capacity (e.g. additional sites), which effectively is a CAPEX reduction. Figure 2 (bottom) illustrates the performance gains from self-healing: in case of e.g. a site failure, surrounding sites quickly identify this failure and adjust their radio parameters in order to limit the locally experienced performance degradation. At the same time, a trigger is automatically generated to request manual repairs.



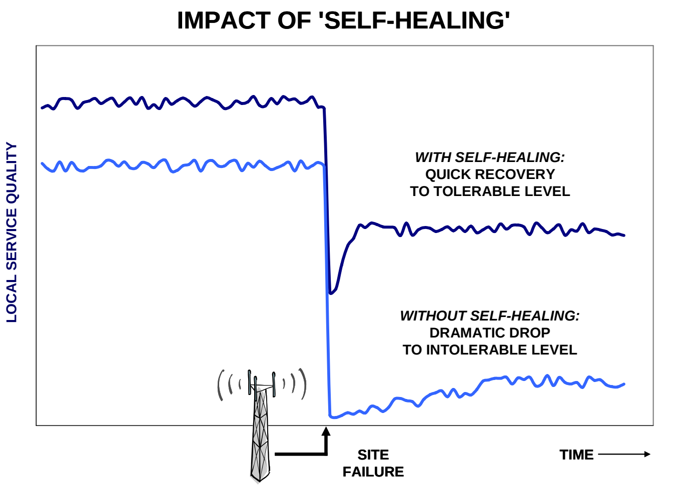


FIGURE 2: NETWORK INVESTMENTS MAY BE POSTPONED AS A RESULT OF SELF-OPTIMISATION (TOP FIGURE). A QUICK RECOVERY TO THE TOLERABLE SERVICE LEVEL IS ACHIEVED WHEN USING SELF-HEALING (BOTTOM FIGURE).

State-of-the-Art

The challenging topic of self-organisation in mobile communication networks is addressed in various publications (see e.g. [6]), projects (see e.g. [7][11][21]) and forums (e.g. NGMN, 3GPP). Based on these activities, the state of the art of network operations and the use of self-organisation methods will be reviewed in this section.

Optimisation in current networks consists of tool-based planning (see e.g. [9][10]), deployment and optimisation using live measurements. Current approaches in optimisation have a number of limitations and drawbacks. A major drawback is that a high degree of manual interaction is required. Further, current network optimisation is based on a longer time scale, e.g. weeks or months, which is not sufficient to adequately support the traffic growth and the diversity of services in future networks. Finally, current automatic optimisation tools generally focus on a small number of radio parameters. There are several publications on optimisation in UMTS, e.g., capacity and coverage balancing [14][15], code planning for UMTS [16][17], base station location [18], and admission control [19]. For a general treatment of planning and optimisation in UMTS refer to [20]. It is noted, however, that these sources do not address (self-) optimisation in 3GPP's evolved UTRAN (EUTRAN), which is the access network technology where self-optimisation is anticipated to be most effective and feasible.

Self-configuration and *self-healing* are relatively new topics in mobile networks, with little state of the art to report on. A few papers study self-configuration of neighbour cell lists, e.g. [12] and [13], while the self-configuration of other radio parameters such as transmit powers, antenna tilts and radio resource management parameters is still largely unaddressed. Self-healing in contemporary networks has few capabilities to recover from faults and more sophisticated approaches are required to provide continuous service to users despite faults.

Within the European research and development programme Celtic, the Gandalf project (2005-2007) explored the potential of automating common management tasks in mobile networks (mostly GSM, UMTS and WLAN) [11]. The project Monotas developed techniques and algorithms allowing radio networks to rapidly adapt network parameters (e.g., pilot power) to changes in traffic load the service usage [21]. Other projects related to self-organisation include ANA [7] (self-organisation of Internet) and BIONETS (pervasive networking) [22]. Future research needs to take advantage of previous results and adapt the findings to the challenges of self-organisation in E-UTRAN networks.

Standardisation is addressed in *3GPP* with the goal of ensuring that the standards will support self-organisation. The overall objective of *NGMN*, a co-operation among world-leading mobile operators, is to collect and promote operator requirements and recommendations on e.g. self-organisation [2]. The work on self-organisation in these forums, however, has mainly a more qualitative character and does not consider the development and quantitative assessment of actual algorithms and methods.

Challenges

Self-organisation in future mobile radio networks is a challenging topic. Such networks are highly complex systems with a multitude of tuneable control mechanisms and parameters acting at time scales varying from milliseconds to days. Moreover, there are intricate interdependencies among the control mechanisms and parameters as well as limitations on measurements, signalling and processing. Understanding and mastering these complexities poses a number of major challenges for the design of effective and dependable self-organisation functionalities:

- *Devise techniques for measuring and probing as a basis for self-organisation.* Generally speaking, measuring and probing are the foundations of automatic online control. To this end, it is necessary to determine what data is needed and should be collected, involving a trade-off between optimality of the self-organisation methods and the signalling cost associated with the data collection. A related research challenge is to optimise the frequency with which the various data is collected from the various sources, which may depend on the urgency of an observed performance issue.

- *Design methods for inference of network status.* Wireless networks are intricate systems making the inference of the up-to-date network status very challenging. The appropriate processing of the collected measurements as well as efficient handling of erroneous/malicious measurement reports are key to reliably estimate the current network status.

- *Devise methodologies to deal with incomplete, delayed and faulty feedback.* The feedback from the network upon control decisions is not immediate, i.e. there are unknown delays from actuation to observation. This unknown delay may affect the efficiency of the self-optimisation process and, as such, there is a need to take this delay into consideration when designing algorithms. In this light it is also necessary to distinguish the effects of the control decisions from those caused by natural variations in e.g. traffic, mobility and propagation characteristics.

- *Effectiveness of self-organisation methods.* The design of effective self-optimisation / healing methods introduces several challenges, such as multivariable control (i.e., controlling several variables simultaneously), optimisation of the frequency and size of control steps. With regard to the intricate dependencies of the different radio (resource management) parameters that are to be tuned, not only the frequency but also the mutual timing of parameter adjustments needs to be considered in order to prevent undesirable oscillations in the delivered service quality. Furthermore, the level in the network where control decisions are taken must be determined (centralised versus distributed control).

- *Reliability of self-organisation methods.* Control decisions must be reliable due to the lack of human expert sanity checking and (possibly) revising the decisions. As such, we are faced with new requirements for methods, algorithms, and quality of models.

- *Shape the network architecture.* Self-organisation algorithms will eventually have to be incorporated into existing and future systems. This affects protocols and interfaces as well as the architecture of networks.

SOCRATES

Several activities are on-going in the area of self-organisation of mobile communication networks.

3GPP is responsible for the standardisation of e.g. the E-UTRAN. As part of this standardisation work, since 2006 the impact of self-organisation on the architecture, protocols and measurements is studied and specified. The NGMN group, which is mainly driven by mobile operators and supported by several manufacturers is active in supporting, guiding or at least closely monitoring related developments at the network vendors. Meanwhile several interactive workshops have been held during which a number of key vendors have presented their vision, developments and plans in the area of self-organisation.

Apart from these industrial forums, there are several international research projects concentrating on self-organisation in future cellular access networks. Among these projects is the recently started research project SOCRATES (Self-Optimisation and self-ConfiguRATion in wirelESs networks) in which two large vendors (Ericsson, Nokia Siemens Networks), a leading mobile network operator (Vodafone) and several European research and consultancy institutes (Atesio, IBBT, Technical University of Braunschweig, TNO ICT) are involved. This project is funded by the European Union in the 7th Framework Program and will run until December 2010.

The main goals are the development, evaluation and demonstration of methods and algorithms for self-configuration, self-optimisation and self-healing, where the 3GPP E-UTRAN has been selected as the radio access technology of focus. In addition, the impact on standardisation, network operations and service provisioning is investigated. The project approach comprises three phases. Firstly, the '*Requirements phase*' includes the identification of use cases and requirements for mechanisms that are to become self-organising in (future) wireless access networks (case-based approach), and furthermore the definition of a self-organisation framework. This framework provides the basis for the next step, the '*Development phase*', where detailed solutions, i.e. methods and algorithms for self-optimisation, self-configuration and self-healing will be developed and validated. In the final phase, the '*Integration phase*', these solutions will be integrated with the previously defined framework, the benefits and implications of the solutions will be demonstrated, and the project results will be disseminated by standardisation contributions and workshops.

While 3GPP and NGMN provide the definitions of use cases and interfaces for self-organisation, SOCRATES aims at providing dedicated solutions, i.e. methods and algorithms, as a step towards the implementation into future wireless access networks.

Substantial progress has already been made by the determination of the essential use cases and their key description attributes. At a high level, these use cases cover several phases of the network lifecycle, e.g. network and radio planning, radio network parameter setting, outage handling, parameter update and optimisation. Each single use case will be described according to e.g. its triggers, input sources, parameter and measurements list, architectural aspects and interfaces, standardisation aspects, and the expected gain from implementation.

Concluding Remarks

Self-organisation of mobile networks is regarded as a key approach in order to reduce O/CAPEX and enable cost-effective support of a range of high-quality mobile communication services and applications for acceptable prices. Although the topic has gained more and more attention in the research community and standardisation bodies during the last years, there is still a long way to go. Many challenges remain and have to be overcome in order to achieve the ultimate goal of integrating network planning, optimisation, (re)configuration and healing in a single autonomous process requiring minimal human intervention. We foresee a gradual, step-wise introduction, where the impact on network behaviour and service quality is well studied before the next step is taken. That way, the (potentially severe) effects of possible 'growing pains' of deploying self-organisation methods can be limited; the operators will gain confidence and be willing to delegate the control to the network itself.

Acknowledgement

This paper was written in the context of the SOCRATES project, which is funded by the European Union within the 7th Framework Program and will run from 2008-2010. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the SOCRATES project.

REFERENCES

[1] 3GPP TR 32.816, 'Telecommunication management; study on management of Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC) (Release 8)', v1.3.1, 2007.
[2] NGMN, 'Next generation mobile networks beyond HSPA & EVDO', white paper, www.ngmn.org, 2006.
[3] M. Heath, et al., 'Picocells and femtocells: will indoor base stations transform the telecoms industry?', research.analysys.com, 2007.
[4] Yankee Group, 'World Mobile CAPEX and OPEX', www.yankeegroup.com, February 2006.
[5] Strategy Analytics, 'Wireless operator performance benchmarking Q2 2007', www.strategyanalytics.net, September 2007.
[6] C. Prehofer and C. Bettstetter, 'Self-Organization in Communication Networks: Principles and Design Paradigms', Communications Magazine, vol. 43, no. 7, 2005
[7] ANA project, see www.ana-project.org/autonomic/network/ana-projectoverview.html, 2006-2009.
[8] 3GPP TR R3.018, 'Evolved UTRA and UTRAN; radio access architecture and interfaces (Release 7)', v0.5.0, 2006.
[9] M. J. Nawrocki, H. Aghvami and M. Dohler (eds.), 'Understanding UMTS radio network modelling, planning and automated optimisation: theory and practice', John Wiley & Sons, 2006.
[10] A. Eisenblätter, et al., 'Final report on automatic planning and optimisation', IST MOMENTUM deliverable D4.7, see www.momentum.zib.de/paper/momentum-d47.pdf , 2003.
[11] Z. Altman, et al., 'Final system definition and validation', Celtic Gandalf deliverable D2.3, www.celtic-gandalf.org, 2007.
[12] J. Baliosian and R. Stadler, 'Decentralized configuration of neighboring cells for radio access networks', Proceedings of IWAS '07, Helsinki, Finland, 2007.
[13] F. Parodi, et al., 'An automatic procedure for neighbor cell list definition in cellular networks', Proceedings of IWAS '07, Helsinki, Finland, 2007.
[14] G. Hampel, et al., 'The tradeoff between coverage and capacity in dynamic optimization of 3G cellular networks', Proceedings of VTC '03, Orlando, USA, 2003.
[15] K. Valkealahti, et al., 'WCDMA common pilot power control for load and coverage balancing', Proceedings of PIMRC '02, Lisbon, Portugal, 2002.
[16] R.M. Joyce, et al., 'A Novel Code Planning Approach for a WCDMA Network', IEEE Conference on 3G Mobile Communication Technologies, 2003.
[17] S. Kourtis 'Code Planning Strategy for UMTS-FDD Networks' Vehicular Technology Conference, 2000.
[18] E. Amaldi, et al., 'Planning UMTS base station location: optimization models with power control and algorithms', IEEE Transactions on Wireless Communications, Volume 2, Issue 5, Sept. 2003.
[19] C. Lindemann, et al., 'Adaptive Call Admission Control for QoS/Revenue Optimization in CDMA Cellular Networks', Journal of Wireless Networks, Volume 10, Number 4, July 2004, Springer.
[20] Jaana Laiho, et al., (eds.) 'Radio Network Planning and Optimisation for UMTS', 2nd Edition, Wiley.
[21] Monotas project, see www.macltd.com/monotas/index.php.
[22] BIONETS project, see www.bionets.org.
[23] SOCRATES project, see www.fp7-socrates.org/.