Self-Management for Unified Heterogeneous Radio Access Networks

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***Abstract*—The development of self-management solutions for (multi-technology, multi-layer) mobile communication networks is driven by their increasing operational complexity. Initial stand-alone SON (Self-Organizing Networks) solutions are already available, but are not sufficient to handle the networks of tomorrow. In this paper we present our approach at developing a unified management framework that integrates the existing and future advanced SON functions across several radio access technologies. The envisioned self-management system comprises *(i)* an integrated SON management system, in charge of policy transformation/supervision and conflict detection/handling; *(ii)* advanced multi-RAT/layer SON functions; and *(iii)* a Decision Support System providing measurement-based assistance for residual operational tasks, such as timely recommendations for targeted new site deployments.**

Keywords—Self-management, self-optimisation, radio access networks, multi-layer, multi-RAT, 3G, LTE, WiFi.

I. Introduction

Nowadays, radio network experts manually carry out most radio network planning and optimization tasks, supported by various software tools, as well as process descriptions, handbooks and guidelines [1]-[5]. Mastering these tasks is slow and tedious. It involves complex error-prone processes and relies on expensive human expertise. These tasks are further complicated by the variety of mechanisms needed to configure and operate the different network elements. With intensifying competition and in face of flat rate service plans, network operators are striving to increase their revenues through rapid introduction of services with high added-value while at the same time trying to cut costs.

Future radio access networks will contain even more Radio Access Technologies (RATs) (integrating also LTE and WiFi technologies on top of GSM/GPRS and UMTS/HSPA), more layers (macro, micro, pico, femto) and denser deployments. This underlines the need for developing self-management capabilities for such networks. Self-management involves self-configuration, -healing and -optimization of new technologies and advanced mechanisms which alleviate the burden on the operator and are carried out autonomously, with no or minimal human intervention.

The first steps towards a self-management system have already been taken with the standardized Self-Organizing Networks (SON) solutions in 3GPP. SON constitutes a first instantiation of this concept at the lowest level of the network hierarchy, namely automated management of network resources at the Network Element (NE) level (Figure 1). The first phase of stand-alone SON use cases and possible solutions that were initiated in NGMN and pursued in 3GPP ([6][7]) focused on self-organization mechanisms (such as mobility robustness optimization, interference management, coverage/ capacity optimization, energy savings) that were isolated from one another [8]-[11]. Typically, these solutions target individual RATs and cellular layers, rather than addressing the network as a whole.

The introduction of SON into mobile cellular networks considerably impacts the way that networks are planned, deployed, optimized and operated [12][13]. SON mechanisms (especially self-optimization) are closed-loop control functions intended for continuous and autonomous tuning of radio parameters, and not only once within weeks or months as in traditional network operations. Some SON function-specific policies have been defined by 3GPP [14][15]. The configuration of (the optimization policy of) individual SON functions becomes highly complicated and the likeliness of conflicts increases significantly with an increasing number of different SON functions operating in parallel and in a non-coordinated manner, covering multiple layers/RATs and coming from different manufacturers. So far, such issues have not been adequately addressed, and there is a clear need for finding solutions to managing these SON functions in an integrated manner and with a system-wide perspective.

These integrated self-management solutions shall provide the operators with the means to efficiently pilot/drive the operation and management of SON features, through enforcement of their global strategies and/or performance

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requirements in an automated manner. At the same time, they will ensure a cost-efficient and harmonized coordination between SON functionalities when a large number of them are deployed in the network.

Within the FP7 SEMAFOUR project [16], we will develop and validate an efficient, high-level, automated network management system, thus addressing an extremely important need for mobile operators. Our consortium combines the expertise of some of Europe's leading equipment vendors and mobile operators, together with prestigious research institutions/universities and an SME (Small or Medium Enterprise) specialized in telecommunication network planning/optimization.

This paper describes the SEMAFOUR vision on self-management of unified heterogeneous radio access networks. Section II contains a high-level description of the network management architecture, which provides the architectural foundation for the targeted self-management framework. Section III introduces the unified self-management system as envisioned by the SEMAFOUR project. Its key components are described in more detail in subsequent sections, viz. the integrated SON management layer (Section IV), advanced multi-RAT/layer SON functions (Section V) and a decision support system to assist the network operator with some residual operational tasks (Section VI). Section VII ends the paper with some concluding remarks.

II. NETWORK MANAGEMENT ARCHITECTURE

Network operations and management systems can structurally be described by an architectural framework. Figure 1 illustrates the 3GPP management reference model [17]. The operator interacts with the network through the Network Management (NM) or Network Management System (NMS), which in turn is connected to Domain Managers (DM)/Element Managers (EM) through the standardized Type 1 interface. The DM/EM manages individual Network Elements (NEs, typically eNodeBs in case of E-UTRAN[1], RNCs[2] and NodeBs in case of UTRAN[3], BSC[4] and BTS[5] in case of GERAN[6]), through a vendor-specific Type 2 interface.

SON features are mapped to this architecture, with objectives to adjust parameters in the Radio Access Network, based on network information and measurements. The following nomenclature is adopted [14]:

- ***NM-centralized SON*** reconfigures NE parameters based on network information fed back from the NEs. It typically takes benefit from its ability to consider long-term data, as well as multiple cells.

- ***DM-centralized SON*** reconfigures NE parameters based on NE feedback information, also including vendor-specific data, but without a multi-vendor scope.

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[1] Evolved UMTS Terrestrial Radio Access Network
[2] Radio Network Controller
[3] UMTS Terrestrial Radio Access Network
[4] Base Station Controller
[5] Base Transceiver Station
[6] GSM EDGE Radio Access Network

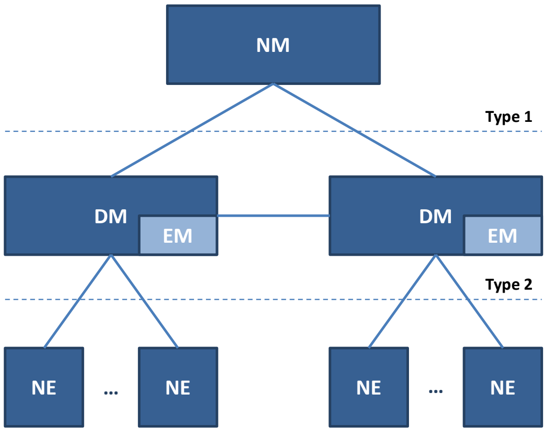

Figure 1. Network management reference model.

- ***Distributed SON*** is implemented in the NEs. It is able to react fast to reports from served UEs and information obtained from other NEs via inter-node interfaces. Moreover, information can be shared between RATs via the core network.

- ***Hybrid SON*** is essentially a combination of both centralized and distributed SON functional components to provide efficient SON operations with multi-vendor support.

It is relevant to relate the self-management vision to this architecture. Mappings of both the integrated SON management and specific SON functions are given in following sections.

III. VISION

With advanced network management solutions as envisioned and targeted by the SEMAFOUR project, mobile network operators no longer need to individually control, optimize and monitor a multitude of RATs and layers. Instead, the operator is able to interact with this complex heterogeneous environment through a *unified self-management system*, which controls the complete environment as one single network. In this targeted system, the operator shall be able to specify general network-oriented objectives that capture the desired network-wide performance in line with the operator's strategy, which are then effectively translated to automatically, dynamically and unifiedly optimized radio networks.

The envisioned unified self-management system is designed to provide considerable gains to the operators in terms of performance and capacity enhancements, improved manageability and cost reductions. We believe in fact that self-management is the only sensible approach to managing an operationally highly complex heterogeneous radio access network. An *uncoordinated* simultaneous operation of stand-alone SON functions, however, may not exploit the full potential of SON. A unified self-management system that includes multi-RAT and multi-layer SON functions *together* with an integrated SON management is developed to effectuate a harmonized and focused operation of SON, thus providing performance and capacity gains. Where multi-RAT/multi-layer SON functions support the operator by automating complex, time-consuming and repetitive tasks, the objective of the integrated SON management layer is to manage the SON functions themselves by enabling the operator to formulate requirements through general network-oriented objectives.

The key components of the self-management system as targeted by the SEMAFOUR project are shown in Figure 2. At the top of this figure is the network operator which interacts with the unified self-management system via the ***integrated SON management*** layer. This layer transforms the network-oriented objectives into dedicated execution policies and rules for individual closed-loop SON functions. The integrated SON management also integrates and coordinates the multitude of individual SON functions, by supervising the functioning of these SON functions. Another functionality of the envisioned integrated SON management is monitoring. This includes the collecting of performance data and data pre-processing for further use within the SON functions and SON coordination. At the bottom of Figure 2 are the individual ***multi-RAT/multi-layer SON functions*** that are operational at the network and network element level. They control the physical network resources in the different RATs and layers.

Although unified self-management as such is in principle well covered by the integrated SON management layer and the multi-RAT/multi-layer SON functions, the SEMAFOUR project further targets, as an add-on, the development of a ***Decision Support System*** (DSS). This DSS leverages many of the intrinsic capabilities of the self-management system, such as performance/load monitoring and performance impact analyses/predictions, in order to provide recommendations towards the operator about possible network deployment and enhancement options. This further improves the operators' options for network management at a significantly higher level.

These three key elements of the self-management system are both envisioned and targeted by the SEMAFOUR project. In the project we will develop the concepts, devise concrete algorithms, assess their feasibility and performance, and showcase them using a demonstration platform. The elements of the self-management system are further elaborated in the following sections, including references to the network management architecture (Section II) with the different SON implementation options.

IV. INTEGRATED SON MANAGEMENT

In SEMAFOUR, we aim at addressing the operational complexities described in the introduction section, by the employment of techniques and methods for an ***integrated SON management*** system, such as SON conflict management, cost-efficient and harmonious SON interworking/co-operation to realize operator-defined general network-oriented performance objectives. Interfacing between the operator-defined general network-oriented performance objectives and the set of multi-RAT/multi-layer SON functions (see Figure 2), the integrated SON management system provides a unified view on the complex heterogeneous network environment, leading to efficient network control and operations. At other levels, these global performance objectives are reflected by the general *network-oriented objectives*, obtained by specifying the desired network-wide performance and behavior in terms of e.g. operational efficiency, end user satisfaction, capacity and coverage, which is in line with the operator´s operational strategy. The ultimate aim/task of the integrated SON management system is to ensure efficient and harmonious co-existence of autonomous SON operations such that the general network-oriented objectives are met. Integrated SON management is essentially about centralized SON as a first step for building trust, but at later stages it can also be motivated to distribute some components to the network elements to implement hybrid SON.

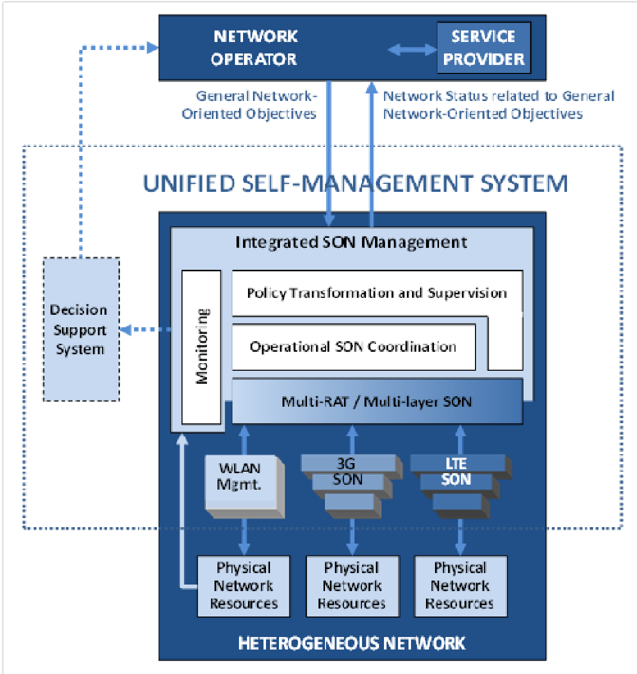

Figure 2. Functional overview of SEMAFOUR's envisioned self-management system for the unified operation of multi-RAT/layer networks.

The integrated SON management system consists of the following functionalities, see Figure 2:

- The ***Policy transformation and supervision*** functionality converts operator's general network-oriented objectives and policies (on performance, efficiency, flexibility, resilience and robustness) into operational SON coordination and conflict resolution functions/actions, which are further translated to dedicated SON function objectives and to NE-level rules/policies. This conversion is in the form of some automated translation of pre-defined rules/policies at different levels of abstraction. An example of such an automated translation is the *policy-refinement* defined and used in computer communications [18]. This automated transformation considers aspects such as the network infrastructure, layout (RATs, layers, geographical information) and configuration, capabilities and configuration of the involved SON functions, and the dependencies between the general network-oriented objectives. For example, objectives on energy efficiency may conflict with those on network coverage and capacity. The policy transformation also integrates the expert knowledge of the human operator, and therefore requires solutions on knowledge management.

- ***Operational SON coordination*** is responsible for supervising the functioning of the multitude of SON functions, real-time detection, analysis and resolution of conflicts, system instabilities and undesired network behavior due to simultaneously operating SON functions at run-time [19]. For example, two SON functions may simultaneously aim at modifying the same configuration parameter of a cell, may both trying to mitigate the same performance issue, or may strive to meet conflicting targets. Countermeasures such as temporal separation of the execution of two conflicting SON functions, or a prioritization of one of the SON functions above another are examples of operational SON coordination actions. SEMAFOUR will provide tangible solutions to operational SON coordination, answering in particular how close we can get to the real-time aspects and on what basis. SON coordination can be implemented either centrally to take advantage of a wider multi-node view, or distributedly to take advantage of shorter delays.
- The ***Monitoring*** functionality has the role to acquire performance data (e.g., counters, timers, KPIs, radio measurements) from network elements and mobile terminals and pre-process this data for further use within the SON functions and operational SON coordination. Furthermore, the monitoring functionality is responsible for giving feedback to the operator regarding the actual network status and performance according to the general network-oriented objectives, possibly in the form of periodic or event-triggered reports. Such a feedback provides a means for improving and tuning of the common policies in comparison to the performance targets derived from the general network-oriented objectives. The monitoring is mainly centralized, even though it can be justified for scalability reasons to delegate some refinement of performance data to the network elements.

V. MULTI-RAT/LAYER SON FUNCTIONS

Although SON as a concept has been introduced fairly recently, radio network automation features of various kinds have existed for many years. With an integrated SON management, it is important to integrate the existing SON functions as well as future SON functions which will be developed to meet the challenges imposed by a complex network deployment with multiple RATs, layers and evolved radio network concepts. These SON functions are designed to operate in line with the SON function objectives, as automatically derived by the policy transformation and supervision functionality of the integrated SON management layer. Some key SON features that will be considered within the SEMAFOUR project for evolutions and enhancements are briefly discussed below.

- ***Automatic Neighbor Relation (ANR) –*** ANR automatically identifies neighbor cells by commanding UEs to report unique identifiers of candidate cells. It can be seen as a feature that supports automatic generation of a logical topology model of the deployed network, and it is typically distributed to the network elements. It is relevant to evolve ANR to also address WiFi as well as new radio network concepts introduced in 3GPP Release 12 and onwards.
- ***Mobility and access robustness optimization –*** Mobility and random access support, e.g. self-optimization of handover thresholds and timers, is critical in terrestrial communication networks. In distributed network architectures, it is important to disclose mobility and access failure causes, and inform the entity responsible for mobility and access decisions to improve performance. Such indications also need to be supported between layers and RATs. There is already some support for mobility robustness and random access optimization in 3GPP via dedicated signaling between layers and RATs to identify the failure root cause in the network elements. This needs to be evolved to address all RATs as well as radio network concepts introduced in 3GPP Release 12 and onwards. The parameter adjustments can be either distributed or centralized.
- ***Mobility Load Balancing (MLB) –*** In order to efficiently support the tempo-spatial variation of traffic demands with adequate service quality, it is important to steer traffic from more congested cells/layers/RATs to others that are better capable of supporting the sessions' QoS requirements. This is also referred to as load sharing, traffic steering or offloading, and can incorporate both 3GPP and WLAN RATs in multiple layers. It is reasonable to decentralize load sharing to the network elements to handle traffic variability. Load sharing can also be seen as a means to steer traffic to the available resources. It can be differentiated by service requirements, resource consumption, radio conditions, etc. and act at short time scales.

  Related radio resource management mechanisms that target a spatially more homogeneous performance experience are Coordinated MultiPoint and 'multiflow' transmissions, where a given flow is not steered to the single most suitable base station (or access point), but is served by multiple cellular base stations in parallel. The self-optimized employment of these mechanisms is also targeted in the SEMAFOUR project.
- ***Interference and spectrum management –*** The spectrum resource is valuable, and should therefore be exploited with optimized efficiency. This involves spectrum assignment to nodes and to user connections, as well as managing interference between different entities in the network. One example is low power network elements, which may not support all carriers and/or RATs, and the carrier/RAT assignment can be crucial. Spectrum and interference can be managed on a fine timescale in the frequency, time, space and power domains, and also via antenna reconfigurations, exploiting e.g. the potential of Active Antenna Systems. Such short-term actions are typically decentralized, while more long-term actions such as operational carrier selection and RAT assignments are more likely to be centralized. An analogy to MLB is that this can on the contrary be seen as steering resources to the traffic needs, and there is thus a need for adequate coordination.
- ***Coverage and Capacity Optimization (CCO) –*** In addition to short term management, the spectrum resource needs to be management on longer terms, for example to ensure coverage to idle mode user terminals but also to address capacity demands in appropriate manners. With multiple layers and

RATs, it is important to establish information about overlaps between layers and RATs to support energy efficiency actions where selected cells can be temporarily deactivated without jeopardizing coverage. Other CCO components include adjustments with objectives to adjust coverage and capacity to meet needs. CCO is naturally an example of centralized SON.

VI. DECISION SUPPORT SYSTEM

A further feedback mechanism from the self-management system to the network operator, as also depicted in Figure 2 is envisioned in the form of a *Decision Support System (DSS)*. The DSS is seen as a collection of features that provides recommendations and valuable information towards the operator regarding e.g. deployment actions, the specification of performance objectives and the (re)negotiation of Service Level Agreements (SLAs) between the operator and the service providers. Its general objective is to exploit and process the network intelligence available in the self-management system in order to assist the network operator as much as possible with its residual operational tasks. As such, the DSS provides an interface between the unified self-management system and human-driven workflows such as network dimensioning, maintenance and servicing.

A key example of such an advanced feature concentrates on the *recommendation of new hardware deployment*. As mobile traffic loads continue to grow, the self-management system strives to handle the offered traffic in the most efficient way that is in line with the operator's general network-oriented performance objectives. At some point, however, further traffic growth or, alternatively, more ambitious service quality targets can only be adequately supported by upgrading or adding hardware, e.g. upgrading an existing base station from GSM to LTE technology, or the deployment of additional (macro, micro, pico, femto) sites, sectors, carrier or antennas. It is then the feature's task *(i)* to automatically identify the need for additional/upgraded hardware deployment in a specific area, and *(ii)* to generate a shortlist of suitable deployment options.

Another example of a decision support feature relates to the *derivation of the 'resource cost of performance'*. The business-oriented benefits of such an assessment relate to the formulation of the operator's general network-oriented performance objectives and its (re)negotiation of SLAs with the served service providers. These may be either the operator's own service provider(s) or 'external' service providers, i.e. Mobile Virtual Network Operators (MVNOs). The agreed SLAs in fact form the key input to the general network-oriented performance objectives the operator feeds into the self-management system.

VII. CONCLUDING REMARKS

In this paper we describe a vision of how mobile network operators can effectively manage their networks in the future. This issue is so pivotal because the mobile networks are becoming increasingly complex with multiple disparate radio access technologies and multiple independent layers. The increasing network complexity and increasing data traffic with different service demands, lead to the observation that operators need support in order to cost-effectively and appropriately manage their networks.

We have given an overview of the SEMAFOUR vision of how to make such support available through a unified self-management system. The vision is based on extending and enhancing the current limited SON system to better handle the complex networks of tomorrow. It includes new powerful cross-RAT and cross-layer SON functions, together with a new integrated SON management layer to coordinate, control and optimize the various SON functions running in the network. It enables the operator to control the disparate complex network in a unified manner and in line with general network-oriented performance objectives.

Looking forward, the next steps for the SEMAFOUR project are to define the set of requirements and use-cases for the self-management system described in this vision paper. Once this is concluded, we will investigate further the necessary design and algorithms for such a system, using simulations to find the most promising solutions. Finally, we will build a demonstration system to showcase the algorithms and the overall concept.

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