Nokia Siemens Networks

Technische Universität München

Universität Augsburg University

Policy-based Coordination and Management of SON Functions

Tobias Bandh – bandh@net.in.tum.de
Technische Universität München

Raphael Romeikat – romeikat@ds-lab.org
University of Augsburg

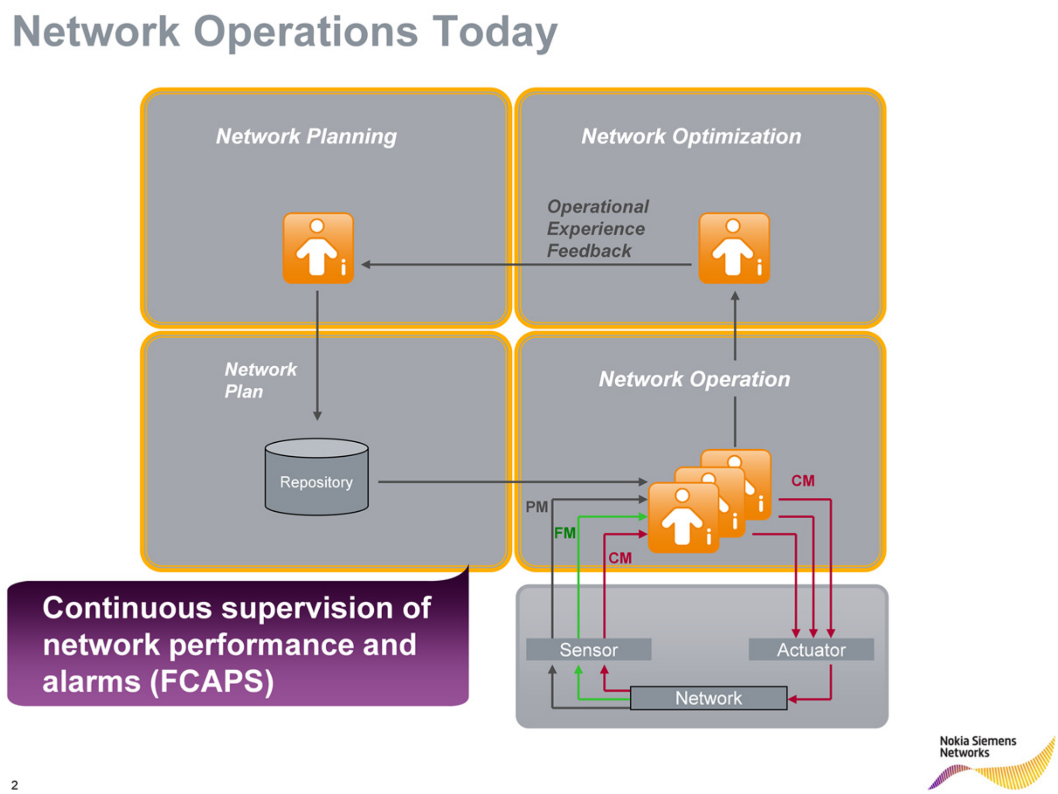
Henning Sanneck – henning.sanneck@nsn.com
Haitao Tang – haitao.tang@nsn.com
Nokia Siemens Networks Research

Abstract

Future wireless networks (LTE and beyond) will experience a continuous growth regarding the number of network elements with increasingly complex interrelations between the configuration of multiple network elements (NEs). A related trend is the seamless integration of multiple radio technologies into a single heterogeneous wireless network. Both developments increase network management complexity and require new management concepts with a very high degree of automation such as Self-Organizing Network (SON) concepts, which are currently discussed in the network operator (NGMN), research, and standardization (3GPP) communities.

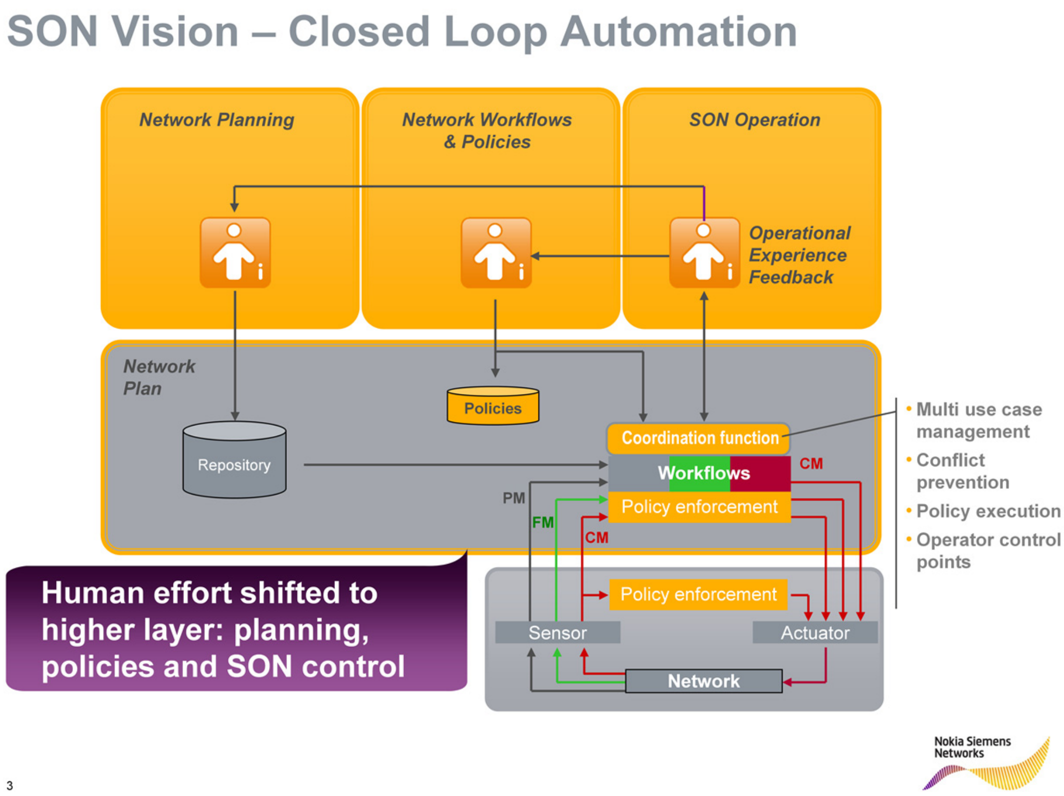
SON functions have to be coordinated and supervised in an automated way in order to enable a stable system operation with tight control over the system behavior by the network operator together with a high degree of automation. Based on a detailed analysis of the requirements for the coordination, a policy-based approach to realize the coordination-related decision making based on the network configuration and SON function context is presented. Results for two use cases (fully automatic hardware to site mapping and coverage & capacity optimization) are presented to show the applicability of the developed approach to diverse SON use cases.

978-1-4244-9220-6/11/$26.00 ©2011 IEEE



Managing radio networks is a complex task especially in cellular mobile communication systems. The complexity is even increased if several radio networks should be seamlessly integrated. Complexity arises from the number of NEs that have to be deployed and managed, but also from interdependencies between their configurations. In a heterogeneous network the variety of deployed technologies and their proprietary operational paradigms are difficult to handle. Configuration (CM), optimization (OM), performance (PM), and fault management (FM) require a high degree of expertise. Management tasks are typically semi-automated only and tightly supervised by human operators, which is time-consuming, expensive, and error-prone. Particularly correlating the knowledge established via the different "sensor" PM/FM/CM paths and linking it to the subsequent CM actions is still incurring a significant amount of manual work.

Network management is usually based on a centralized operation, administration, and maintenance (OAM) architecture. Configuration and optimization of NEs is performed centrally from an operations and maintenance center (OMC) with support of a set of planning and optimization tools. However, this still requires a lot of human interaction. Introducing new features through a software update or new NEs from different vendors requires changes in operational procedures. The staff uses their operational experience to find optimized configurations and they know when they have to diverge from standard procedures. Fault management procedures are also particularly based on operational experience.

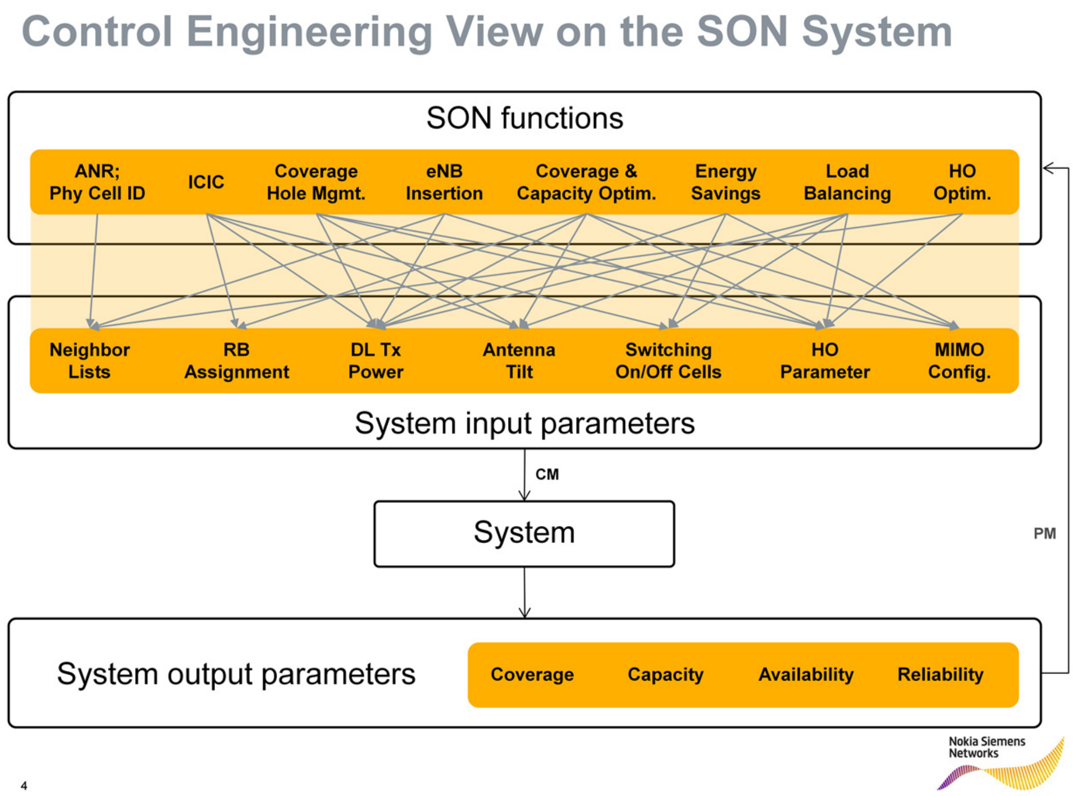


LTE/SAE is the standard for next generation 3GPP mobile network evolution. For the introduction of such a "Next Generation Mobile Network" [1], operators have expressed a strong request for the introduction of Network Management automation features to reduce operational expenditures (OPEX) while assuring a high service quality at the same time [2].

3GPP has addressed this with the standardization of a framework for Self-Organizing Networks [3]. The introduction of SON features aims at reducing the workload on the operation and maintenance staff in order to free them from time-consuming standard tasks so they are able to focus on crucial problems. Even more important, a higher level of availability is gained through the automation of operation and maintenance tasks.

The target is to gradually move towards a pure monitoring and guiding of the SON. Vendors are able to implement SON functions step-by-step according to NGMN requirements. Finally, only high-level guidelines need to be inserted and updated in the system instead of supervising the actual changes via CM manually. Thus the PM/FM/CM "sensor" paths are much more integrated together and linked to the CM actions.

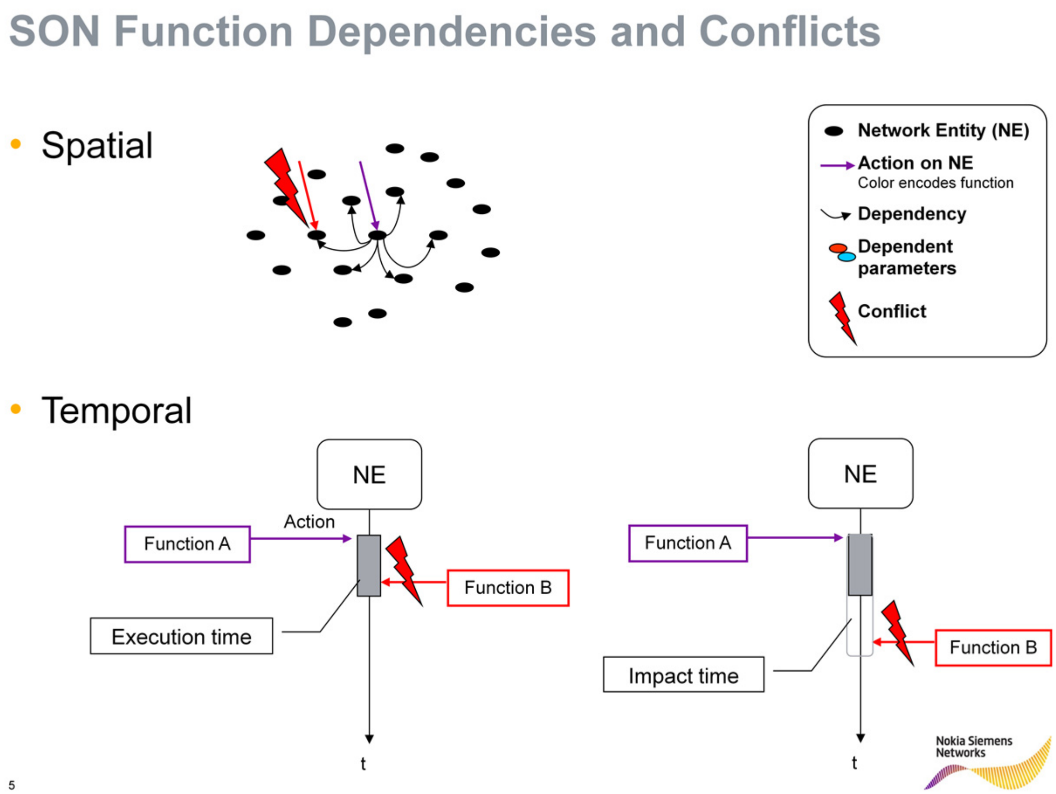
The building blocks to reach a SON-enabled system are a workflow execution system as a mean to for automated execution of SON functions and a policy system for automated decision making [4]. Policies control workflow execution and the adaptation of the control flow to the context. The usage of policies also allows to abstract from technical details and to change system behavior at runtime. Both components together assure the control of the human operator as well as the stability of the SON-enabled system where many functions are executed concurrently.



The figure shows how the general framework of control engineering can be mapped to the case of a SON-enabled network. The system itself is very complex and hence can only be modeled in a limited way. Therefore, in the design of an individual controller there is no simple "measured output" (PM data) to "system output" (e.g. coverage) relationship.

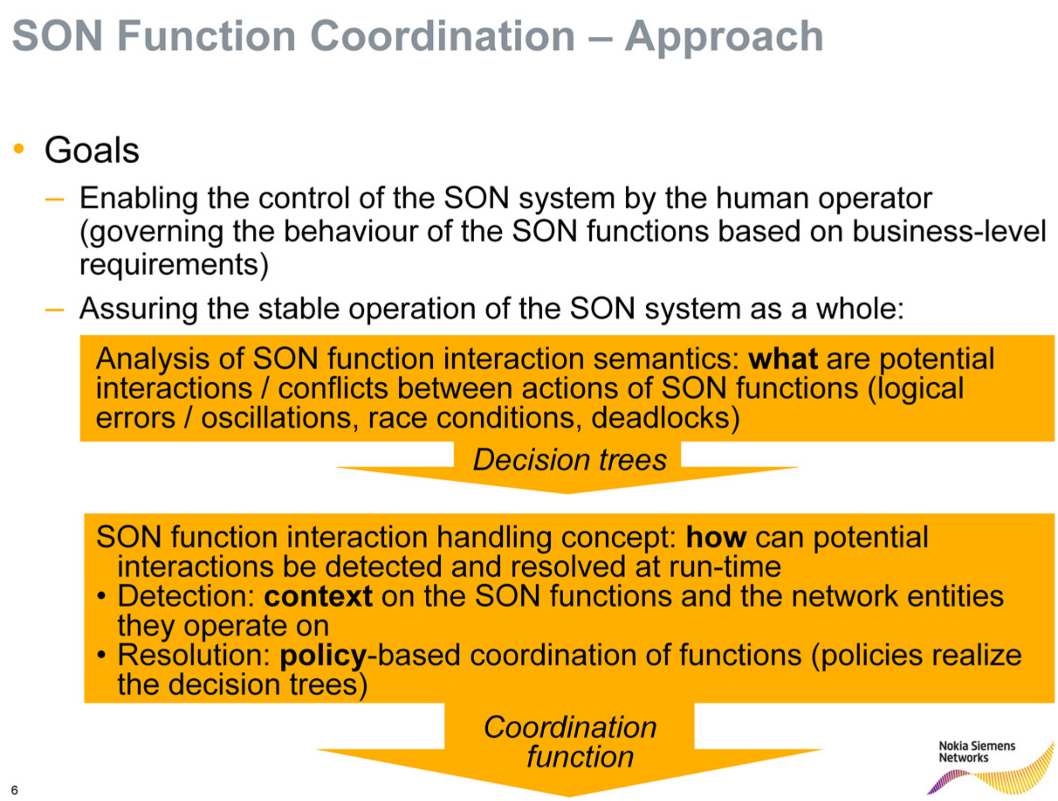
The overall state of the system is characterized by its output parameters like radio access capacity and coverage. PM conveys measurements in the form of key performance indicators (KPIs) to the controllers which are in fact the SON functions defined within the 3GPP framework (e.g. the Automatic Neighbor Relationship setup and Coverage and Capacity Optimization). Those functions manipulate rather few key system parameters like neighbor lists, transmit power and antenna parameters. Those parameters in turn influence usually more than one system output parameters at the same time. Thus, there are potentially many dependencies between the SON functions as can be seen from the figure. Therefore, the desired action from the perspective of an individual SON functions needs to be coordinated („interaction handling") with other potential actions from other functions before any action is committed via the CM to the network.

Individual SON use cases are addressed in different research projects like the EU FP7 project "SOCRATES" [5]. SOCRATES also works on a high-level coordination framework. In this paper we develop a concrete solution within that framework. Previous research has already outlined briefly the need for SON coordination, proposing to use policies for decision making [6]. However, that work has not yet considered the 3GPP SON framework for LTE/SAE as well as general applicability to a wide variety of use cases.



In radio access both the spatial and temporal dependencies between NEs and especially between cells in cellular network have to be considered:

- Actions on a single network entity may have impact on adjacent network entities. Other actions on those network entities may result in a conflict and thus instable and undesired state of the system. Cells where a SON function possibly has impact are called "impact area" of that function. Note that the dependency does not necessarily relate to the same parameter but can also refer to some inter-parameter dependency. It can even relate to physical system characteristics such as coverage, which were introduced in the previous figure as "system output parameters".
- The mentioned conflicting actions of course have some temporal characteristic, i.e., only within a limited time window actions have to be considered as interacting. This time window is called "impact time" and is not necessarily limited to the execution time of a function, but considers the actual impact to a measurable physical characteristic of the system and may last for a longer time period.



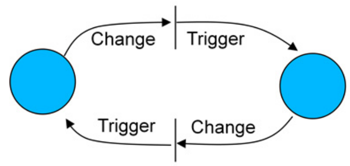
SON function interaction semantics are firstly expressed as decision trees. Policies are then employed to realize those decision trees and implement them into a real system, potentially together with other policy-controlled system functions [7].

Policies represent reaction rules that specify the reactive behavior of a system. The event-condition-action (ECA) model is a common way to specify policies. A policy correlates a set of events, a set of conditions, and a set of actions to specify the reaction to a certain situation. The conditions are evaluated on the occurrence of an event and determine whether the policy is applicable or not in that particular situation. The actions are only executed if the conditions are met.

Policy-based management has gained attention in research and industry as a management paradigm as it allows administrators to adapt the behavior of a complex system without changing source code or considering technical details. Policies define the desired behavior of a system in a declarative way and therefore allow to control a complex system on a high level of abstraction. A system can continuously be adjusted to externally imposed constraints by changing the determining policies.

SON Function Coordination – Oscillations

- Oscillation is a major danger in a system with autonomically acting entities (SON functions)
  - A change performed by a SON function triggers a second SON function and vice versa



- Coordination function is used to prevent oscillating behavior
  - Prioritization of SON functions
  - Impact time: assure stabilized KPI values
    - Highest risk for oscillating behavior is between a performed change and its visibility in the KPIs
- SON operation detects design errors in SON functions or coordination function that cause oscillating behavior

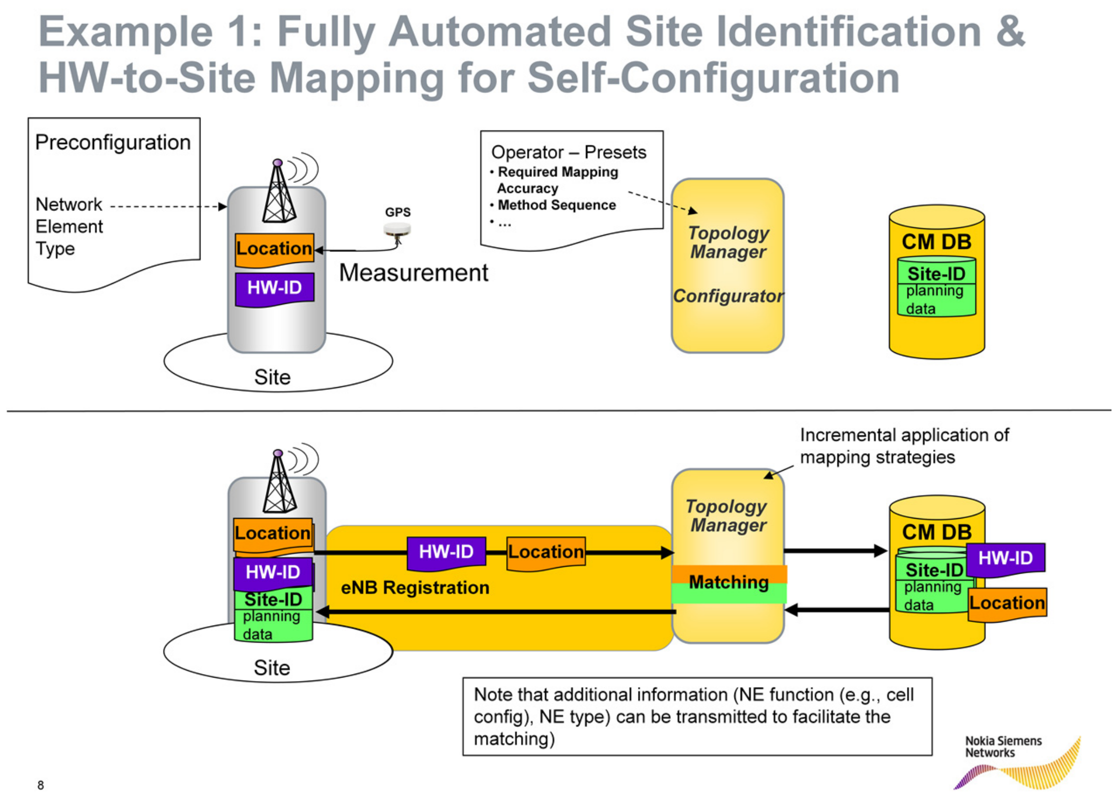
7

In any autonomic system oscillation is a great danger. Oscillation occurs if two or more autonomous functions detect the output of the other function as a problem and try to fix it. Through this interrelation they operate in a loop unless they are interrupted by another entity which detected the loop. Therefore, oscillating SON functions are handled explicitly in our approach.

For this purpose, several countermeasures are combined to defend against oscillations. The interrelations of different SON functions are captured within the coordination function. The countermeasures are mainly based on two parts:

- Priority: The coordination function takes care of the priority of the functions and assures that on the same target cells higher priority functions are executed while lower priority functions are not executed as long as the higher priority ones are still active. The coordination function considers a function active from the moment it is acknowledged until the end of its impact time.
- Impact Time: There is a noticeable delay between the time a function takes some actions and the time these changes are visible within the KPI values. The impact time is chosen in a way that all changes performed by the function have taken effect and the KPI values have stabilized again. This assures that other functions will not use the unchanged or partly changed KPI values as input and thus will not cause oscillating behavior.

As long as all SON functions are designed properly the coordination function is capable to prevent oscillating behavior. If not, the SON operation as shown on slide 3 serves as a second line of defense. There could be additional SON functions that monitor requests received at the coordination function, which checks whether there are returning requests for the same functions on the same targets. Such functions can then either have a direct interaction with the coordination function or request human interaction.

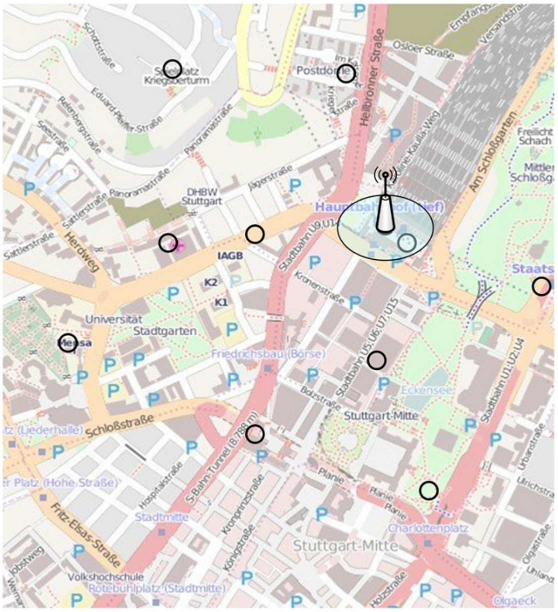


Deploying new base stations is a very complex and expensive task. After a long preparation phase with a lot of interactions between operator and vendors, the NEs are set up on-site where they will receive a location and hardware-specific configuration. The operator is informed about a certain hardware at a specific position which enables him to continue with the configuration. The major disadvantage of this way of deploying a base station is that it is hardly possible to deploy hardware at a different place as initially intended. [8] provides a concept where an off-the-shelf base station is shipped without any pre-configuration. After installation and connection to electrical power and data network, the location is measured and the self-configuration process determines the configuration based on the network plan details for that location.

The question here is how the site contained in the network plan can be determined from the location information which is transmitted to the OAM system together with the hardware ID. Determining the site based on the measured geographical position with a very high probability is a challenging task for several reasons. Even with satellite-based positioning system such as GPS, still for a small percentage of NEs the identification of a particular site is not possible. Especially co-located sites of the same operator in urban areas are hard to handle as several NEs may be physically installed at the same site very close to each other. Furthermore, GPS measurement may deviate scores of meters in urban areas with a high building density. This mandates to enable context-sensitive strategies for an effective hardware to site mapping. Those strategies consider configuration information about the sites within the network in order to identify the desired site.

Site identification is realized as SON function and for this reason it is important to coordinate site identification with other SON functions. The coordination function triggers the site identification process and handles interactions with other SON functions. Within site identification the coordination function triggers the incremental application of mapping strategies. Policies specify which strategies should be applied in which sequence. At any time the operator may change the policies in order to change the available strategies and their sequence of execution.

Example 1: Fully Automated Site Identification & HW-to-Site Mapping for Self-Configuration



Site Planning
(Each site has a distinct Site-ID)

Deploy Network Element
(NE has distinct HW-ID)

Establish Position
(E.g. GPS Measurement)

Map Position to Site
(No distinct Mapping possible)

Execute additional site identification means (context)
Reduce set of potential sites until distinct mapping possible
Operator presets (→ policies) specify available methods
Operator presets (→ policies) specify sequence of methods

Map HW ID to Site ID

Start Site and HW Specific Configuration

9 Nokia Siemens Networks

Automated site identification with an on-site GPS receiver works as follows:

- An NE is installed on the site.
- The installer thus triggers the auto-connectivity setup at the NE.
- The NE queries the GPS receiver for the location coordinates.
- The NE establishes a secure connection with the Configuration Server (CS) and sends an announce-ment message including the measured GPS location coordinates, the hardware ID, and possibly additional parameters that distinguish the NE from nearby NEs (e.g. NE type, detected hardware module types) .
- The CS uses a geographic matching algorithm and the geographic site plan of the planned NEs to determine the site ID related to the received GPS coordinates. The algorithm shall include a tolerance radius around the planned site locations for coping with uncertainties of the GPS measurement and the GPS receiver location. When there is ambiguity between multiple sites, the additional information of the NE and/or the rollout time may be used to determine the actual site ID.
- The CS accesses the configuration database to enter the hardware ID in the database record related with the site ID and to retrieve a subset of the planning data related to the site. The planning data subset is then forwarded to the NE.

The quality of the identification to the required level until a mapping is unambiguous is accomplished by adding operator-specific knowledge to the system. A mapping strategy consists of a set of additional means and the strategy (i.e. sequence) how they are applied. This can easily realized with policies. Examples for additional site identification means are:

- remove_all_km: Removes all sites that are further away than a given distance.
- remove_other_types: Removes all sites from the candidate set, that require other NE types .
- remove_enabled: Removes all sites from the candidate set, which already set-up with an active NE.
- closest: Selects the site closest to the given geo-position.
- 80_20: Compares the ratio of the distance of the two closest sites and can be used instead of closest.
- askOperator: In case no mapping can be made, this fallback strategy queries the operator to perform the mapping.

Example 2: Fully Automated Coverage and Capacity Optimization

- Modification of cell sizes to
  - reach full coverage
  - balance load and optimize the per cell capacity
- Two independent SON functions realize the CCO
  - CCO(TXP) ➔ Changes transmission power
  - CCO(RET) ➔ Changes antenna tilt
- Both functions influence cell size / coverage area
  - Concurrent execution on the same cell not possible
- Requires coordination of functions to avoid negative impacts
  - A request for a configuration change by a SON function causes an evaluation of the network context
  - The request is acknowledged (ACK), rescheduled (RESCH) or discarded (NACK)
  - An acknowledged change might be rolled back (RB) later

10

Nokia Siemens Networks

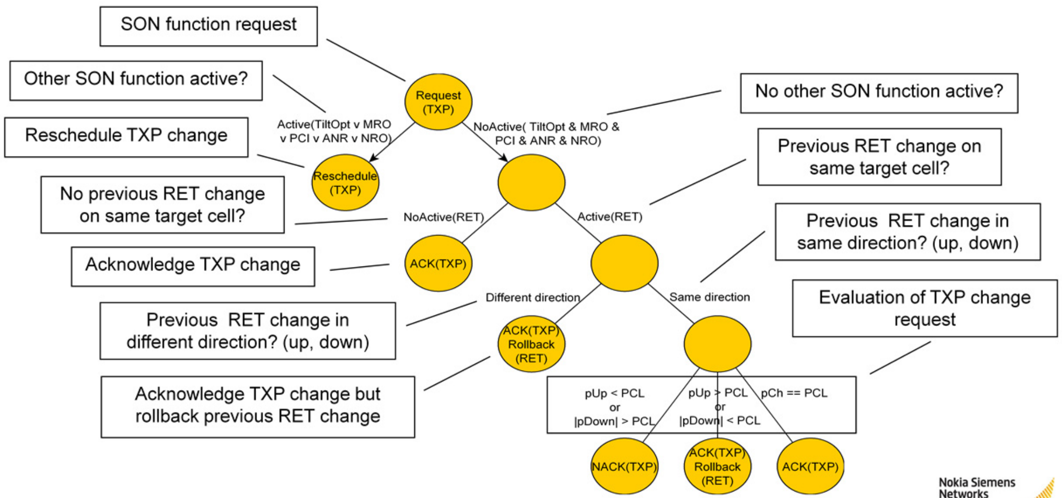
Coverage optimization is an important task within cellular networks. It is important that cells of the network provide a complete coverage without areas having no coverage at all. The coverage are of each cell is determined through multiple factors.

- Position: Location and direction of an antenna are the main determining factors for the coverage area of a cell. These parameters are preplanned and are almost not adjustable after deployment as this would require expensive human on-site intervention.
- Transmission Power: Later adaptations of the transmission power (TXP) have a direct impact on the size of a cell's coverage area. Adaptations can be performed remotely through the operation and maintenance system.
- Tilt: There are two ways to adjust the tilt of an antenna, either mechanically or through electrical changes. A rough mechanical adjustment is done when the antenna is deployed. Later adaptations of the antenna tilt are done through electric changes within the antenna called Remote Electrical Tilt changes (RET). These changes can be performed remotely by operation and maintenance staff.

In order to optimize coverage within the network, usually a sequence of power and tilt adaptations is used since these can be executed remotely. After each change the situation is re-evaluated through the analysis of measurement reports. The results of this evaluation are used to determine whether additional adaptions are required or not.

Example 2: Fully Automated Coverage and Capacity Optimization

- Analysis of SON functions produces solution-agnostic decision trees
- Step by step guideline for acknowledgement or discarding of SON function execution request



11

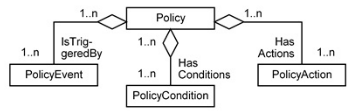
Decision trees show the required decision steps for the coordination of a SON function towards other SON functions. The trees are organized as follows:

- Root node: a SON function execution request to be processed.
- Edges: conditions to be checked.
- Leaves: decision actions to be executed.

For each occurrence of a TXP or RET change request the decision tree is traversed. Starting from the root of the tree the decisions are taken based on the current context. Depending if there has been a previous TXP or RET change for the same cell, the new request is compared to the previously executed changes. Based on this comparison a decision is taken for the requested change. This decision may be one out of ACK (acknowledge the requested change), NACK (reject the requested change), or RESCH (reschedule the requested change to a later point in time). Additionally, the previously executed change can be rolled back before the current change is executed.

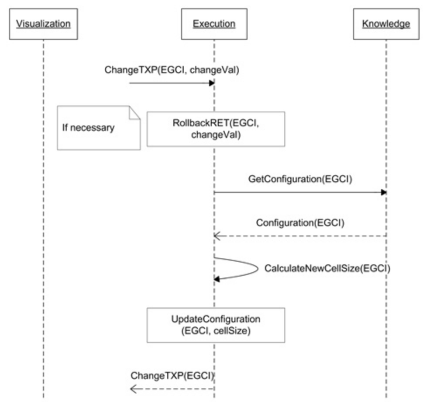
Example 2: Fully Automated Coverage and Capacity Optimization

- Trigger policy for TXP (ACK)




```
policy event: root/event/workflow/ExecuteTXP;
       condition: [ :property :changeVal |
         (root/conditionChecker noActiveTXP:property) |
         (root/conditionChecker lastActiveRETWithDifferentDirection:property changeVal:changeVal) |
         (root/conditionChecker powerConditionTXP:changeVal)
       ];
       action: [ :property :changeVal |
            root/actionExecutor changeTXP:property changeVal:changeVal
       ];
       active: true.
```

- SON function for TXP



12

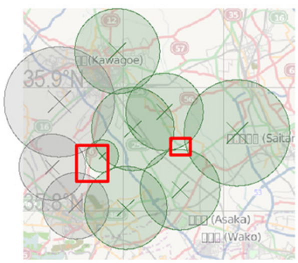
The decision trees are mapped into trigger policies. Three policies for TXP and three for RET requests are sufficient, each one representing one out of the possible decisions. Those policies represent the decision logic to make the decision whether to execute a change request now, later, or not at all. As soon as the change request is to be executed, they trigger the basic workflows for TXP and RET requests. The second decision that has to be taken is whether there is a rollback required or not. Therefore both basic workflows include a rollback request, which is executed as an additional subworkflow via another trigger policy.

In the example shown above, a SON function for CCO has made the internal decision that the transmission power at a cell should be changed (the specific algorithm how to come to that decision is use case specific and should not be part of the SON coordination). This change request is announced by an event which then triggers the evaluation of the TXP policies. The policies regard the context and make a decision for the TXP change request. If the decision is ACK, the actual change is performed by the SON function for TXP shown above. In the example above the respective workflow involves two different entities (Execution and Knowledge module) of the employed experimental system.

Example 2: Fully Automated Coverage and Capacity Optimization

- Result with coordination: optimized coverage

- Result without coordination: coverage holes remaining



Change	Value	Cell	Coordination
RET	-1	18	ACK
RET	-1	17	ACK
RET	-0.5	16	ACK
TXP	0.25	20	ACK
TXP	0.25	23	ACK
TXP	0.4	25	ACK
TXP	-0.6	16	NACK
TXP	0.35	17	ACK, Rollback
TXP	0.2	19	ACK
TXP	0.3	18	ACK, Rollback

The figure shows an example where the experimental system for SON function coordination is connected to a radio network simulator. SON functions for Coverage and Capacity Optimization (CCO) permanently analyze the situation in the radio network and propose TXP and RET changes respectively.

Based on the coordination logic implemented in the policies, changes which are undesired from a system level perspective (rather than an individual SON function perspective) can be detected and blocked (NACK) or rolled back respectively (Rollback). In the example above, TXP on cell 16 is rejected due to the previous RET on cell 16 which is the preferred change for such a case. TXP on cell 17 triggers a rollback of the previous RET on cell 17. TXP on cell 18 triggers a rollback of the previous RET on cell 18.

Without coordination, finally some coverage holes (as well as capacity issues) remain due to the undesired interaction between the TXP and RET functions. In the visualization only the coverage is shown whereas in the actual simulation both coverage and capacity are considered in the optimization.

Conclusions

- Automation of network management is crucial for the introduction of next generation (mobile) network technologies
- Control by the human operator as well as stability of the automated network management system is assured
  - High efficiency through parallel SON function execution
  - Conflicts in case of common impact area and impact time are avoided
- Policy-based management and coordination of SON functions provides framework for
  - Automated enforcement of "operator presets"
  - Automated conflict avoidance based on context

14

Nokia Siemens Networks

References

[1] H. Akhavan, T. Geitner, H. Dr. Lennertz, Y. Sha, T. Utano, and B. West, Next Generation Mobile Networks – Beyond HSPA & EVDO – Whitepaper, Technical report, NGMN Ltd., 2006.

[2] Vodafone, T-Mobile, NGMN Operations Requirements, Top ten network operations requirements for multi-vendor, multi-technology environment, Rel. 1.0, OPREQ-2009-01, TM Forum, December 2009.

[3] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Telecommunication Management; Self-Organizing Networks (SON); Concepts and requirements (Release 9), 3GPP TS 32.500, December 2009.

[4] H. Sanneck, C. Schmelz, T. Bandh, R. Romeikat, G. Carle, B. Bauer, Policy-driven Workflows for Mobile Network Management Automation, in 6th International Wireless Communications and Mobile Computing Conference (IWCMC), Caen, France, June 2010.

[5] Mehdi Amirijoo, Andreas Eisenblaetter, Remco Litjens, Michaela Neuland, Lars Christoph Schmelz, John Turk, A Coordination Framework for Self-Organisation in LTE Networks, submitted to 12th International Symposium on Integrated Management (IM) 2011, Dublin, Ireland, May 2011.

[6] Javier Baliosian, Françoise Sailhan, Ann Devitt, Anne-Marie Bosneag, The Omega Architecture: Towards Adaptable, Self-Managed Networks, in 1st Annual Workshop on Distributed Autonomous Network Management Systems (DANMS), Dublin, Ireland, June 2006.

[7] J. C. Strassner, Policy-Based Network Management: Solutions for the Next Generation, Morgan Kaufmann Publishers, San Francisco, CA, USA, 2003.

[8] H. Sanneck, C. Schmelz, E. Troch, L. De Bie, Auto-Connectivity and Security Setup for Access Network Elements, in 11th International Symposium on Integrated Management (IM), New York, NY, June 2009.