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Self-Organizing Networks in 3GPP: Standardization and Future Trends

It is important that integrating and operating new and existing network nodes require minimal manual efforts to control OPEX. Consequently, considerable industry momentum has built recently to develop Self-Organizing Network features that can automate mobile network deployment, operation and maintenance.

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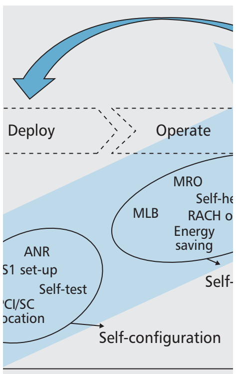

Abstract

Self-Organizing Networks (SON) is a common term for mobile network automation, critical to the cost-efficient deployment, operation and maintenance of mobile networks. This article provides an overview of SON standardization in 3GPP, including both existing and planned functionalities. It also provides an operator perspective on the relevance and use of 3GPP SON functionalities at different stages of the network design-and-operations cycle. In the long-term it is envisaged that automation will become a natural component in network operations, although the success of SON will depend on automation's benefits in relation to its cost.

Introduction

Recent developments in mobile networks have been driven by the insatiable demand by users for high-speed data. This has led mobile operators to deploy ever more complex networks. In turn, mobile operators now face the challenge of managing these increasingly complex networks comprised of multiple Radio Access Technologies (RATs), different cell types and users with a variety of QoS requirements. At the same time the income of the mobile operators is, typically, decreasing. Thus, it is important that integrating and operating new and existing network nodes require minimal manual efforts to control OPEX. Consequently, considerable industry momentum has built recently to develop Self-Organizing Network (SON) features that can automate mobile network deployment, operation and maintenance.

Within the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) standardization, SON was among the early system requirements; SON features were included in the first 3GPP LTE release, Release 8 [1, 2]. SON work in 3GPP has been inspired by existing SON studies and the set of requirements defined by the operators' alliance, Next Generation Mobile Networks (NGMN) [3]. In recent literature, SON has been described in [4] and [5]. SON is also related to Minimization of Drive Tests (MDT) [6].

A major driver for mobile operators implementing SON is to decrease CAPEX and OPEX in all phases of the network engineering life cycle: planning, deployment, and operation. The SON features also aim to enhance network performance. The use of SON is crucial, if not inevitable, for most operators running multi-RAT, multi-vendor and multi-layer networks in which an overwhelming number of parameters have to be configured and optimized. For SON to be attractive to mobile operators, its benefits, including both performance improvement and CAPEX/OPEX reduction, should outweigh the cost to implement and manage SON-related functionalities. Towards this goal, operators have a number of high-level objectives for each phase of the network engineering life cycle:

1 **Planning** of new sites (or extension of existing ones) should be as easy, time- and cost-effective as possible, yield the fewest number of sites (or the most cost-effective deployment) for a desired performance, and be based on sufficiently accurate information.

2 **Deployment** of new sites should be as easy as possible with the lowest effort and cost—i.e,"plug and play"—and with no interoperability issues.

3 **Operation** of the network(s) should also be as easy as possible with the lowest effort and cost, allow for quick and effective identification of a problem and its cause, ensure immediate (and preferably automatic) reaction to problems (for example, self-healing and self-optimization), and yield the best possible performance and optimal use of the deployed resources.

An overview of SON functionalities and where they fit in the network engineering life cycle is summarized in Fig. 1. This figure shows that operational efficiency for mobile operators is expected to increase as new SON features become available. By operational efficiency, we mean efficiency in cost and effort spent in planning, deployment and operation, as well as network performance.

COMMUNICATIONS STANDARDS

This article provides an overview of SON 3GPP standardization, including its relation to MDT and its expected use in the three network engineering phases. First, existing SON solutions in 3GPP (up to Release 11, completed in early 2013) are described. Following that an overview of ongoing SON standardization (i.e., Release 12, expected to be completed at the end of 2014) and a future vision for SON is presented. Finally, we provide a perspective on how these solutions are relevant to mobile operators, including potential challenges.

Existing SON Mechanisms in 3GPP (up to Release 11)

SON has been discussed as a key enabler of network automation from the very start of work on the LTE Evolved UTRAN (E-UTRAN) specification. The work has materialized as requirements and policies at node behavior level and inter-eNodeB (eNB) signaling procedures, as well as User Equipment (UE) measurements

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and reports. The E-UTRAN (Fig. 2, right) is maintained and supervised via the network management (NM) system (Fig. 2, left).

The operator interacts with the network at a high level through the NM system, which in turn interacts with the domain manager (DM) through the standardized Interface-North (Itf-N). The DM manages individual network elements (NEs), e.g., eNBs, through the Interface-South, Itf-S.

As described in [2], SON functions can be classified into different types, according to how they are mapped onto the network architecture.

- **NM-centralized SON** operates to meet centralized policies defined in the NM, reconfiguring NE parameters based on network information fed back from the NEs. It is based on the performance indicators and policies defined in the OAM specifications in 3GPP.
- **Distributed SON** is implemented in the NEs (typically eNBs in the case of E-UTRAN, and the Radio Network Controller (RNC) for the UMTS Terrestrial Radio Access Network (UTRAN)). Policies are received from, and KPIs provided to, the NM through the DM over the Itf-N/S interfaces. Inter-NE signaling takes place over standardized interfaces.
- **Hybrid SON** is essentially a combination of both NM-centralized and distributed SON functional components.

In the rest of this section we survey existing SON features and describe them in relation to the management architecture. Specifically, we focus on the additions in Release 11.

Self-Configuration

The initial configuration of network elements in a mobile network is complicated by a large number of parameters. Handling configuration manually is tedious and time consuming. This is an obvious candidate for automation because network nodes typically have common values for large portions of the configuration settings..

In self-configuration network elements may be associated with an initial set of site-specific parameters in an optional planning step. This set of parameters may be configured through the 3GPP automatic radio configuration data-handling function (ARCF), and may include cell identities, pre-configured neighbor relations, antenna configurations, transmit power levels, operational carrier, etc. The ARCF, together with any software upgrades, are transferred to the eNB in the self-configuration installation procedure once connectivity has been established. After self-testing, the eNB is operational and ready to serve mobile terminals.

Automatic Neighbor Relations (ANR)

Traditionally, a major configuration/optimization cost for operators has been the manual generation of neighbor relations between cells. This depends on the LTE ANR function located in the eNB. It supports management of neighbor cell relations within E-UTRAN, between E-UTRAN and UTRAN and from E-UTRAN to GERAN and CDMA2000 cells. Based on the UE ANR feature, an eNB or an RNC can request a UE to decode neighbor cell system information and report the decoded information back. Based on this information, the eNB can determine a unique cell identifier for the neighbor cell. This means that the serving eNB has sufficient information to initiate a handover to

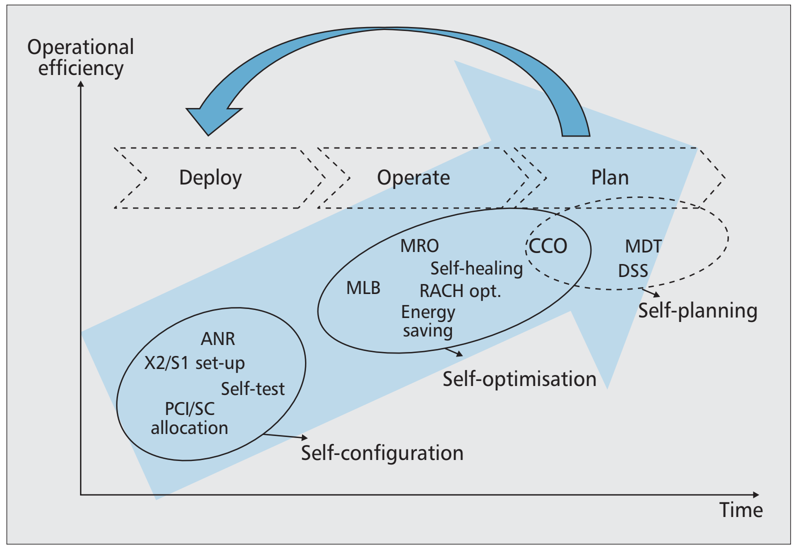

Figure 1. Evolution of SON features.

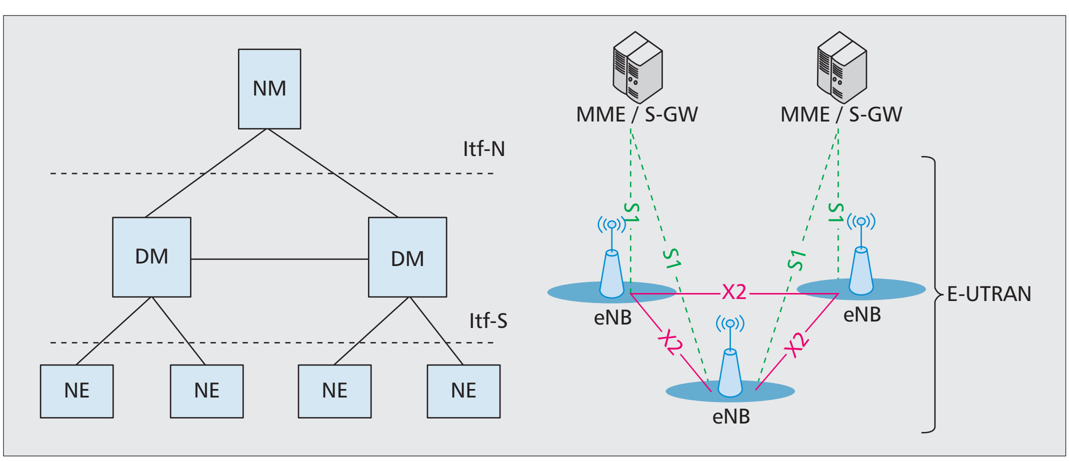

Figure 2. 3GPP network management architecture (left) and E-UTRAN architecture (right).

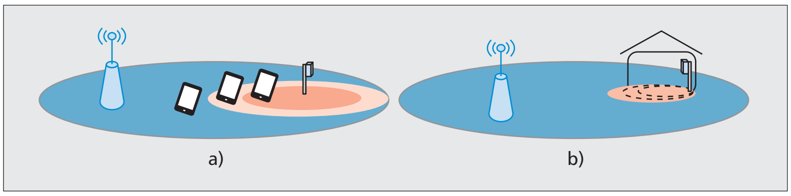

Figure 3. Load balancing between a macro cell and a small cell by adjusting the small cell coverage area via adjustments of a) a range expansion bias, and b) the small cell transmission power.

the discovered cell. Optionally, the eNB may further use the unique cell identifier to retrieve connectivity information from the neighbor base station via S1 eNB/MME configuration-transfer procedures and initiate establishment of an X2 interface. The evident advantage of ANR is that by using UEs to create and update neighbor relations the whole process can be completed automatically. Given the number of UEs in a network, this method is quicker, more reliable and cost effective than drive tests or manual configuration.

Automatic Cell Identity Management

Mobility in 3GPP networks is based on UE-assisted reporting of physical cell identifiers (PCIs) that preferably should be locally unique. Non-unique PCIs can lead to *confusion* (a cell has two or more neighbor cells with the same cell identifier) or *collision* (adjacent cells have the same cell identifier). PCI confusion/collision can be detected via the UE ANR procedure. The OAM system, notified of the detected PCI confusion/collision, can initiate a centralized PCI reassignment mechanism. This proposes a new PCI to the cell based on the neighbor-relation information in the OAM system. Alternatively, the OAM system may provide the eNB with a set of available PCIs to select from, and authorize the eNB to select an alternative PCI, in consideration of assigned PCIs in surrounding eNBs.

Random Access Optimization

The main purpose of the random access procedure is for UEs to notify their presence to the network and establish uplink time synchronization with it. In the procedure, the UE will select a preamble waveform, an access slot and a transmission power. These parameters are subject to optimization to meet requirements in terms of:

- *Access probability*, which is the probability of a UE having completed access after a certain number of random access attempts, or
- *Access delay (AD) probability*, where access delay is defined as the time duration for a random access procedure to complete once it is initiated by a UE.

To assist RACH performance estimation and optimization, the UE can be instructed to provide a RACH report to the eNB after a completed access attempt. This solution is based on UE reports because the UE can monitor radio-related issues which the network may not be aware of. Hence, similarly to the ANR function, this feature makes use of UE monitoring and reporting capabilities.

Mobility Robustness Optimization (MRO)

Robust mobility support is central to mobile networks and MRO is a key SON feature. MRO requirements for intra-LTE mobility are specified in terms of acceptable mobility failure rates while avoiding unnecessary handovers as much as possible. The corresponding requirements for handovers can also be formulated within any RAT or between any two RATs.

The LTE MRO function can be located in the eNB. The handovers are UE-assisted, which means that the UE is configured by its serving eNB to send a Measurement Report (MR) once a reporting criterion is met. Upon receiving a measurement report including information about the candidate cell triggering the report, the serving eNB may initiate the handover procedure to the target cell via X2 or S1 signaling. If the handover fails, the UE will try to re-establish the connection to the radio access network or move to idle mode and reconnect at a later stage.

Recent additions to UE Radio Link Failure (RLF) reports in Release 11 include feedback about the time elapsed since failure (e.g., for removal of stale reports) and information and signaling to detect inter-RAT mobility failures. Similarly, a handover (HO) report can be sent from a different RAT to E-UTRAN to indicate an unnecessary inter-RAT HO. In such cases, upon indication from the source E-UTRAN and after a completed handover, the target RAT configures the UE with inter-RAT measurements of cells in the source RAT (E-UTRAN). If the coverage of one or more E-UTRAN cells is evaluated as acceptable for a specific time after the HO, then the inter-RAT HO is considered unnecessary. The same mechanism allows E-UTRAN to configure a timer in a target RAT to detect inter-RAT ping pongs. Namely, if an inter-RAT HO towards E-UTRAN occurs within such a predefined time window, the HO is considered "too early".

The MRO solution combines events monitored by UEs which are not visible directly from the network together with information from multiple eNBs to detect the root cause of failure. Note that from Release 10, MRO enables UE signalling of RLF Reports after active-idle transitions, which is particularly useful in inter-RAT mobility failure resolution.

Mobility Load Balancing (MLB)

The objective of MLB is to manage uneven traffic distributions, while minimizing the number of needed HOs and redirections. The thresholds triggering an offloading action can be enabled by typical cell overload and related load-performance indicators. To avoid jeopardizing mobility robustness, the same targets specified for MRO can also be considered. The MLB function is in the eNB.

An issue with heterogeneous networks is that small cells may attract too little traffic, which calls for macrocell offloading techniques. One such technique is cell range expansion, where a Range Expansion Bias (REB) is considered for small cells when evaluating measurement-report triggering criteria for some or all UEs (Fig. 3a). The adjustment of the REB can be seen as mobility load balancing. Such adjustments need to consider UE-specific aspects such as detection capabilities and current traffic-load contributions due to the volatile nature of interference in the range-expansion area. In 3GPP, eNBs can share resource status information via X2. This provides information to select an offload cell and to negotiate mobility parameters via X2 signaling. This design was chosen to enable offloading of UEs, which would otherwise not be retained, to cells with spare capacity without changing radio channel configurations. An alternative offloading technique adjusts the pilot power level of the small cell to increase or decrease its coverage (Fig. 3b).

Energy Savings

Energy is a major cost in operating mobile networks. The only standardized mechanism to reduce energy consumption is to deactivate cells that are temporarily not needed. To facilitate network energy saving, signaling support is specified between base stations as well as between RATs. If an eNB has switched off a particular cell to lower energy consumption, it may notify neighbor eNBs via a deactivation indication over X2. Furthermore, an eNB can request a neighbor eNB to re-activate a previously switched-off cell via a cell-activation request. Release 11 has introduced some inter-RAT support, where it is possible to transfer cell activation/deactivation information between RATs (e.g., UTRAN) via SON transfer messages. The latter approach minimizes complexity while maintaining interoperability.

Minimization of Drive Tests (MDT)

Traditionally, detailed information about actual radio network performance is obtained through drive tests. However, drive tests are costly, time consuming, and typically limited to roads far from where most UEs are located. One attractive alternative is to use UEs as probes that report measurements to the network. In 3GPP, this is referred to as MDT, which was introduced in Release 10, with enhancements in Release 11. MDT is based on the 3GPP trace functionality and enables the operator to configure and initiate trace logging of radio measurements (including RLF Report used for MRO) and optional location information either towards a specific UE or a particular cell or area. MDT is thoroughly described in [6]. Similar to ANR, the rationale behind the MDT design is to be able to use existing UEs in an ad-hoc manner to monitor network behavior and performance. This provides a plethora of statistics to operators without the cost of running dedicated drive tests.

Potential SON Function Conflicts and Resolutions

With many automatic SON functions in the network, there is a concern that they may cause unwanted interactions and even unstable behavior. Potential conflicts between SON functions can be due to how different SON functions affect the same parameter within overlapping time frames. One solution is to rely on standard coordination mechanisms as discussed in 3GPP [8] while another is to ensure that different SON function types are mutually isolated via design principles [9].

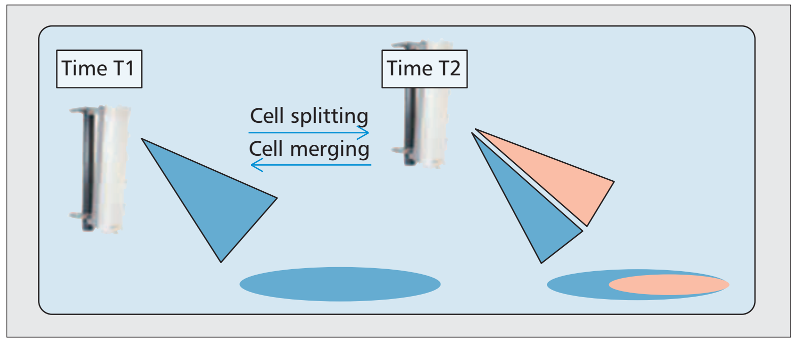

Figure 4. Changing cell pattern of active antenna.

SON for Release 12 and Beyond

Following the work done on SON and MDT in earlier 3GPP Releases, a new study item [7] to extend SON began in early 2013 and concluded in mid-2014. Specification work commenced thereafter and is expected to finish by the end of 2014. In the following sections we detail the Release 12 developments further. Possible developments beyond Release 12 are then also described.

Release 12 SON

Per UE Mobility Differentiation Enhancements — Current specifications enable mobility settings between different UEs to be differentiated. The objective of the "SON for UE types" task is to evaluate if such differentiation can have a negative impact on interoperability. If this is so, then solutions to the interoperability problems are considered. One problem identified is the ping-pong handovers caused by different mobility settings in adjacent cells.

Active Antenna Enhancements — Active antenna systems are one way to increase the capacity of existing networks. Currently, deployments tend to be relatively static, typically just adding vertical sectorization. However, the technology does enable the possibility of more dynamic use, involving UE-specific beam forming, cell shaping, cell splitting and merging. The situation where the number of cells and the cell coverage change over time is shown in Fig. 4. Such merging and splitting can be used to adapt system capacity depending on traffic conditions. It can be seen as a way to provide more flexible coverage/capacity management. However, the ability to merge and split cells dynamically makes the actual management of such systems increasingly complex.

With this in mind the work in Release 12 aimed at enabling support for network deployments based on the generic features of active antennas. More specifically it studied whether existing SON features for deployment automation can be extended to handle dynamic changes possible with active antennas, such as cell splitting or merging. The main focus in the study item concerned connection failures due to cell splitting and merging, as well as impacts on MRO. The work will continue with a Release 13 work item.

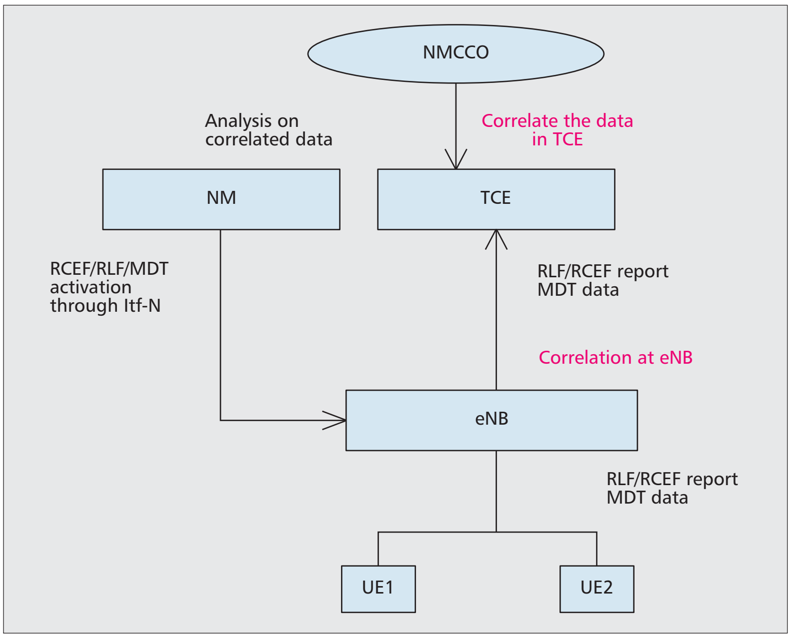

Figure 5. Input data (RLF/RCEF and MDT) for CCO at network management (Fig. 7.3.2.-1 in [10]).

Pre-Release 12 Small Cells Enhancements — The term *small cells* broadly describes operator-controlled, low-power, radio-access nodes. Small cells, which include femto-, pico-, metro- and micro-cells, have a range from tens to hundreds of meters. They're usually deployed by operators wherever additional capacity is needed. Specific SON functions for small cells may reduce network-planning efforts, enhance network optimization and address problems and scenarios specific to small-cell deployment.

Mobility robustness is a challenge, especially because moving UEs may switch rapidly among small cells. The proposed Release 12 enhancements are intended to provide the network additional information (e.g., further RLF reports if failure occurs after re-establishment and UE time-to-trigger (TTT) information), which can be used during MRO analysis so that better corrective actions can be taken. Additionally, S1- and OAM-based solutions have been proposed to simplify inter-RAT RLF reporting in "LTE island coverage" scenarios where there is no LTE coverage surrounding the small cells.

NM-Centralized Coverage and Capacity Optimization and Coordination — The NM-centralized coverage and capacity optimization (CCO) function was facilitated in Release 10 and Release 11 by standardizing activation and reporting of measurement traces reported by the UE or the eNB, including MDT data, radio-link failure (RLF) events, and RRC re-establishment failure (RCEF) events. These traces are then stored at the Trace Collection Entity (TCE) and processed by the CCO functions at the NM level for discovering capacity or coverage issues (Fig. 5). In Release 12, the CCO work focused on anonymous data collection to protect user privacy and correlation of the data from the UEs and eNB either at the eNB level or TCE level (Fig. 5). The targeted use cases were discovering coverage holes and capacity issues in LTE and UMTS, adapting the cell coverage to the user spatial traffic demand, discovering LTE coverage holes via underlying UMTS coverage, etc., as listed in [10].

Multi-Vendor Network Element Plug and Play — The Release 12 work item covered scenarios where an eNB is connected to the secure operator network either via an external network or a non-secure operator network. Server addresses needed for various configurations are obtained via domain name servers [11].

Future Directions

The current work on Release 12 is likely to introduce a number of new features that may well require refinements and additions to existing SON and MDT functionality. One example is Release 12's small-cell enhancements, such as Dual Connectivity [12], that could lead to significant changes to the overall 3GPP Radio Access Network architecture and operation. Another example is 3GPP-WiFi integration. These envision mass deployment of small cells to increase system capacity and user throughput, which by definition requires automated deployment and management for costs to be acceptable to the operators.

The practical and market issues from deployed networks also shape the future directions for SON and MDT development. Changes in user behavior and expectations can cause new problems or requirements so that operators might aim at optimizing quality of experience (QoE) for particular services and users in specific conditions. New deployment trends (e.g., network sharing, small cells, dual connectivity, multicast and broadcast data transfer, or device-to-device communication) can highlight issues or increase the priority for SON and MDT solutions in specific areas.

Research work also leads the way to new ideas and functionality for SON and MDT. The European FP7 SEMAFOUR project[1] [13] is one relevant research project that aims at a unified self-management system. This would enable network operators to holistically manage and operate their complex heterogeneous mobile networks. The ultimate goal is a system that enables an enhanced quality of user experience, improved network performance, improved manageability and reduced operational costs. An envisioned future of the SON system is shown in Fig. 6.

The key new element is the integrated SON management layer. This includes a policy-translation layer which converts high-level goals down to individual SON functions. Further, there is a centralized or decentralized SON-coordination functionality to avoid conflicts between individual SON functions, and a set of powerful new multi-RAT, multi-layer SON functions to handle the complex mobile-communication networks of tomorrow. A decision support system (DSS) [14] is envisioned for automatic generation of recommendations for relevant network extensions based on current and desired performance KPIs, available options for network extensions (e.g., reconfiguration or extension of existing sites,

[1] The research leading to these results has received funding from the European Union, Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 316384.

adding new sites, etc.), projections of future traffic trends and cost constraints.

Operator Perspective on SON

The trend in network operations is to gradually move from "semi-manual" toward autonomous planning, deployment, and optimization (Fig. 1). A semi-manual, or open loop, operation means that SON functionalities suggest configurations which are first approved by the operator before being implemented. Autonomous network operation, also known as closed-loop, means that approval by the operator is skipped. Instead, the operator simply defines high-level performance goals (in the form of a policy) and monitors to what degree the policy is satisfied in the network.

In the **planning phase**, the CCO and DSS functions, with the support of MDT, can reduce the operator's effort in planning (i.e., reduce OPEX) and selecting optimal network extensions (i.e., reduce CAPEX). Operators will still need an initial planning effort to deploy the coverage layer, but this effort will diminish as the coverage layer is enlarged (or completed) and has to be extended with a capacity layer. It is expected that the CCO and DSS functions will be centralized and will typically run at the NM level. This is because CCO and DSS analyse and optimize a cluster of base stations and the dynamics of the recommended reconfigurations or extensions are relatively slow, e.g., up to a few reconfigurations per day or week for CCO or long-term extensions deployed over several months for DSS.

To include NM-centralized SON in the planning phase successfully, operators must address the following challenges:

1 **Availability and accuracy of input data for proper NM-centralized SON decision-making.** Input data provided to NM-centralized SON functions may be in the form of MDT and KPI reports/traces, enriched with geographic coordinates. Collecting this data is facilitated by UE and eNB features that are only optional. Due to this and the existence of legacy UEs and base stations, the availability of input data may be limited. A considerable portion of input data may be provided by vendor-proprietary solutions.

2 **Facilitating the collection and processing of data.** Due to the large number of base stations and users, as well as frequent logging and reporting of relevant information, a huge amount of data needs to be handled by the operator's network management system. This requires sufficient Itf-N transport network capacity, data storage capacity and processing capacity for the NM-centralized SON algorithms.

3 **Linking and synchronizing the NM-centralized SON functions functions with an operator's existing planning tools and processes, as well as BSS/OSS systems.** It is important that the same, up-to-date input data is available to all tools/processes involved in the planning phase. Discrepancies in input data among different processes and tools during planning might result in sub-optimal configurations and network instabilities.

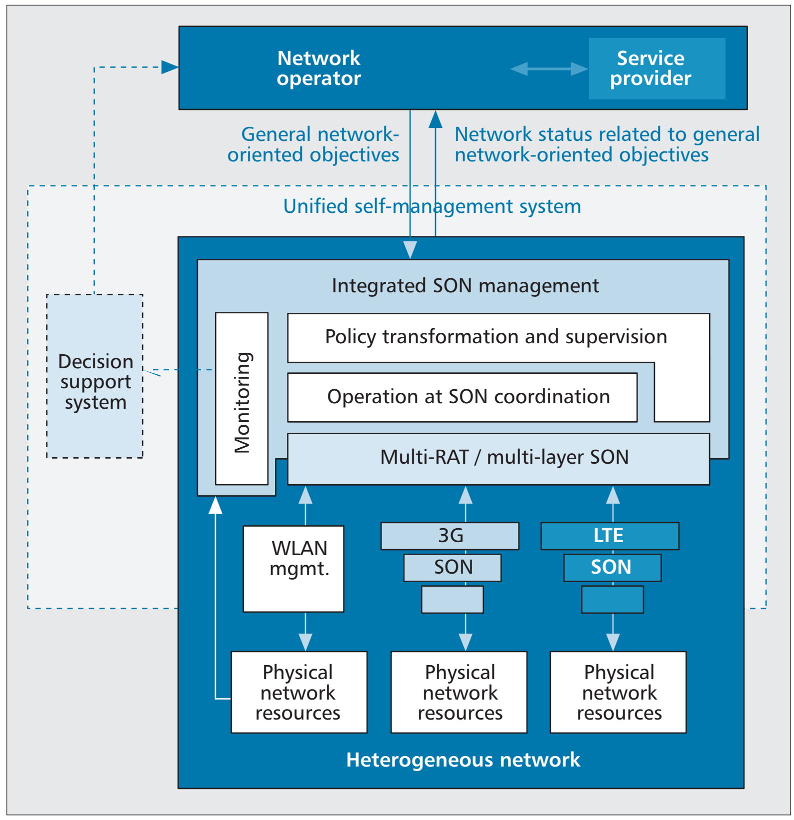

Figure 6. SEMAFOUR vision for future SON system.

In the **deployment phase**, the self-configuration functions enable operators to install new nodes (including Home eNBs) in plug-and-play fashion. Operators' effort in configuring and optimizing intra- and inter-LTE neighbors is reduced (or ideally completely avoided) by the utilization of ANR. Because the LTE neighbor relation establishment includes automatic X2 setup this phase has to be tested in the case of a multi-vendor deployment with neighboring base stations from different vendors. Additionally, the effort in PCI allocation is also avoided because assigning PCIs to cells is automated with the assistance of ANR, and coordinated via the central OAM system, as explained in Section 2. Note here that in case of multi-vendor and small cells deployment, the PCI assignment among the different vendors' nodes and layers has to be coordinated. The self-configuration development of Release 12 can facilitate multi-vendor eNB plug-and-play support that is especially important when deploying network elements with backhaul outside the secure network of the operator.

In the **operations phase**, the distributed SON functions (e.g., MRO, MLB, Energy Saving, etc.) enable operators to have cell-specific and dynamic configurations (e.g., typically few changes per hour), in contrast to base station cluster-based, slowly varying configurations in the planning phase. Cell-specific and dynamic configurations are even more applicable for small cells deployments because (optimal) configuration of small cells and surrounding macro-cells depends on

SON functions standardized up to 3GPP Release 11 include self-configuration and self-optimization features. These features are supported by MDT, which facilitates the gathering of measurements from UEs. In 3GPP Release 12, to be completed in December 2014, further SON enhancements have been investigated.

local traffic and radio- propagation conditions. Because these SON functions operate on a short time-scale and are based on local conditions, they are typically deployed in a distributed or hybrid architecture. Consequently, for multi-vendor deployments in which X2 signaling messages are exchanged, agreements on parameter configurations between neighbor eNBs are crucial for the self-optimization SON functions [15] to work properly. One example is the exchange of load-level information and handover-cause information between eNBs, which has been subject recently to alignment agreements in Release 12.

Conclusions

Network automation in general and SON specifically provide the most promising paths for mobile network operators to handle the increasing pressure to provide ever-higher-performing services, while reducing costs at the same time.

A considerable number of SON functions have been standardized in 3GPP to facilitate automation of planning, deployment and optimization for mobile operators. There is a clear trend that network operations are shifting from manually intensive and static (or slowly changing) network configurations toward (semi-) automated and dynamic/pro-active network operations.

SON functions standardized up to Release 11 include self-configuration and self-optimization features. These features are supported by MDT, which facilitates the gathering of measurements from UEs. In Release 12, to be completed in December 2014, further SON enhancements have been investigated. These can enable operators to have tailor-made optimization based on UE groups, facilitate dynamic shaping of the cell coverage area (including cell splitting) for eNBs equipped with adaptive antenna systems, and assist in the planning phase with the deployment of a NM-centralized CCO function.

Operators must meet several challenges if they're to incorporate NM-centralized SON functionalities successfully. First, the operator's management system should be able to handle the huge amount of data needed for the different SON functions and ensure that the data is synchronized and up-to-date in all supporting tools and processes. Second, although there has been a considerable amount of SON standardization, vendor-proprietary solutions due to legacy UEs or network systems (e.g., GSM and UMTS) will be needed to facilitate the SON functions, which might add to complexity in multi-vendor deployments.

References

[1] Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (EUTRAN); Overall Description; Stage 2, 3GPP Standard TS 36.300, v. 12.1.0.

[2] Telecommunication Management; Self-Organizing Networks (SON); Concepts and Requirements, 3GPP Standard TS 32.500, v. 11.1.0.

[3] NGMN, "Recommendation on SON and O&M Requirements," 2008.

[4] O.G. Aliu *et al.*, "A Survey of Self Organization in Future Cellular Networks," *IEEE Commun. Surveys & Tutorials*, vol. 15, no. 1, 2013, pp. 336–61.

[5] M. Peng *et al.*, "Self-Configuration and Self-Optimization in LTE-Advanced Heterogeneous Networks," *IEEE Commun. Mag.*, vol. 51, no. 5, May 2013, pp. 36–45.

[6] J. Johansson *et al.*, "Minimization of Drive Tests in 3GPP Release 11," *IEEE Commun. Mag.*, vol. 50, no. 11, Nov. 2012, pp. 36-43.

[7] Study on Next Generation SON for UTRA and LTE, 3GPP Technical Report TR 37.822, v 1.4.0.

[8] Telecommunication Management; Self-Organizing Networks (SON); Policy Resource Network Model (NRM). 3GPP Technical Specification TS 36.522, v11.7.0.

[9] K. Zetterberg *et al.*, "On Design Principles for Self-Organizing Network Functions," IWSON at ISWCS 2014, Aug. 2014.

[10] Telecommunication management; Study on Network Management (NM) Centralized Coverage and Capacity Optimization (CCO) Self-Organizing Networks (SON) function. 3GPP Technical Report TR 32.836, v12.0.0.

[11] Telecommunication Management; Procedure Flows for Multi-Vendor Plug-and-Play eNode B Connection to the Network (Release 12), 3GPP Technical Specification TS 32.508, v12.0.0.

[12] Scenarios and Requirements for Small Cell Enhancements for E-UTRA and E-UTRAN (Release 12), 3GPP Technical Report TR 36.932, v12.1.0.

[13] SEMAFOUR: Self-Management for Unified Heterogeneous Radio Access Networks, http://www.fp7-semafour.eu/, accessed 2 May 2014.

[14] A. Eisenblatter *et al.*, "Integrated Self-Management for Future Radio Access Networks: Vision and Key Challenges," Future Network and Mobile Summit 2013, July 2013.

[15] 4G Americas, "Self-Optimizing Networks in 3GPP Release 11: The Benefits of SON in LTE," Oct. 2013.

Biographies

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Adrian Pais is project manager and consultant at TNO where he contributes to research and consultancy projects in wireless networks. He has BE with honors and Ph.D. degrees from The University of Auckland, New Zealand. His most recent technical interests include device-to-device communication, self-organizing networks, network energy savings, and 5G networks. Adrian represents Dutch mobile operator KPN in 3GPP RAN standardization. He currently serves as a director on the board of the IEEE Foundation, the philanthropic arm of the IEEE.

Fredrik Gunnarsson [SM'14] received the M.Sc. and Ph.D. degrees in electrical engineering from Linköping University, Sweden, in 1996 and 2000, respectively. In 2001, he joined Ericsson Research, Linköping, where he is currently a senior specialist in radio self-organizing networks (SONs). He is also an associate professor in automatic control at Linköping. His research interests include signal processing and automatic control aspects of RRM and mobile localization. He is associate editor of *IEEE Transactions on Vehicular Technology*.

Angelo Centonza obtained his B.Sc. and M.Sc. degrees with honors in electrical engineering in 2002 from Politecnico di Bari, Italy. He went on to obtain a Ph.D. in hybrid broadcast/telecommunication networks at Brunel University, London, UK. After working in the areas of IEEE/3GPP standardization and telecommunication systems for defense applications, Angelo joined Ericsson Research in 2011 where he is involved in the research of SON, HetNet and small cells. He is also a 3GPP standardization delegate.

Colin Willcock is head of radio network standardization at Nokia Networks, Munich. He received a B.Sc. degree from Sheffield University, UK, in 1986, an M.Sc. from Edinburgh University in 1987, and a Ph.D. in parallel computation from the University of Kent, also in the UK, in 1992. Colin was part of the core ETSI team that developed the TTCN-3 language and spent many years leading TTCN-3 language development. In the past, he has worked on numerous standardization efforts at ETSI, ITU-T, and 3GPP. He also has also led other European research projects. Currently he is leading the FP7 SEMAFOUR project, which is developing the next generation of SON solutions.