Integrated Self-Management for Future Radio Access Networks: Vision and Key Challenges

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Abstract: Future radio access networks will require new self-management solutions to handle the increasing operational complexity caused by multi-technology and multi-layer deployments. Current networks already include stand-alone SON (Self-Organizing Networks) solutions, but these are not sufficient to properly handle the networks of tomorrow. In this paper, we highlight the key challenges for such self-management solutions based on our research and extensive feedback from several major operators. Based on these challenges we present a set of relevant use cases to validate future solutions and discuss our vision for a unified management framework, which integrates the existing and future advanced SON functions across several radio access technologies. It 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

1. Introduction

Cellular radio access networks are sharply increasing in complexity, with an increasing number of radio access technologies in concurrent use. Operators presently add LTE and WiFi on top of large-scale GSM/GPRS and UMTS/HSPA deployments. More layers need to be considered as the traditional macro cellular deployments with a few indoor and outdoor capacity add-ons are densified and grow inhomogeneous by the addition of more micro and pico cells as well as femto cells. Network operators therefore have a keen interest in self-management capabilities for such networks. The goal is to have many network operations and management related tasks being carried out automatically and autonomously with minimal human intervention.

First steps towards a self-management system have already been taken with the standardized Self-Organizing Networks (SON) solutions in 3GPP. SON is an instantiation of self-management at a low level of the network hierarchy. SON mechanisms (especially self-optimization) are closed-loop control functions intended for continuous and autonomous tuning of radio parameters, rather than once within weeks or months as in traditional network operations. The first phase of stand-alone SON use cases and possible solutions that were initiated in NGMN and pursued in 3GPP ([1][2]) focused on self-configuration (such as dynamic plug-and-play configuration, automatic neighbour relationships) and self-optimization mechanisms (such as mobility robustness optimization, interference management, coverage and capacity optimization, energy savings) that were isolated from one another [3][4][5][6]. Typically, these solutions target individual RATs and cellular layers, rather than addressing the network as a whole. Some SON function-specific policies have been defined by 3GPP [7][8].

A SON function for mobility robustness optimization (MRO), for example, continuously tunes radio network parameters in order to best support mobility under the present or expected local network conditions. How to make specific trade-offs in the course of this optimization may be determined by control parameters of the SON function. The more SON functions are operating in parallel in time, and addressing the same cells, the more complex the interplay of the SON functions may become. The more complex will also be the orchestration of the individual SON functions in order to have them consistently contributing to implement the desired network behaviour.

More specifically, the likeliness of conflicts among SON function increases with the number of different SON functions operating in parallel, in overlapping areas, at different cell layers, addressing different radio network technologies, or considering hardware from different manufacturers. Integrated self-management solutions need to provide the operators with the means to efficiently pilot and drive the operation and management of SON features. This is in order to truly reduce the complexity of network operation and management, and not to just move it to another domain (namely, managing self-management systems). So far, such issues have not been adequately addressed, and there is a clear need for solutions to manage SON functions in an integrated manner and with a system-wide perspective. Three domains are of high interest in this respect: *(i)* means to express global strategies and/or performance objectives and requirements in a formalized manner; *(ii)* mechanisms to automatically map those objectives and requirements to individual SON functions and their input parameters; and *(iii)* mechanisms to ensure a cost-efficient and harmonized coordination among large numbers of concurrently active SON functionalities.

This paper describes the vision of the EU FP7 project SEMAFOUR [9] on self-management for unified heterogeneous radio access networks. The project consortium combines the expertise of some of Europe's leading equipment vendors and mobile operators, together with renowned research institutions and universities, and an SME specialized in telecommunication network planning and optimization. An external advisory board consisting of seven major European mobile network operators supports the project by providing input on operator objectives and feedback on use case definitions and solution developments.

The outline of the paper is as follows. Section 2 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 3), advanced multi-RAT/layer SON functions (Section 4) and a Decision Support System to assist the network operator with some residual operational tasks (Section 5). Section 6 ends the paper with concluding remarks.

2. Vision

Automation is the only sensible approach to cost-effective management of operationally complex heterogeneous mobile access networks. The SEMAFOUR project therefore targets the development of a *unified self-management system*, which controls the complex network environment as a single entity. This self-management system shall enable the network operator to specify network-oriented objectives regarding, e.g., the desired service coverage, resource efficiency and quality of experience, and shall effectuate these objectives in the unified and automated optimisation of the underlying integrated access networks, i.e. to tune the radio (resource management) parameters of these networks in line with these targets. The project targets concept and algorithm development, feasibility and performance assessments, and advanced demonstrations of the developed solutions. The system is designed to provide considerable gains to the operators in terms of *(i)* enhanced resource efficiency, implying increased capacity and hence delayed investments in network expansions and/or equipment upgrades; *(ii)* improved manageability and hence lower operational costs; and *(iii)* enhanced performance in terms of service availability, seamless session continuity and user-level quality of experience.

A functional overview of the self-management system is presented in Figure 1. The top of the figure depicts a service provider, which maintains a Service Level Agreement (SLA) with a network operator, contractually formalising their agreement regarding performance and tariffs. Integrating such performance obligations with its own business strategy, the operator formulates its network-oriented objectives and provides these as an input to the ***integrated SON management*** layer, which serves as its interface to the self-management system. Key purposes of this layer are *(i)* to transform these objectives into dedicated execution policies for specific SON functions; *(ii)* to supervise and coordinate these SON functions; and *(iii)* to monitor their performance, providing input to periodic operator reports, SON management, SON functions and Decision Support Systems.

The policy transformation aims at configuring individual SON functions such that they jointly target the overall objectives ('heading harmonisation'), while, one level lower, SON coordination aims at resolving potential 'misbehaviour' of SON functions, e.g. conflicting parameter changes or performance effects, or undesirable radio parameter oscillations ('tailing harmonisation'). The SEMAFOUR project targets the development, assessment and demonstration of such integrated SON management solutions.

Single/multi-RAT/layer SON functions will reside at the functional layer below the integrated SON management (cf. Figure 1). These SON functions control the physical network resources in different RATs and layers and can be implemented in a distributed fashion in the network elements, or in a centralized fashion in the network management system. Numerous SON functions have been developed so far, including the above-mentioned MRO and MLB SON functions,. They mostly focus on single-RAT/layer scenarios. SEMAFOUR targets multi-RAT/layer SON functions, addressing amongst others advanced traffic steering between WiFi and 3G/LTE cellular layers, dynamic allocation of spectrum over RATs and layers, and the automated (de)activation and tuning of site sectorisation.

The integrated SON management layer and the single/multi-RAT/layer SON functions jointly pursue the effective enforcement of the operator-specified network-oriented objectives, thus relieving the network operator of an otherwise hugely challenging manual task. Although tasks such as the deployment of new sites, upgrading of existing sites or spectrum refarming cannot be readily automated, they can be aided by a ***Decision Support System*** (DSS). Leveraging intrinsic capabilities of the self-management system, such as performance/load monitoring and performance impact analyses/predictions, DSS features will be devised in SEMAFOUR, providing input and recommendations towards the operator. As an illustrative example, in the SLA negotiations between a network operator and the service providers, it is imperative for an operator to know what performance targets it can realistically achieve and at what resource cost. Both this performance feasibility and the associated performance-*vs*-cost trade-off can be determined by suitable processing of passive or active measurements in the self-managed network. Such a DSS will make an operator better prepared in the process of SLA (re)negotiations. Other examples of DSSs include the automated anticipation of capacity bottlenecks and, accordingly, the timely recommendation of network upgrades, and suggestions for spectrum swaps or technology migrations on existing sites.

These three key components of the envisioned unified self-management system are further elaborated in the following sections.

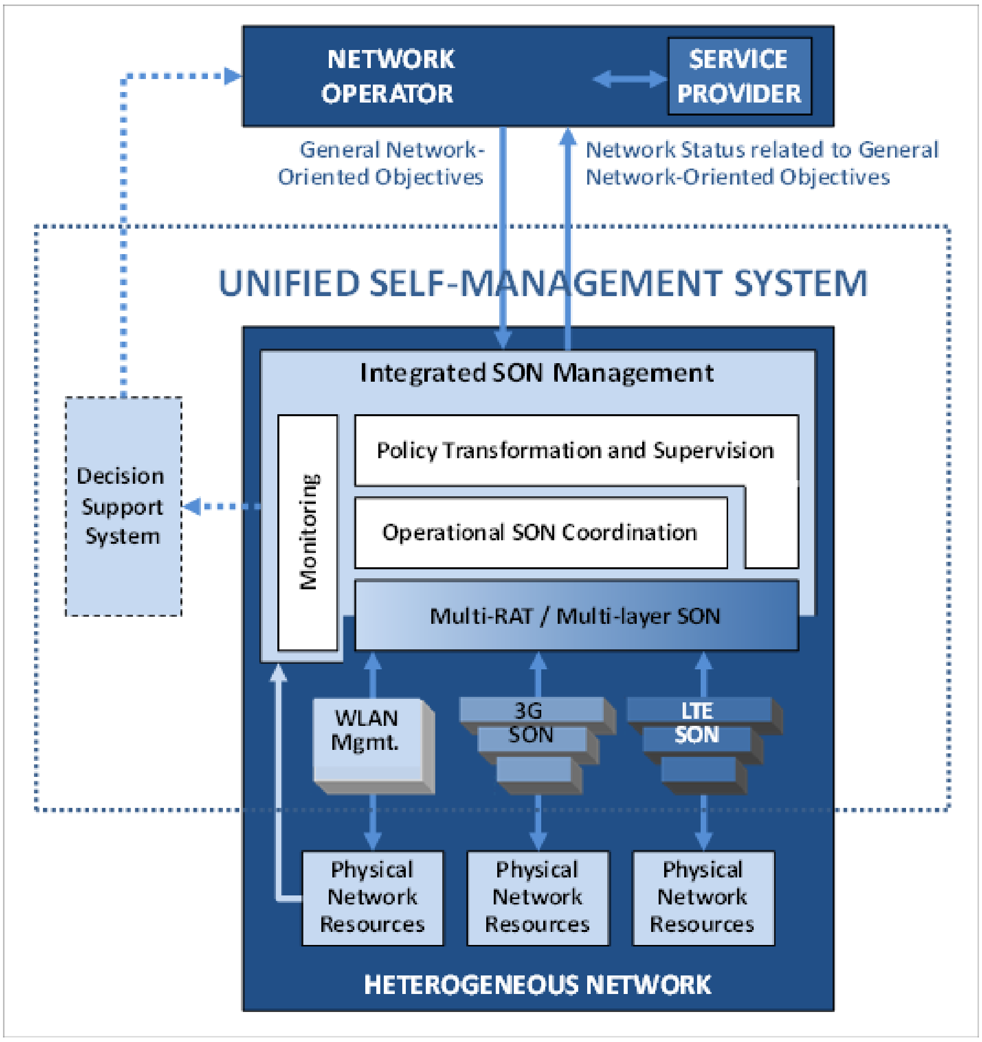

Figure 1: Overview of SEMAFOUR's envisioned unified self-management system.

3. Integrated SON Management

We address the operational complexities sketched in the introduction by means of an ***integrated SON management system*** (see Figure 1). This includes an effective and harmonious SON interworking and conflict management (*operational SON Coordination*), an policy-driven SON operation (*Policy Transformation and Supervision*), and a *Monitoring* component to supervise the functioning of the SON management system.

We use the phrase operator's network-oriented objectives to denote the operator's technical objectives regarding the network performance and behaviour at various levels, for example, related to operational efficiency, end-user satisfaction, network capacity and coverage, operational strategies, or SLAs with other (third) parties. The external advisory board of SEMAFOUR has provided an elaborate list of such network-oriented objectives, which serve as our basis for the development of integrated SON management.

In detail, the integrated SON management functional building blocks are:

- The ***Policy transformation and supervision*** functionality transforms the operator's network-oriented objectives into dedicated (executable) policies and rules for the individual SON functions and for the operational SON coordination. The transformation is performed in the form of an automated derivation of system-wide (and technology independent) policies and rules describing the behaviour of the heterogeneous mobile radio network. They are further translated into the dedicated, technology- and Network Element (NE)/SON function-specific execution policies and rules (see Figure 2). The transformation may involve several intermediate levels of abstraction (see the definition of *policy-refinement* defined and used in computer communications [10]), considering aspects such as interdependencies between the general network-oriented objectives, capabilities and characteristics of the network infrastructure, network layout (RATs, layers, geographical information) and configuration, and the capabilities and configuration of the involved SON functions. For example, regarding interdependencies between objectives, energy efficiency objectives may conflict with those on network coverage and capacity. On the SON function level, each SON function has parameters enabling its configuration. SON function specific policies aim at setting these parameters such that the behaviour of the SON function is in line with the operator's network-oriented objectives. As an example, the policy transformation sets the timers, activation / de-activation thresholds, offsets, step sizes, and responsiveness settings characterising the Mobility Load Balancing (MLB) and MRO SON functions, thereby influencing their behaviour and hence their impact in the network such that this is in line with the operator's network-oriented objectives regarding network quality and robustness, resource efficiency, and service quality. The policy transformation also integrates the expert knowledge of the human operator, and therefore entails knowledge management.
- ***Operational SON coordination*** is responsible for supervising the functioning of the multitude of simultaneously active SON functions at run-time, including the real-time detection, analysis and resolution of conflicts, system instabilities and undesired network behaviour [11]. Two SON functions simultaneously operating within the same network area and within a similar time schedule, may aim at modifying the same configuration parameter of a cell, or trying to mitigate the same performance issue, or striving to meet conflicting targets. Again the MLB and MRO SON functions can be taken as an example as both can modify configuration parameters related to handover thresholds, which has the potential of conflicting parameter changes in case the both functions simultaneously operate on the same cell. SEMAFOUR operational SON coordination will provide tangible solutions to

countermeasure such conflicts, answering in particular how close to real-time such a run-time coordination between different SON functions (including multi-RAT and multi-layer aspects) can come, and on what technical basis this can be achieved.

- The role of the ***Monitoring*** functionality is to acquire performance data (e.g., counters, timers, KPIs, radio measurements) from network elements and mobile terminals and to pre-process this data for further use within the SON functions and operational SON coordination. The monitoring functionality is also responsible for giving feedback to the operator regarding the actual network status and performance according to its own network-oriented objectives. Such a feedback provides a means for improving and tuning of the common policies in comparison to the performance targets derived from the network-oriented objectives.

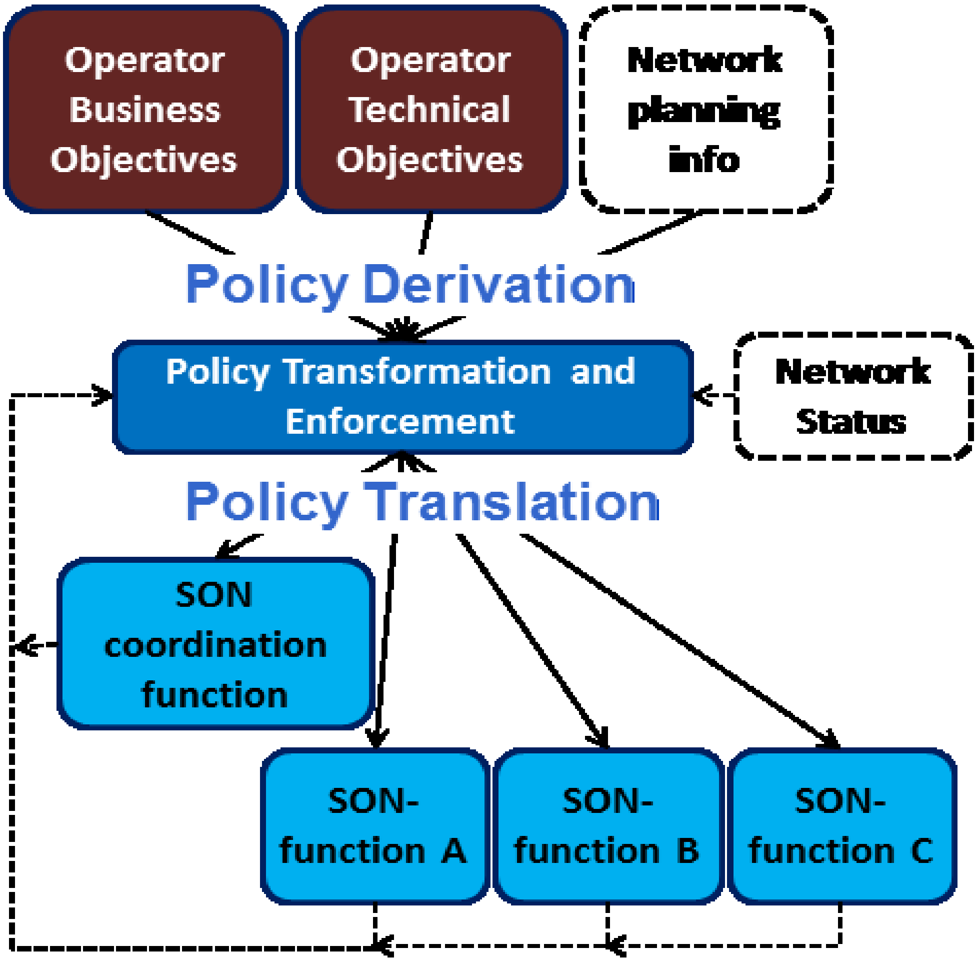

Figure 2: Functional architecture of Policy Transformation and Enforcement.

4. Multi-RAT/layer SON Functions

Future radio networks will continue providing services using radio resources from multiple RATs. In addition, the available resources may be shared among two or more cell layers. Based on input from the advisory board, SEMAFOUR will consider two different approaches to radio resource management and SON, based on the advanced features that are considered to be deployed in the operators' networks. Figure 3 illustrates some available configuration options.

On the one hand, resources are assigned and/or optimised to serve a given traffic load/mix by e.g. a dynamic spectrum assignment and interference management mechanism, or a mechanism that automatically tunes adaptive antenna system parameters. On the other hand, offered traffic is assigned to a given set of resources by traffic steering and load sharing, also addressing mechanisms that are discussed for future radio access networks.

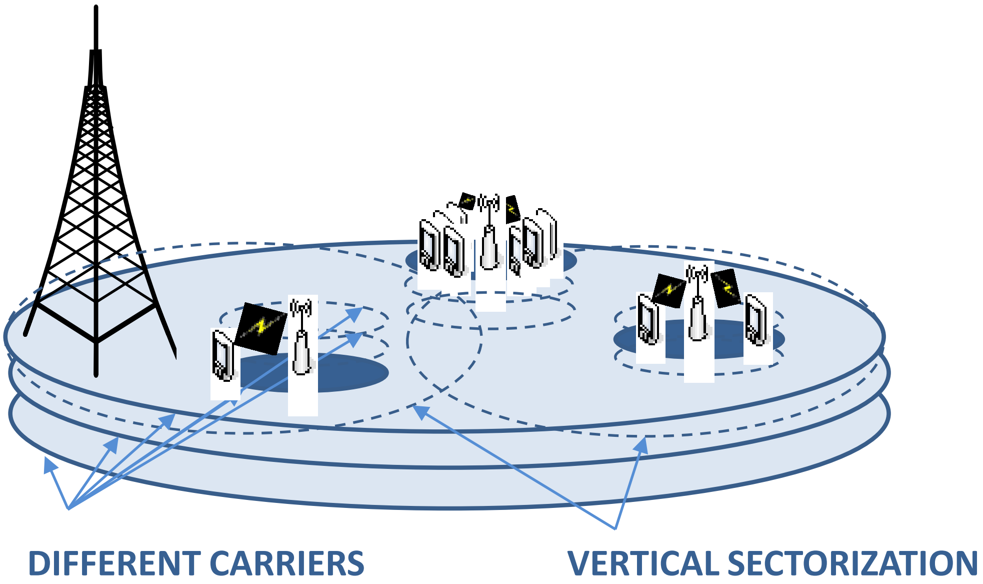

Figure 3: Some available configuration options in multi-RAT/layer SON, including operational carrier assignment, interference management and antenna adjustment on one hand, and per-user allocation of resources via traffic steering and load sharing on the other, considering user needs and mobility behaviour.

Considering the first category of mechanisms, the following use cases are addressed in SEMAFOUR:

- ***Dynamic spectrum allocation and interference management*** – The purpose of this use case is to develop and assess algorithms and strategies for joint dynamic spectrum allocation and interference management multi-layer and in multi-RAT environments. The scope of multi-RAT dynamic spectrum allocation is that existing GSM or UMTS spectrum may be dynamically allocated to LTE (e.g. up to 10 MHz bandwidth). Traffic peaks and busy hour traffic conditions can be observed at different places and at different times of the day. To avoid overload or underutilization of carriers a new or lightly-utilized carrier frequency could be (re-) assigned to a base station that is in or near overload and is requesting additional carrier. In an LTE multi-layer network the assignment of carriers to the different layers follow the same principle. Dynamic spectrum allocation is complemented by interference management. Typical actions of interference management are the assignment of bandwidth within the assigned carriers, the dynamic changing of the bandwidth partitioning/usage between LTE macro and pico/femto layers, and the adjustment of the transmitting power of the base station. The possibility of switching to another technology is subject to the condition that the actual measure can be realized. This means that the UE needs to be able to support the chosen frequency bands as well as the chosen technologies. The use case includes three scenarios: intra-LTE with and without small cells, and multi-RAT, where bandwidth re-farming across different 3GPP technologies is considered, but also the cost of cell reconfigurations. As seen in Figure 3, interference between cells can be avoided by conservative carrier assignments, while capacity can be improved by assigning a carrier to multiple layers, and instead handle the interference when needed.
- ***Active/reconfigurable antenna systems (AAS)*** – Two cases are considered: *(i)* cell densification is considered within a single RAT by employing Vertical Sectorisation (VS-AAS); the aim of VS-AAS is to increase network capacity by splitting a cell

into two cells, as illustrated by Figure 3, each identifying itself as a cell, broadcasting system information., etc; the targeted SON function automatically (de)activates the VS-AAS feature as well as tunes its downtilt and beamwidth parameters to the observed/estimated spatial traffic distribution, thereby considering the trade-off between additional traffic handling capacity versus raised interference levels; *(ii)* for Multi-RATs using the same antenna, any change of a common characteristic (say, mechanical tilt) will impact all related RATs. Therefore, such characteristics need to be optimized with respect to all RATs simultaneously, considering both different characteristics of the RATs, as well as the traffic situation for each RAT.

Considering the second category of mechanisms, optimising the assignment of traffic to available resources, the following use cases are addressed:

- ***LTE/WiFi traffic steering*** – In a heterogeneous network, automatic traffic steering is of utmost importance. The goal here is to identify requirements and technical challenges for WiFi-cellular integration as well as to propose network-controlled and UE-assisted QoS based WiFi traffic steering solution(s). Today's WiFi network discovery, selection and access are typically user-controlled. This leaves the mobile operators with limited control over the cellular offloading to WiFi and leads to degraded QoS/QoE for the end user when WiFi experiences high load and poor coverage conditions. This use case will consider both user service requirements and LTE and WiFi capabilities including traffic load and transport capabilities to optimize resource utilization while meeting user QoS requirements. In relation to Figure 3, the considered mechanisms will steer traffic between nodes and layers on a per user basis.
- ***Traffic steering for high-mobility users*** – This use case is about steering UEs to the most suitable (likely macro) cell when high mobility poses a noticeable impact on the UE (reduced QoS/QoE) and network performance (signalling overhead in the core network due to high handover signalling). Also, highly mobile user terminals are unlikely to benefit from services provided by small cells before moving on to the next cell. Key aspects are terminal velocity estimation and traffic steering mechanisms considering such velocity information to continue to serve a user terminal by a macro cell, when small cell alternatives are not considered favourable.
- ***Idle mode mobility*** – Resources can also be managed by controlling the idle mode behaviour of user terminals. Cell (re)selection mechanism adjustments will focus on two objectives. First, to minimize the amount of connected to idle mode transitions so that the user is offered a good QoS but at the same time that the UE battery life is prolonged. Second, to implement pre-emptive traffic steering by optimizing the UE cell (re)selection in consideration of the traffic load and resource utilization. This can be seen as traffic steering with specific restrictions. Therefore, it is relevant to also compare to connected-mode traffic steering.
- ***Resource management supporting dual connectivity***- One feature that will be in focus in the 3GPP Rel. 12 Small Cell Enhancement study item [12] is dual connectivity, where user terminals can be connected to more than one base station at the time. The implementation of dual connectivity needs to consider the quality of the backhaul, and may also include nodes operating different RATs. For low latency backhaul, Coordinated MultiPoint (CoMP) is an attractive option, but the study will investigate support for any backhaul. This use case will consider how dual connectivity can have an impact on the traffic steering strategies. It is expected to be initiated when the 3GPP Release 12 small cell enhancement studies regarding dual connectivity has matured.

5. Decision Support System

Besides reporting the network status related to the operator's network-oriented objectives, the Decision Support System (DSS) is another feedback mechanism from the self-management system to the network operator, cf. Figure 1. The DSS can be seen as an offline method, which eases taking decisions on how to extend or otherwise upgrade the network and to improve its operation. As such, the DSS provides an interface between the unified self-management system and human-driven workflows such as network dimensioning, maintenance and servicing. Three DSS use cases, which have been ranked as important on a medium- to long-term time scale by the project advisory board, will be investigated:

- ***DSS for Spectrum and Technology Management***, recommendations on assigning either another spectrum and/or another technology to a base station.
- ***DSS for Network Evolution***, e.g. recommendations on suitable new site deployments to cope with traffic growth.
- ***DSS for Determining the Resource Cost of QoS***, useful as an input for SLA (Service Level Agreement) management, i.e. to understand the trade-off between QoS levels promised to service providers and the resource costs associated with delivering upon such promises.

Exemplarily we describe the targeted *DSS for Spectrum and Technology Management* in more detail. For example, SON functions like Dynamic Spectrum Allocation and Interference Management, which will be developed within SEMAFOUR, are dealing with an operational LTE network. Under the constraint of the installed hardware these SON functions may find only sub-optimal solutions or show bottlenecks in the network at a specific time and space. In this case operators may swap their base stations to other technologies or frequency bands.

The DSS for spectrum and technology management will assist the operator in selecting the optimal technology and spectrum for base stations in the progress of swapping to other RATs and/or refarming of spectrum. Examples are an upgrade of a GSM base station to LTE and the change from the 900 MHz band to 1800 MHz or vice versa. By adapting the proposed changes, a more effective use of available spectrum and technology can be achieved exploiting also the evolving penetration of more capable UEs (RAT, spectrum). This feature may also help to prepare strategies in spectrum auctions.

6. Concluding remarks

Mobile networks are increasingly complex with disparate radio access technologies and multiple layers. The increasing complexity and growing data traffic make operators call for support in order to cost-effectively and appropriately manage their networks.

We presented the key challenges for self-management solutions in future radio access networks as the SEMAFOUR project perceives them. These challenges are in line with detailed feedback from several major operators. Based on these challenges we propose a set of specific use cases which can be used to validate possible solutions for these issues. In addition we presented the SEMAFOUR vision of a future unified self-management system to address these challenges. The vision is based on extending and enhancing the current limited SON system to better handle the complex networks of tomorrow. It includes new 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 network-oriented performance objectives. In addition it provides a

DSS, which assists the network operator in handling both future upgrades of the network and SLAs.

The SEMAFOUR project will work on the use cases presented in this paper, in order to investigate the necessary design and algorithms for the envisioned self-management 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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