The EUREKA GANDALF Project: Monitoring and Self-Tuning Techiques for Heterogeneous Radio Access Networks

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Abstract—**The introduction and evolution of third-generation (3G) mobile radio systems leads to a heterogeneous radio access network landscape. Network management will become crucial to guarantee optimum cooperation between network sub-systems. This paper summarizes the objectives and first solution ideas of the European project Gandalf, which has been accepted in the framework of the EUREKA/CELTIC initiative [1].**

The aim of the Gandalf project is to employ large-scale network monitoring, *Advanced Radio Resource Management* (ARRM), parameter optimization and configuration management techniques in order to achieve automation of network management tasks in a multi-system environment. The *radio access technologies* (RATs) *Global System for Mobile Communication* (GSM), *Universal Mobile Communication System* (UMTS) and *Wireless Local Area Network* (WLAN) IEEE 802.11 are considered.

The project will develop appropriate techniques to collect and process network data on a large scale in order to produce key performance indicators allowing to identify malfunctions and to dynamically propose and perform healing actions. To optimize the user-perceived *quality-of-service* (QoS) and overall system performance, the project will propose new radio resource management algorithms together with methods for self-tuning. The project will demonstrate through network simulations the feasibility of the multi-system self-tuning concept. Finally, hardware demonstrations will prove the viability of the ARRM and auto-tuning concepts.

Keywords—**Autonomic network management, radio resource management, performance monitoring, self-tuning**

I. INTRODUCTION

Mobile and wireless communication has seen a tremendous growth in the last years. According to the *International Telecommunications Union* (ITU), the number of mobile subscribers worldwide has increased from 215 million in 1997 to more than 1000 million in 2004. It is predicted that by the year 2010 there will be more than 1700 million terrestrial mobile subscribers worldwide. The number of portable handsets has already exceeded the number of fixed line telephones. This growth has, up to now, been dominated by voice-oriented services. Future growth of mobile and wireless communications is expected mainly from data-oriented services and applications. User expectations are continuously increasing with regard to the variety of ubiquitous services and applications across a range of devices. There will be a corresponding change from predominantly circuit-switched to packet-based delivery to allow more efficient delivery of services and "always on" without high cost. Many future services will require higher data rates and, therefore, higher bandwidth in order to provide suitable user satisfaction [2].

For this reason, new and more efficient radio access technologies will be needed. In addition, there is an ongoing paradigm shift driven by the user who expects ubiquitous communication providing higher performance at a suitable cost-benefit-ratio without having to take care of the underlying technology. According to the ITU-R vision for the evolution of 3G systems, existing and evolving access systems will be integrated on a packet-based platform to enable cooperation and inter-working of these systems in the sense of "optimally connected anywhere, anytime" [3].

Within this continuous expansion and technological evolution, network monitoring and optimization tasks are today more than ever key issues to provide high-quality services.

In spite of its relevance, automated network management and joint radio resource management algorithms in a multi-system context have received little attention in the academic area so far. Different research projects and standardization bodies have

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recently covered the problem of interoperability of different networks with re-configurable terminals supporting multiple connections (e.g. [4, 5]). Likewise, manufacturers have manifested their interest on these issues [6, 7]. Nonetheless, first efforts have been centered on the definition of a generic procedure of intersystem handover [8], joint admission control [9, 10] and possible deployment scenarios [5].

The paper is structured as follows: Section 2 gives an overview of the main objectives of the Gandalf project. The expected impact of Gandalf is discussed in Section 3 by three case studies. Next, the state of the art in the area of network monitoring, troubleshooting and auto-tuning is discussed in Section 4. Section 5 presents the solution approach for monitoring, self-diagnosis and self-tuning.

II. OBJECTIVES

The main objective of the Gandalf project is the development of off-line and on-line (dynamic) optimisation algorithms to select the most appropriate values for RRM network parameters. A characteristic of the on-line algorithms is that they have to be executed quickly (of the order of a few seconds or minutes), whereas the off-line algorithms can be processed over much longer time scales. In order to make real-time optimisation tractable, it is essential to develop efficient heuristic techniques.

The Gandalf project will produce results in several domains, the main key being the multi-system self-tuning concept definition and assessment. The project will produce network architecture specifications, performance indicators, resource management algorithms, optimisation algorithms and emulation methods. The results will be analyzed through simulations and will be experimentally demonstrated using software and hardware demonstrations.

III. EXPECTED IMPACT

The migration from manual to automatic cell and frequency planning in cellular systems has induced a significant quality enhancement and deployment cost reduction. Similar gains are expected from the automation of parts of the operation of a mobile radio network. This expectation is especially justified in complex systems like UMTS or even heterogeneous access networks. In the following the impact of automatic cell planning is reviewed. As an indication of the impact of multi-system RRM and self-tuning techniques, the capacity gain achieved by network cooperation and the performance gain achieved by self-tuning techniques in UMTS networks are presented in the following.

A. Technical and economic impact of automatic cell planning

Cell planning aims at optimizing network performance (in terms of capacity, coverage, quality of service and mobility) by adjusting antenna parameters and common channel powers.

Automatic cell planning has been utilized for both GSM and UMTS networks, and has a particular success in the latter case due to the lack of frequency planning. Furthermore, the sharing of frequency resources in UMTS networks renders network planning and design complex. The sectors of the network can be strongly coupled in the sense that traffic fluctuations or small parameter modifications in one sector can modify the performance of other sectors. For this reason, UMTS network operators have invested a lot of interest in automatic cell planning that can automate and simplify the planning process.

A high quality *Automatic Cell Planners* (ACP) can typically lead to a capacity increase of 30 to 40 percent. This improvement is accompanied by the reduction of interference and improvement in quality of service offered to the end users. In terms of *capital expenditure* (CAPEX), the saving in number of sites has been estimated to vary between 25 to 30 percent, which is translated to savings in the order of 100 to 200 million euros for an operator in a big European country. Gain of *operational expenditure* (OPEX) is more moderate and is estimated in the order of one to several man years, namely the time required for an engineering team to perform the planning and design tasks.

B. Trunking gain achieved by RAT cooperation

The joint operation of a multi-radio system (e.g. GSM-EDGE + WCDMA UMTS) yields more capacity than just the addition of the individual capacities. This fact is somewhat intuitive, as the capacity grows in a nonlinear way with available resources when a common pool of resources is established, due to the underlying trunking gain. As an example, a manufacturers' whitepaper [7] depicts the trunking gain expected when different services are realized over GSM-EDGE and WCDMA separately and jointly. The results are summarized in Table 1.

TABLE I. CPACITY GAIN BY RAT COOPERATION [7]

System Configuration	**Service Type**		
	Speech	***Data 64 kbps***	***Data 144 kbps***
WCDMA/EDGE individual capacities	49.7 Erl.	5.1 Erl.	1.6 Erl.
WCDMA+EDGE capacity op. separately	99.4 Erl.	10.2 Erl.	3.2 Erl.
WCDMA+EDGE capacity joint op.	107.4 Erl.	13.1 Erl.	5.1 Erl.
Trunking gain	8%	28%	60%

The figures in the table are calculated for 5 MHz of allocated spectrum (1 WCDMA channel / 25 EDGE channels) with a blocking probability of 2%. Note that the trunking gain rises up as the number of physical resources decreases, i.e., as the bandwidth required by the services increases.

C. Gain through self-tuning in 3G

Self-tuning has been studied recently in the context of 3G networks [11]. The main focus has been given to tuning of admission control and macro-diversity parameters. In both cases, self-tuning considerably improves network performance, and allows the network to adapt itself to traffic variations.

The following example illustrates the gain in UMTS network performance brought by tuning of macro-diversity add- and drop-window parameters, station by station. The self-tuning process is evaluated in terms of average dropping and blocking rates. A network with different uniform add- and drop-window parameters is taken as references, and is represented in Figure 1 in the (average) dropping and blocking plane. These points comprise the uniform parameterisation

Pareto front. The Pareto front for the optimised, self-tuned network is situated below the uniform front, indicating the improvement in blocking and dropping rates. The different solutions are obtained using different self-tuning strategies.

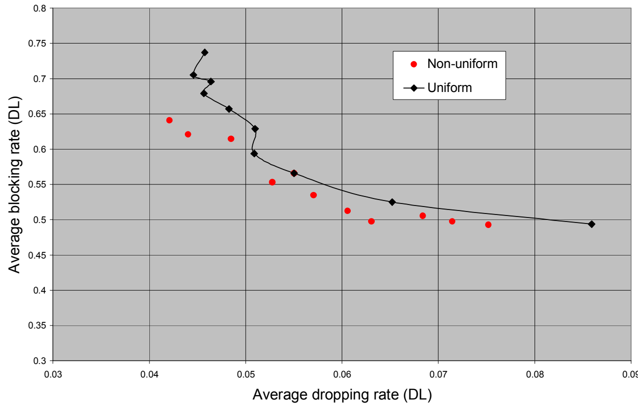

Figure 1. Network performance in the blocking and dropping plane for uniform and self-tuned add- and drop-window parameters for the 5 percent of stations with the worst performance (source France Telecom R&D)

IV. STATE OF THE ART IN MULTI-SYSTEM SELF-TUNING

Today, management tasks such as monitoring, troubleshooting and optimization are primarily manual processes. Staff carry out a series of checks to establish the causes of the problem, then analyze possible solutions and finally launch the best healing action. In this process, several applications and databases have to be queried in order to analyze performance data and update the configuration of the network. Thus, operators have tried to cope with the increase of network complexity by increasing their personnel and over-dimensioning resources.

However, the growing size of cellular networks, together with the increasing complexity of network elements, makes this strategy no longer feasible. First, the time consuming nature of these management tasks has a severe impact on operational expenditure (OPEX). Likewise, due to effort and expenses, default values for parameters of RRM algorithms are set all over the network, even if non-optimum performance is achieved. Therefore, the flexibility from the large parameter set defined on a cell (or even adjacency) basis is not fully seized. These sub-optimal network settings set artificial but effective limits on network capacity, leading to premature increase of capital expenditure (CAPEX) and avoidable reductions in operator revenues. Consequently, operators currently demand automatic tools that simplify planning, roll-out and operation of their networks. In addition, these automated processes should not only automate their current repetitive procedures, but provide new optimization procedures that increase network performance at a minimum cost.

Thus, several automated network management solutions have been proposed and tested. First results have been achieved in the fields of self-testing, automated fault identification and self-tuning, mainly for GSM/GPRS/EDGE networks [12, 13]. Likewise, similar recent studies have also been reported for UMTS networks [14, 15, 11].

V. SOLUTION IDEAS FOR SELF-TUNING OF RRM PARAMETERS

As proposed by Gandalf, individual segment monitoring should be performed to combine local (i.e. RAN specific) and global (i.e. network) radio resource management strategies to enhance both quality and capacity of the overall system. Disparity between RAN-specific quality measures across the different RATs is dealt with by comparing the performance indicators to the common service quality objectives being sought by the heterogeneous network. Using a combination of these techniques, efficient use of resources and optimal cooperation between systems are assured, maximizing returns on investments and minimizing capital and operational expenditures. As a result, unnecessary network extensions and upgrades are delayed. In a feedback based regulation loop, the self-tuning module will calculate optimal values for the RRM parameters by dynamically processing the KPI.

Network performance data is collected from the network technology layers via element management systems deployed for network management purposes (see Figure 2). These are typically vendor-specific, network technology-specific and/or equipment type specific. Network level data is also forwarded to the service performance measurement and reporting function. This function maps the network level data to delivered services, combines it with supplementary service performance data to create an additional set of service performance and service usage indicators. These are also forwarded to the optimization function. This optimization function generates sets of revised RRM parameters relevant to each of the vendor, technology and equipment-type specific element management systems. In addition, new network and service quality performance targets are generated and returned to the service performance management system, which then measures the re-configured network against the revised targets, and reports on the results of the optimization process.

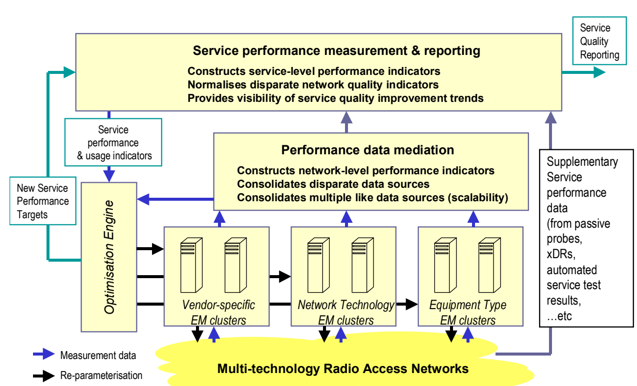

Figure 2. Self-tuning optimization scheme

The following methods are envisaged for self-diagnosis and self-tuning algorithms:

A. Monitoring at the Service Level

As the service portfolio of network operators becomes more and more diverse, differences in the value (in terms of revenue, market position and strategic business development) associated with each service, become more important. Operators are therefore now recognising the need to manage at the service level, in order to achieve differentiated service management on a service-by-service basis. For this reason, service level management systems are just beginning to be deployed, and solution evaluations are known to be taking place in most mobile network operators in Europe and the USA.

Service level management systems map (where possible) subsets of the network level data to delivered services. This information is combined with additional service-oriented data collected from passive probe systems, billing records and end-to-end service test results, to produce an analysis of delivered service quality. Service usage and quality data is passed to the operators' business management layer that bases its business decisions on the service data produced by the service layer, financial information and resource information. These decisions are relayed back to service management in the form of differentiated investment in services and service resources.

By monitoring at the service level (as well as at the network level), emerging service quality-based business management models can be supported.

B. Self-Diagnosis

For the troubleshooting process, artificial intelligence techniques seem the most promising alternative. Among them, Bayesian networks [16] have several advantages when compared to rule-based systems. Bayesian networks are probabilistic representations for uncertain relations, which have been successfully applied to real-world problems, as diagnosis of medical diseases [17] and troubleshooting of printers [18]. In a Bayesian network, the domain is modeled by means of nodes or variables connected with arrows, which represent causal relations between the nodes. The variables can be continuous or discrete, having a number of exclusive states. Probabilities are incorporated to the model as the "strength" of the connecting arrows.

In order to build a Bayesian model that could be applied to diagnosis in mobile networks the following variables should be identified [19]: causes (e.g. HW problem, interference in downlink), symptoms (e.g. signal level decreased, increased number of HOs) and conditions (e.g. interference problems are more likely in densely populated area). Once the model is developed, an automated troubleshooting tool, which is in charge of diagnosing the most probable cause of problems based on automatically collected evidences and the Bayesian model, should be designed. Unfortunately, the knowledge acquisition stage, where knowledge of experts is translated into Bayesian models, remains a bottleneck. Even if some simplifications are made about the structure, still the number of probabilities that has to be specified is usually high. Furthermore, experts in troubleshooting normally do not know how to build a Bayesian model directly. Therefore, a semi-automated knowledge acquisition tool to help the user seems to be an essential requirement [20].

C. Self-tuning

Regarding the self-tuning process, current strategies can be broadly classified according to their reaction time in long-term and short-term approaches. Long-term (or off-line) strategies make use of measurements collected in network management equipment over long periods (e.g. week) to re-plan network configuration parameters. Thus, adaptation to the uneven spatial propagation and traffic distribution in urban areas with its slow variation during a day can be achieved. For these scenarios, optimization algorithms for the most relevant planning parameters in the network (e.g. frequencies [14, 21], adjacencies [14, 22]) have been successfully tested in real networks. Likewise, permanent modification of the operational area of cells in a live network through optimized RRM parameter tuning has also lead to excellent results. Examples are signal-level constraints in cell selection [23] and handover [24], handover thresholds [25] and handover margins [26].

As an added value of this long-term approach, a comprehensive model of the overall system can be built, based on the statistical information available. An objective function is thus obtained, which explicitly relates parameter settings and performance indicators. Thereafter, principles of the optimization theory can be applied over the model to find the optimal parameter configuration. Thus, proactive methods that outperform traditional reactive approaches are obtained [27, 28] whenever the system model remains valid. Nonetheless, several issues make the search of a solution not a trivial problem. The non-linear or discrete nature of the objective function hinders (or even prevents) the application of classical optimization algorithms based on gradient information. Modern heuristic approaches, such as simulated annealing, genetic algorithms, evolutionary programming, taboo search and swarm intelligence, have been recently proved as effective tools for this kind of problems (for a list of references in optimization techniques, see [29]).

In contrast to the previous approach, short-term (or on-line) adaptation strategies modify network parameters based on instantaneous indicators. The need for immediate access to these indicators and parameters are linked to real RRM algorithms, with their inherent capabilities (e.g. adaptation to temporal variation of traffic or interference) and limitations (e.g. lack of overall system information). Agile handover margin adaptation of a load balancing algorithm in a GSM network [30] is a clear example of this category.

With the launch of the first UMTS networks, research on RRM parameter self-tuning over these networks has gained momentum. Most initial efforts have been focused on parameters of admission and congestion control algorithms that take charge of the capacity-coverage and RT-NRT traffic trade-offs in a cell. In particular, the total power (or load) target used in power-based (or throughput-based) admission and congestion control can be optimized on a cell basis from quality measurements during high load periods [31]. Also, adjustment of the power of the primary common pilot channels (and all other common channels that are set with respect to it) gives improvement in downlink coverage and capacity [14, 32]. Likewise, parameters in handover control, cell selection and power control algorithms are potential candidate for auto-tuning.

VI. CONCLUSIONS

The Gandalf project is a European initiative with the aim to develop appropriate techniques for the automation of management tasks in multi-system radio access networks. The approach is to collect and process network data on a large scale in order to produce key performance indicators for identifying malfunctions and to dynamically propose and perform healing and optimization actions. To optimize QoS delivery and overall systems performance in a multi-system environment, the project will propose new radio resource management algorithms together with methods for self-tuning. The project will evaluate the performance gain of the multi-system self-tuning concept through network simulations. Finally, hardware demonstrations will prove the feasibility of the ARRM and auto-tuning concepts developed in the project.
The Gandalf project is composed of a consortium comprising 7 European partners from 4 different countries covering operators, equipment manufacturers, universities and small and medium enterprises. The important technical domains that are necessary for the project, mobile radio networks, network management, diagnosis, and optimization theory are well covered.

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