Coordination of Self-Organizing Network Mechanisms: Framework and Enablers

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Abstract. Future wireless access networks, e.g. LTE and LTE-Advanced, will be empowered by Self-Organizing Network (SON) mechanisms with the objective to increase performance, reduce the cost of operations, and simplify the network management. This article describes a management framework which enables the automatic, policy-driven coordination of SON control functions, and introduces future necessary evolutions that will allow to fully benefiting from the SON paradigm in operational networks.

Keywords: self-organizing network, network management, framework, automation, policy.

1 Introduction

The current wireless ecosystem is driven by the increasing complexity and heterogeneity of radio systems. New generation of advanced devices enables implementing different waveforms with a variety of modulation schemes, using flexibly different carrier frequencies with different power levels, providing Multi-Input Multi-Output (MIMO), iterative transceiver architectures etc. Controlling and setting such a system turns into a very complex combinatorial optimization problem. Radio network management is part of this problem, which is in vital need of a certain degree of automation and capability to learn. The skills needed for radio network administration forms a long list, ranging from maximization of user satisfaction through coverage, capacity and QoS/QoE optimization to OPEX reduction through more efficient use of resources, including simultaneous optimization of several radio resource management functionalities like intra-/inter-system mobility, interference mitigation, load balancing, admission/load control, energy efficiency etc. It is evident that the possibility to find such a combination is an impossible task. If, however, it becomes possible up to certain extent it would be an invaluable asset for an operator.

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With all these challenges, it is nearly impossible to do efficient network management in conventional ways. The networks are intractably complex and user demands are overwhelming. In this context, Self-Organizing Networks (SON) provide relief with autonomic management of network elements. Self-organization is an emerging paradigm in wireless communications. So far, most of the operational and management functions of the wireless networks have been centrally organized and require significant manual configuration, such as frequency planning, mobility management etc. However, the emergence of IP-based networks, with their decentralized congestion control and address auto-configuration has set a trend toward self-organized control functions. With the introduction of LTE in release 8 of the 3GPP standard in 2008 [1], several SON use cases have been standardized. Mobility management is one of these use cases, which optimizes the quality of seamless connection through multiple cells, frequencies and technologies by adjusting certain thresholds, offsets and timers. Another SON use case, namely coverage and capacity optimization, tries to find an optimum trade-off between coverage and capacity, through adjustment of transmission powers and/or scheduler parameters.

Although standalone SON use cases have been thoroughly treated so far, the impact of simultaneously active SON mechanisms on network behaviour and on high-level operator goals is not known and is difficult to evaluate. Therefore, interactions, dependencies and conflicts between SON autonomic functions need to be evaluated and a proper management framework need to be established. This must be complemented with a vertical analysis of the effects of different SON mechanisms on high-level operator goals and policies.

The upcoming deployments of LTE in major European countries with embedded SON features calls for a global solution to this problem. To the best of our knowledge, no such solution has been clearly proposed in the wireless community. A developing situation is that some vendors have already started working on the subject and are currently developing proprietary solutions, meaning that such solutions will appear soon on the market. The challenge lays in a unified coordination of (multiple vendors) SON mechanisms in the domain of a network operator. Thus, we propose to set the basis of this Unified Management Framework (UMF) and outline how its components (or enablers) will help in solving the SON mechanisms coordination issue that may arise in operational networks.

2 Unified Management Framework Principles

The Unified Management Framework (UMF) is a framework developed within the FP7 project UniverSelf [2] that aims at designing functions for self-management using a service-centric view and an “Everything-as-a-managed Service” paradigm with respect to operators and vendors requirements. In the perspective of the evolution of network management described above, three main aspects have to be addressed by the UMF.

First, UMF shall tackle the management of future networks so as to enable an open service environment for the development of new distributed and autonomic networking ecosystems. Indeed, the Telecom/ICT and Internet stakeholders will face high complexity, dynamicity and intertwined network relationships, therefore the importance of the openness of service environment cannot be underestimated since it facilitates the environment evolution through increased modularity, extensibility, portability and interoperability.

Furthermore, UMF shall enable the shift from resource-centric management to network and service co-management, providing operators with the possibility to easily extend, diversify and customize their catalogues of services without completely re-engineering their underlying networking infrastructures and technologies.

Finally, UMF shall address both deployed and new autonomic management systems. It should ensure compatibility with legacy solutions and newly proposed autonomic management systems, covering multi-vendor and multi-domain issues.

Such a framework intends to directly benefit the network management systems vendors, network element manufacturers, network operators and Internet service providers. The service-oriented ecosystem created by the models, processes and guidelines defined by the UMF will impact their products, tools and workflows. It will also foster the creation of new business opportunities and reduce the time-to-market of network services for the whole ICT industry. Consequently, end users will benefit from higher QoS and QoE and new services. Standard making bodies will also be fed with a new approach to engineering with technical criteria, methods, processes and practices related to management, control, operation and assessment of Future Networks. Finally, UMF will provide an open framework and guidelines for the development of new management solutions for Future Internet stakeholders in "business-driven, service and network management" and researchers. A set of guiding principles (Table 1) has been proposed in UniverSelf in order to start tackling the design of the framework.

Table 1. UMF principles and design implications

Unification/Federation	
Principle	Design implications
UMF will be architecture-agnostic in the sense that it will be able to cope with any type of management architecture including autonomic networking architectures that is those where elements of self-management, or perhaps completely self-managed systems are already present	The designer can no longer assume that the entire functionality of a system under design is known at the design phase; the boundary between functions (features) that are to be "On" is decided at run-time by the system itself.

Table 2. (*continued*)

Governance	
Principle	Design implications
UMF will bridge the gap between the high-level business goals expressing clients' performance objectives and the low level primitives addressing resources configuration. It will ensure a shift towards the governance of self-managed behaviours.	Conventional manager configures a managed object by low level (device-specific and network-specific) configuration policies to behave in conformance with certain service requirements while the managed objects will remain largely service unaware. Additionally, the governance shall configure the entire network infrastructure with service specific *goal policies*, leading to devices/functions to translate these semantically rich policies into low level configurations.
Interoperability	
Principle	Design implications
(Standardization): Major UMF aspects will be pushed towards standards in order to foster their spread, adoption, and interoperability thus going toward unification and federation goals.	Since the amount of different empowered features is not known in advance for each use case of interest, the design will inevitably face the state explosion issue typical for any concurrency.
Intelligence Embodiment	
Principle	Design implications
UMF will provide facilities for in-network management, i.e. empower network nodes and management tools with self-x functions. This feature and the respective platform and mechanisms are anticipated to enable the coping with evolution of technologies and management intelligence.	The self-x functions are those native to a respective device/function, therefore the design challenge is not to embed a generic knowledge but device/function-specific know-how that shall enable then the device to be intelligent in a domain-specific sense, i.e. better solve domain specific problems pertaining to the device/function.
Confidence/Trust	
Principle	Design implications
UMF will define processes and guidelines for building confidence and trust in autonomic systems. This point is crucial for the large adoption of autonomic networking by the ICT industry.	Trust must be verifiable not only during the design but at run-time as well, therefore additional non-functional provisions must be embedded into the system
Cost reduction	
Principle	Design implications
The main business targets of UMF are OPEX savings through reduction of human efforts and mistakes thanks to self-x functions and CAPEX savings through optimal resources allocation and utilization.	Both types of savings challenge the conventional design by the need not only to provide novel (non-functional) features into the system under design but also to guarantee that run-time operation is not degraded compared to existing designs.

3 Applying UMF Principles for SON Mechanisms Coordination

The *coordination of SON mechanisms according to operator policies* is one of the six core use cases that UniverSelf project has identified as expressing representative operator problems. The exact problem statement of the use case is the management of radio access networks by means of SON entities operating in a coordinated manner to enforce high level operator goals.

The SON coordination use case has been developed, in conjunction with the other use cases and taking into account the design implications of Section 2, in order to derive a set of requirements that could lead to a first functional view of the UMF. More specifically, three kinds of requirements have been derived: functional, non functional and business requirements.

Functional requirements have identified *functions*, which are required to solve the use case problems; *models*, consisting of information and knowledge bases, policy repositories, storage etc., that are required to fulfill the functions' operation; and *interfaces* for the realization of use case flows. These management functions have designated eleven functional blocks (FB), which are design blocks that exhibit great levels of reusability and cohesion irrespectively of the different, multiple use cases, and can be used to implement a core function of the UMF.

Monitoring (M_FB) is required for monitoring the network, service and customer domains and collecting measurements in order to find out if the desired performance is satisfied. *Situation Analysis/Diagnosis (SAD_FB)* analyzes events, such as network and business triggers (measurements, business goals etc) and triggers appropriate actions. *Candidate Solutions Computation (CSC_FB)* discovers and reasons about potential solutions (reparation/mitigation plans, (re)configuration) to be enforced. *Solution Selection and Elaboration (SSE_FB)* is the decision engine, which is also responsible for addressing coordination and resolving conflicts inside the same domain. *Configuration Enforcement (CE_FB)* identifies the relative equipment and applies the configuration decision after translating the command to device-specific language. *Solution Evaluation/Assessment (SEA_FB)* assesses the solution and its application and triggers for fine-tuning/optimizations if the level of operation is not the desired one. *Governance (G_FB)* allows the insertion of the business level goals through a human-to-network (H2N) interface and the notification of the operator about undesired and critical conditions. *Policy Derivation and Management (PDM_FB)* translates high level goals/objectives provided through the *G_FB* into low level, conflict-free, configuration policies over the network. *Cooperation (C_FB)* addresses the coordination and conflicts resolution among different segments/domains and between UMF and legacy systems. *Information and Knowledge Building (IKB_FB)* refers to any functionality handling dynamic knowledge, such as storing, retrieval, update, building through learning etc. Finally, *Profiles and Models (PM_FB)* represents static knowledge about network elements, user profiles etc. that is stored in databases.

The derived functional blocks may be aggregated to four Functional Groups (FG), each of one realizing a higher level management function. The Governance functional group includes the G_FB and PDM_FB, the Knowledge Management functional group contains the M_FB, PM_FB, IKB_FB and SAD_FB, the Intelligence functional group incorporates the SSE_FB, CSC_FB, C_FB and SEA_FB, while the Enforcement functional group has the CE_FB. A strong relation among these functional groups and UMF enablers, as identified by UniverSelf, namely *Governance, Information and Knowledge Management* and *Intelligence Embodiment*, is identified.

In order to address design issues, such as scalability, usability by operators, extensibility for new scenarios, stability etc. non functional and business requirements have been set. These requirements will be taken into account, in addition to the design implications of Section 2, in order to find out the best distribution of management functions among the management systems or network elements, thus resulting in an appropriate system view of the UMF.

After introducing the UMF management functions in terms of functional groups and functional blocks, the next step is to proceed with a possible mapping of these blocks onto the network topology and elements in the context of the *SON mechanisms coordination* use case. The network topology of this specific use case consists of a heterogeneous environment, including user terminals, eNodeBs, pico and femto cells, relays, etc. at a low architectural level and Network Management system (NMS), Operations Support System (OSS) at a higher level. However, only eNodeBs and NMS, OSS will be analysed here in detail since they are the main intelligent entities where the derived control and management functions will be mapped. Communication between eNodeBs is enabled through X2 interface and between eNodeB and NMS through Itf-N interface. In general, SON algorithms can be located in NMS or eNodeB or both of them. The same applies for some of the derived functional groups. Therefore, according to the location, the SON architecture can be centralized, distributed or semi-distributed.

However, in order to be consistent with the intelligent embodiment design implication, an attempt will be made to deploy at least the core function of the Intelligence functional group, i.e. SSE_FB, at the eNodeB level. Of course, it is inevitable, at least in the early deployment phase, to avoid having some management functionality at the NMS level, specifically for the more global and complicated functions. In next releases, UMF will provide a migration path to support the progressive introduction of self-x management features in the existing NE/EMS/NMS/OSS/BSS management chain and in particular, the embedding of intelligence to services and network domains, thus offering an in-band network management in an incremental approach.

Therefore, the mapping of the UMF management functions with respect to SON mechanisms coordination use case is depicted in Fig. 1 and is analyzed as follows.

Knowledge Management: it is located in both the NMS and eNodeB, but different functional blocks may be instantiated in each case. SAD_FB is only used in the NMS, in order to determine the involved SON entities based on the operator targets, since this needs to be done at a high layer. M_FB is located both in eNodeBs and in NMS, since existing measurements should be processed in both of them. Finally, IKB_FB is located in both NMS and eNodeB. NMS needs knowledge functionality about SON entities and their location (SAD_FB), already active policies (PDM_FB), bandwidth allocation and on how achieving efficient SON processes through coordination (SSE_FB). eNodeB needs knowledge functionality about SON coordination (SSE_FB).

Governance: it is located in OSS when G_FB and the H2N tool are involved and in NMS when the PDM_FB is used. PDM_FB intends to generate the SON entities specific policies based on the output of the SAD_FB that means the information about the involved SON entities and the operator targets. This functionality, related to governance and the translation of operator targets to SON specific policies, needs to be done at a high layer.

Intelligence: it is located in both NMS and eNodeB. When SSE_FB is involved, it resides both in the NMS (offline mode) and the eNodeBs (online mode), in order to coordinate the SON entities to enforce the policies derived by the PDM_FB. SSE_FB is actually the decision-making procedure and consists of various interacting, even possibly conflicting, control loops. Moreover, network performance problems are tackled through the SON coordination. When SEA_FB is involved, it resides in the NMS, in order to evaluate the SON process and coordination in an end-to-end manner and to trigger re-optimizations or for new operator goals when certain KPI thresholds are crossed and/or degradation exists. It is noted that evaluation is not explicitly introduced in eNodeBs, since it is considered that it is a typical, already existing prerequisite in SON. C_FB resides in the NMS and is used only in the case that different administrative domains exist, which are controlled by different NMSs, and there is a need for this functional block to assist the inter-domain communication among the source domain and other target domains.

Enforcement: it is not explicitly mapped somewhere, since the enforcement in SON takes place through the already existing, self configuration procedures.

At this point, we will focus on the functionality of SSE_FB, which represents the “steering wheel” of the specific *SON mechanisms coordination* use case. This functional block is the management function responsible for the simultaneous coordination of running SON mechanisms, since they are located in the same domain. If SON entities reside in different domains, the coordinator role will be assigned to C_FB. Different operation scenarios can be envisaged: the SON functionalities share the same or different (possibly conflicting) performance or QoS objectives, and act upon the same or different parameters. The SON algorithms should cover these four possibilities (same/different objectives/parameters), ensuring a stable and robust operation of the network. We must note that scalability, stability and robustness are thus guaranteed through the design of stable and scalable SON solutions, e.g. a SON entity within a network node should be capable of learning in an environment of other learning nodes, except for the overall UMF design. Such a SON mechanism is presented in Section 3.2.

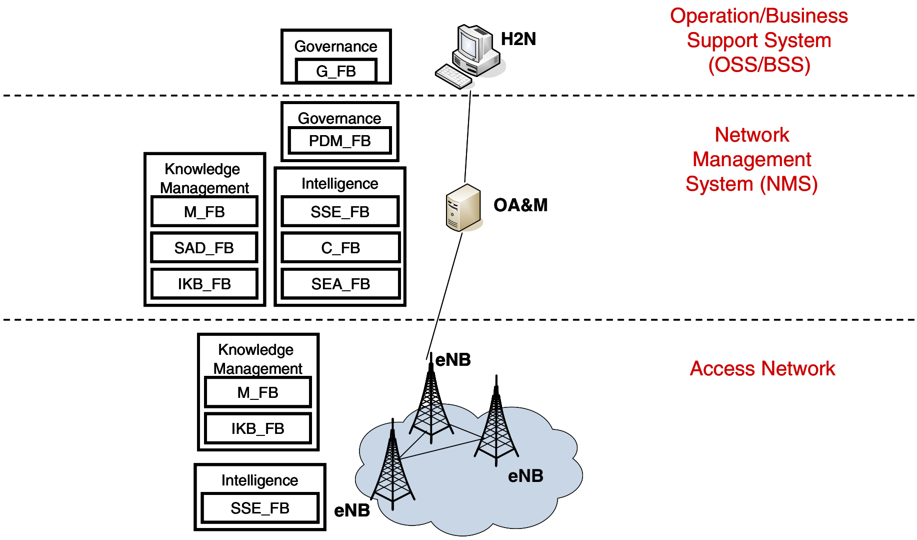

Fig. 1. Mapping of functional groups to the SON coordination network layout. Inside each functional group, the instantiated functional blocks exist, dependently on the location of the functional group.

3.1 Message flows between Functional Blocks

The triggering event consists of operator goals, which are inserted via a H2N tool (Governance Functional Group) at OSS, perhaps after a Violation_Notification from Intelligence FG (SEA_FB) at NMS. The GoalsProvision primitive carries these operator goals to the Knowledge Management FG (SAD_FB) at NMS and the SON_Determination primitive informs Governance FG (PDM_FB) at NMS about the involved SON entities. Then, Governance FG triggers the Intelligence FG (SSE_FB) either at NMS as an offline process or at eNB as an online process with SON-specific policies through PolicyProvision primitive. At this point of time, the SON coordination takes place via control loops and conflicts are resolved based on the provided policies. The parameters are also configured in a self and automatic way. Then, Intelligence FG notifies Knowledge Management FG (M_FB) at eNB for the metrics to be monitored via KPI_Determination. Knowledge Management FG at eNB reports to Knowledge Management FG (M_FB) at NMS the monitoring results (KPIs) periodically through KPI_Information and Knowledge Management FG at NMS sends KPI information to Intelligence FG (SEA_FB) at NMS either periodically (KPI_Information) or when there is KPI violation (KPI_Violation). Finally, the operator is informed through H2N tool (Governance FG) at OSS via a Violation_Notification message about a KPI violation.

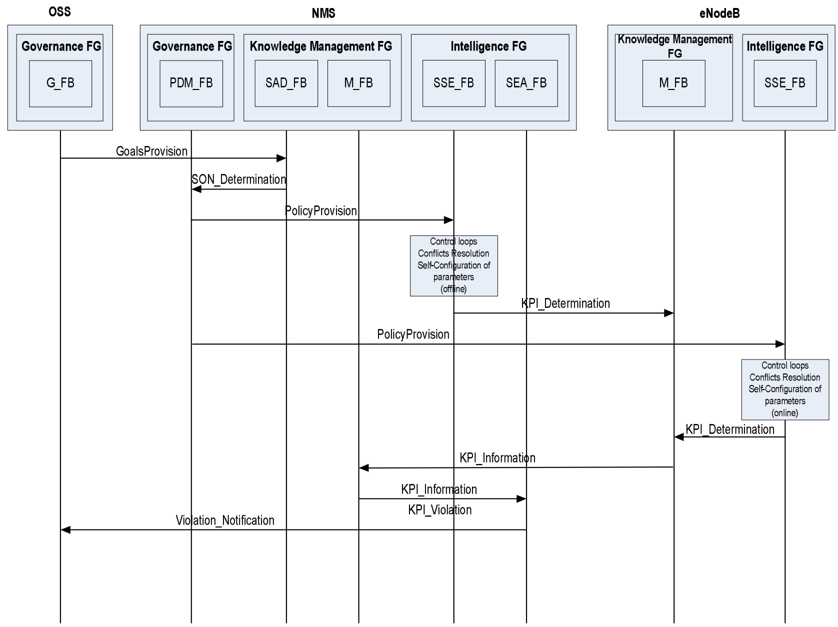

Fig. 2. Example of Message Sequence Chart between functional groups and functional blocks for the SON mechanisms coordination

3.2 Load Balancing for Resource Management of Control Plane Data

The dynamic management of Future Networks requires the modelling, incorporation and integration of suitable mechanisms and algorithms for the network decision making process. An important part of such procedure is the end-users' load-balancing, which is related to their decision-making requests (control plane data). Such challenge is closely related to SON and SON collaboration according to operator policies, dealing with the problem of designing distinct SON functionalities in network nodes to efficiently self-configure and self-optimize network resources. The SON functionalities at a given node (e.g. base stations) should allow self-adapting to varying operation conditions, in the presence of other self-organizing neighbouring nodes, to assure stability and scalability. To this end, the design of optimization techniques for the load balancing of users' requests is a key challenge.

In this direction, this present work deals with an appropriate model of the network decision-making process for mobile devices adaptation, assuming reconfigurable and autonomous mobile devices. The proposed algorithmic framework for the load balancing of users requests is based on the introduced metric of user satisfaction; such metric is a function of the network response time for serving the decision making requests. Such a framework is important for guiding the load balancing/relocation of mobile terminals so as to achieve offloading, based on the values of the user satisfaction.

This framework which is based on previous work [3], is extended with load prediction models that allow predicting future values of user satisfaction. More specifically, we consider the load-prediction models applied in Web-based systems [4],[5]. The latter are not based directly on resource measures but on the representation of the load behaviour of system resources (load trackers). Such models ensure that not only a limited view of the resources is provided but also a view of the behavioural trend. Specifically, the predicted values the user satisfaction are used to proactively trigger the load balancing of the decision-making requests to avoid the saturation of the computational resources.

Fig. **3.** Load Balancing for Resource Management of Control Plane Data: Basic Steps.

Presents the key steps of the load balancing algorithm. At first, the user satisfaction degree is dynamically computed during real-time based on network response time measurements, per class of mobile device. In addition, the predicted value of the user satisfaction is computed for specific future instances. Next, we define the user satisfaction threshold: a threshold for the lowest possible value of the user satisfaction [3]. If the user satisfaction is found to be lower than this threshold, then the requests reallocation procedure is triggered. In this work, we consider that the requests reallocation is applied in the neighbouring network nodes that handle similar requests. Thereafter, the most suitable network nodes are selected and the load balancing of the user requests' is finally applied.

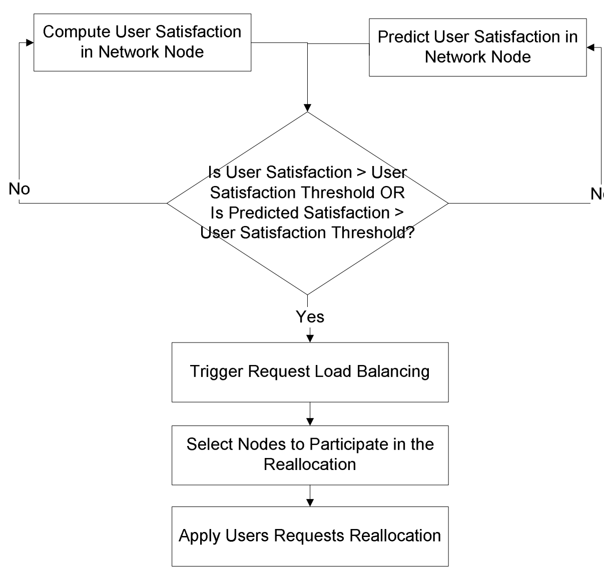

Fig. 3. Load Balancing for Resource Management of Control Plane Data: Basic Steps

Future steps of our work will focus on the detailed evaluation of this mechanism in a case study, considering a system model for the management of decision-making requests based on the UMF design and guidelines. In such a model, we assume two different types of physical entities: the mobile devices that generate the decision-making requests as well as the network nodes that are responsible for the user request management. Leveraging on our previous work in [3], the evaluation of this prediction-based load balancing mechanism targets two main goals: a) to evaluate the accuracy of the prediction with regards to the load balancing mechanism: this work will focus on the comparison between the actual and the predicted values of the user satisfaction or network response time and b) to investigate the gain of introducing prediction schemes in the load balancing mechanism. This may include the number of dropped user requests and other key network metrics. First results of the evaluation work show that the prediction of the response time/user satisfaction approaches very well its real value. For example the precision error that is defined as the relative error between the actual and predictive values of the response time is found to be less than 0.3. Therefore, the introduction of the prediction functionality in the load-balancing of the decision-making requests is expected to enable the proactive management of such requests, improving the network management procedure.

4 Conclusion

This article presents a preliminary approach on the design of the Unified Management Framework (UMF) and its application to the coordination of SON mechanisms in wireless access networks. The base principles of the UMF are proposed and a tentative mapping of the functional blocks/groups over the SON architecture is realized. An illustrative application on the load balancing for resource management of control plane messages is also presented.

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