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An overview of Self-Organizing Networks

Μια επισκόπηση των Αυτο-Οργανωμένων Δικτύων

Ντζαρντανίδη Ελένη
Δαγκινάκη Ελισάβετ

Πανεπιστήμιο Μακεδονίας
ΔΠΜΣ Πληροφοριακά Συστήματα
Μάθημα: Δίκτυα Υπολογιστών
Καθηγητής Α.Α. Οικονομίδης

University of Macedonia
Master in Information Systems
Course: Computer Networks
Professor A.A. Economides

ABSTRACT

The rapid global increase in smart devices of various technologies that aim to simultaneously access wireless cellular networks has resulted in increasingly complicated networks, thus making their manual planning, configuration, management and maintenance highly difficult and introducing the need for Self-Organizing Networks. In the present study, we discuss how Self-Organizing Networks are implemented in order to automate network tasks, diminishing human involvement in them.

We first present the strengths of SON implementation accompanied with the criteria that are used to assess the performance of the implementation. Afterwards, we present and compare the three possible types of architecture, which are centralized with SON functions on higher levels and fewer locations or distributed with SON functions in many locations at a relatively low level and a combination of them. We then discuss the principal objective of SON functions which is to introduce self-configuration, self-optimization and self-healing, in all stages of a network's life cycle. A brief focus on the main routing protocols in SON is made to address the issue of how this important network function is achieved in SONs.

In conclusion, we identify the weaknesses that may arise from SON implementation in regards with the complexity of their design and application, as well as the opportunities form the growing establishment of SONs as an exceptional solution that promises improvements and market potential for future wireless networks.

Η παγκόσμια αύξηση των έξυπνων συσκευών διαφόρων τεχνολογιών που αποσκοπούν στην ταυτόχρονη πρόσβαση σε ασύρματα δίκτυα έχει οδηγήσει σε όλο και πιο περίπλοκα δίκτυα, καθιστώντας έτσι τον προγραμματισμό, τη διαμόρφωση, τη διαχείριση και τη συντήρησή τους εξαιρετικά δύσκολες και εισάγοντας την ανάγκη για Αυτο-οργανωτικά Δίκτυα (SON). Στην παρούσα εργασία, μελετάμε την υλοποίηση SON ώστε να αυτοματοποιηθούν τα καθήκοντα του δικτύου, μειώνοντας την χειρονακτική συμμετοχή σε αυτά.
Αρχικά, παρουσιάζουμε τα πλεονεκτήματα της υλοποίησης συνοδευόμενα από κάποια κριτήρια αξιολόγησης. Στη συνέχεια, παρουσιάζουμε και συγκρίνουμε τους τρεις τύπους αρχιτεκτονικής, όπου οι λειτουργίες SON είτε συγκεντρώνονται σε υψηλότερα επίπεδα και λιγότερα σημεία ή διανέμονται σε πολλά σημεία χαμηλότερου επιπέδου και ένας συνδυασμός αυτών. Στη συνέχεια, συζητάμε τον κύριο στόχο των λειτουργιών SON που είναι να εισαγάγει την αυτο-διαμόρφωση, την αυτο-βελτιστοποίηση και την αυτο-θεραπεία σε όλα τα στάδια του κύκλου ζωής ενός δικτύου. Μια σύντομη εστίαση στα κύρια πρωτόκολλα δρομολόγησης στον SON γίνεται για να αντιμετωπιστεί το ζήτημα του τρόπου με τον οποίο επιτυγχάνεται αυτή η σημαντική λειτουργία στα SONs.

Εν κατακλείδι, εντοπίζουμε τις αδυναμίες που μπορεί να προκύψουν από την υλοποίηση SON σε σχέση με την πολυπλοκότητα του σχεδιασμού και της εφαρμογής τους, καθώς και τις ευκαιρίες από την αυξανόμενη εγκαθίδρυση των SONs ως μια εξαιρετική λύση που υπόσχεται βελτιώσεις και δυνατότητες ανάπτυξης για μελλοντικά ασύρματα δίκτυα.

Keywords: SON, 3GPP, Self-Configuration, Self-Optimization, Self-Healing, SON routing protocols

CONTENTS

INTRODUCTION

During the last decade there has been a significant increase in the number of mobile-users worldwide; users that produce an unprecedented amount of online content causing the demand for high-speed data to rise exponentially. In order to accommodate this growing demand, mobile operators are having to deploy increasingly complex networks and are challenged to find new and innovative ways to manage them with the minimal manual efforts and cost. Self-Organizing Networks (SONs) promise to minimize these challenges through automation of network operations (Mwanje, Schmelz, & Mitschele-Thiel, 2016).

SON (Self-Organizing Network) technology is an automation whose function is to evaluate specific metrics and decide on some actions based on a predefined set of rules and without any external control entity. Well-designed and efficient SONs achieve the *elimination* of manual involvement in operations, administrations, and maintenance (OAM) activities such as planning, configuration and improving network mechanisms, as well as optimizing decisions and healing during the operation of the mobile radio access network (Kumar, 2016).

SON functionality and behavior has been defined and codified within the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE).

Drivers for SON implementation

The main types of gain that the mobile operators obtain from implementing SONs can be categorized into:

- Reduction of capital and/or operational expenditures (CapEx, OpEx)
- Improvement of network capacity and coverage
- Higher Quality of Service (QoS)

An appropriate balance should be maintained between the gains accumulated by adding SON functionality and any implementation expenditures that should arise (Kamboh, Yang, & Qin, 2017).

Examples of the benefits which have already been witnessed by some of the early implementers of SON are boosted rollout times, simplified network upgrades, fewer dropped calls, better call setup success rates, higher end-user throughput, alleviation of congestion during special occasions, holidays etc., increased subscriber satisfaction and loyalty, energy and cost savings, and actually freeing up engineers from repetitive manual tasks (MarketResearchNest, 2019).

ASSESSMENT CRITERIA

To assess the benefits of implementing self-organisation methods in the network, a set of well-defined metrics are required. These metrics are organized in categories in direct relation to the potential gain of the implementation (Ghadialy, 2016).

- **Performance metrics** express the service level experience from the user perspective and include packet delay statistics, packet loss ratio, call blocking ratio, call dropping ratio etc.
- **Coverage metrics** refer to the fraction of area where a user can experience a given service with adequate quality and some pre-specified data rate.
- **Capacity metrics** are relevant to the maximum number of concurrent calls and total supportable traffic load in each cell under some pre-specified requirements.
- **CapEx** encompass the investments made to create future benefits e.g. the site equipment cost to support the SON functions or new transmission bandwidth requirements due to increased signaling overhead.
- **OpEx** are associated with the network operations costs, i.e. the human labor involved in gathering input data, determining new parameter settings and performing some manual adjustments.

ARCHITECTURE

Before discussing the three possible architectures for implementing various SON use cases, an introduction to some basic network concepts is appropriate (Kumar, 2016).

- The **User equipment** (**UE**) is any device used directly by the end-user to communicate (e.g. the mobile phone)
- The **Network Element** (NE) is the physical hardware (e.g. the eNodeB in LTE networks) used to execute all the processes and functions of network, providing the connection between the UE and the wider network.
- The **Elements Management system** (EMS) is responsible for managing the NEs and it also has a user friendly graphic interface to present the data to the.
- The **Network Management system** (NMS) is the server that controls, maintains and configures the network.

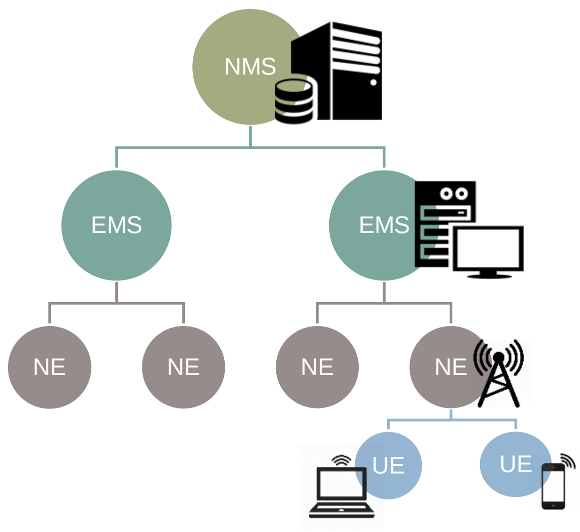

Figure 1: The main levels in a Network

In a nutshell, the NEs connect with and collect measurements from the UE. The EMS gathers the information from the NEs and interacts with the NMD by providing it with data based on the collected and aggregated information (Jorguseski, Pais, Gunnarsson, Centonza, & Willcock, 2014).

I. Centralized SON (C-SON)

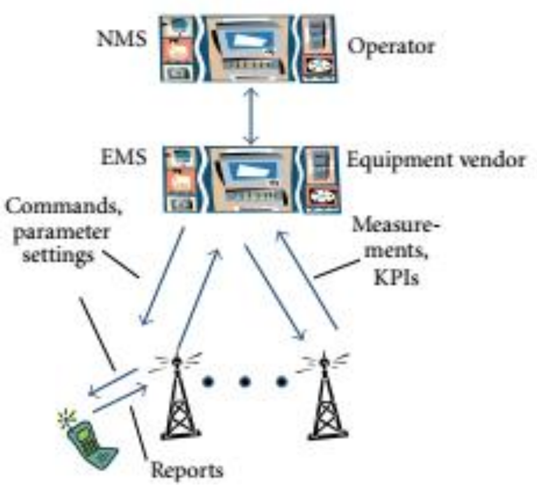

Figure 2: Centralized SON

SON solution where optimization algorithms are stored and executed in a small number of locations, at a high level in the architecture. This allows a broader overview of edge elements and coordination of load across a wider geographic area.

As depicted in Figure 2, commands, requests and parameter settings are reconfigured by the Network Management system based on feedback information such as measurement data and reports from Network Elements (ETSI 3GPP, 2018; Kumar, 2016).

This approach has several benefits and drawbacks discussed further bellow (Osterbo & Grondalen, 2012).

The main **benefits** of this approach are:

- It is possible to globally optimize the network parameters (at least the slowly varying ones) because information from all parts of the network is taken into consideration.
- It exhibits a robustness against network instabilities. Due to the control of all SON functions being done centrally, they can be coordinated to avoid possible conflicts of those who run simultaneously.
- It is possible to have multivendor and third party SON solutions, since they are not implemented in the Network Elements level where specific solutions are usually required but higher.

The main **drawbacks** on the other hand are:

- Longer response times which limit the speed at which the network can adapt to changes and can sometimes cause network instabilities.
- Increased backbone traffic, due to instructions and measurement data being sent back and forth between the Network Management system and the Network Elements. This traffic becomes more significant with the addition of cells to the network.
- That it represents a single point of failure makes the implementation all the more vulnerable.

II. Distributed SON (D-SON)

In Distributed SON, optimization algorithms are stored and executed in many locations at a relatively low level in the architecture. This increases the deployment efforts and requires coordination in order for network as a whole to be optimized.

As depicted in Figure 3, the Network Elements exchange SON related messages directly with each other, they receive policies from the Network Management through the Elements Management and provide them with KPIs (ETSI 3GPP, 2018; Kumar, 2016; Osterbo & Grondalen, 2012).

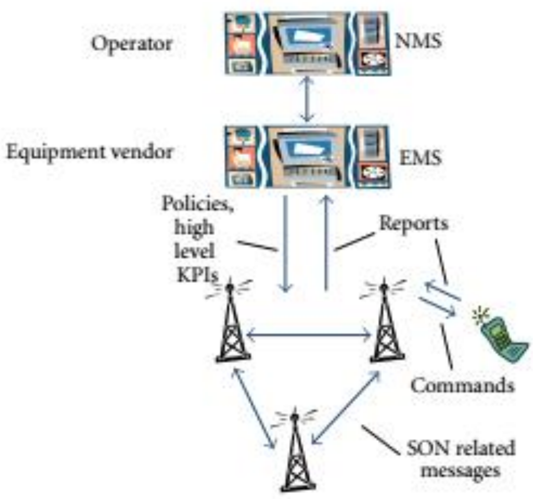

Figure 3: Distributed SON

Main **benefits** of this architecture are:

⇨ It makes the SON functions much more dynamic, which enables the network to adapt to changes much faster.
⇨ It scales very well for increased number of cells in the network.

The main **drawbacks** are:

⇨ It is not easy to avoid possible network instabilities, since the sum of all the optimizations done at cell level do not guarantee optimum operation of the network as a whole.
⇨ Third party solutions are difficult to have, since the SON algorithms implemented in the Network Elements are vendor specific.

III. Hybrid SON

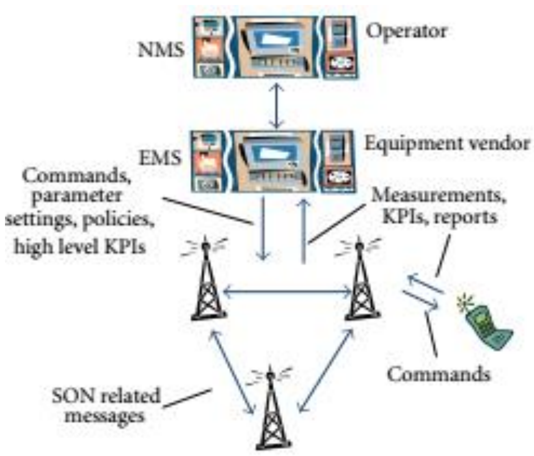

Figure 4: Hybrid SON

The Hybrid SON solution is a combination of Centralized and Distributed SON, where optimization algorithms are executed at multiple levels in the architecture, attempting to combine centralized coordination of the SON functions and faster adaptability to changes.

The term is not clearly defined as some vendors classify their solutions as “hybrid” if the network management system can control the SON function by setting main parameters/policies, receiving reports and being able to disable it on occasion.

Figure 4 shows that part of the SON algorithm, such as simple and quick optimization schemes, is implemented at the Network Elements while the part that includes complex optimization schemes is run in the Network Management system and/or Elements Management system (ETSI 3GPP, 2018; Osterbo & Grondalen, 2012).

This approach combines the main **benefits** of both centralized and distributed SON, being flexible to support different kinds of optimization cases.

But on the other hand, the **drawbacks** of both solutions are also inherited (Osterbo & Grondalen, 2012):

⇨ It needs significant deployment effort and costly interface extension work.

- It might not scale well, since the SON-related traffic in the backbone and processing required at the Network Management system, are proportional to the number of Network Elements in the network.
- Third party solutions are difficult to implement since parts of the SON algorithms are running in the Network Elements.

Architecture Selection

The implementation of SON functionalities is achievable in all SON architectures, the key differentiator between them being the performance and cost factors that influence each use-case.

While C-SON solutions give the operator more control over the network at the NMS level, the potential scalability problem is a significant drawback, as well as the risk of network wide interruptions caused by “single point of failure”.

Hybrid SON solutions have the same unavoidable weaknesses with respect to scalability and single point of failure, even for solutions with low backbone traffic and less scalability problems.

In D-SON solutions, being able to monitor and control SON functions through parameter/policy settings, albeit not having the same control over them, is usually sufficient. However, coordination of SON function with conflicting goals, might be challenging.

In regard to the lack of third party solutions for distributed and hybrid SON, it is usually not that important since it is easier for the operator to deal with one vendor that has full accountability for any failures in the whole network (Premnath & Rajavelu, 2011).

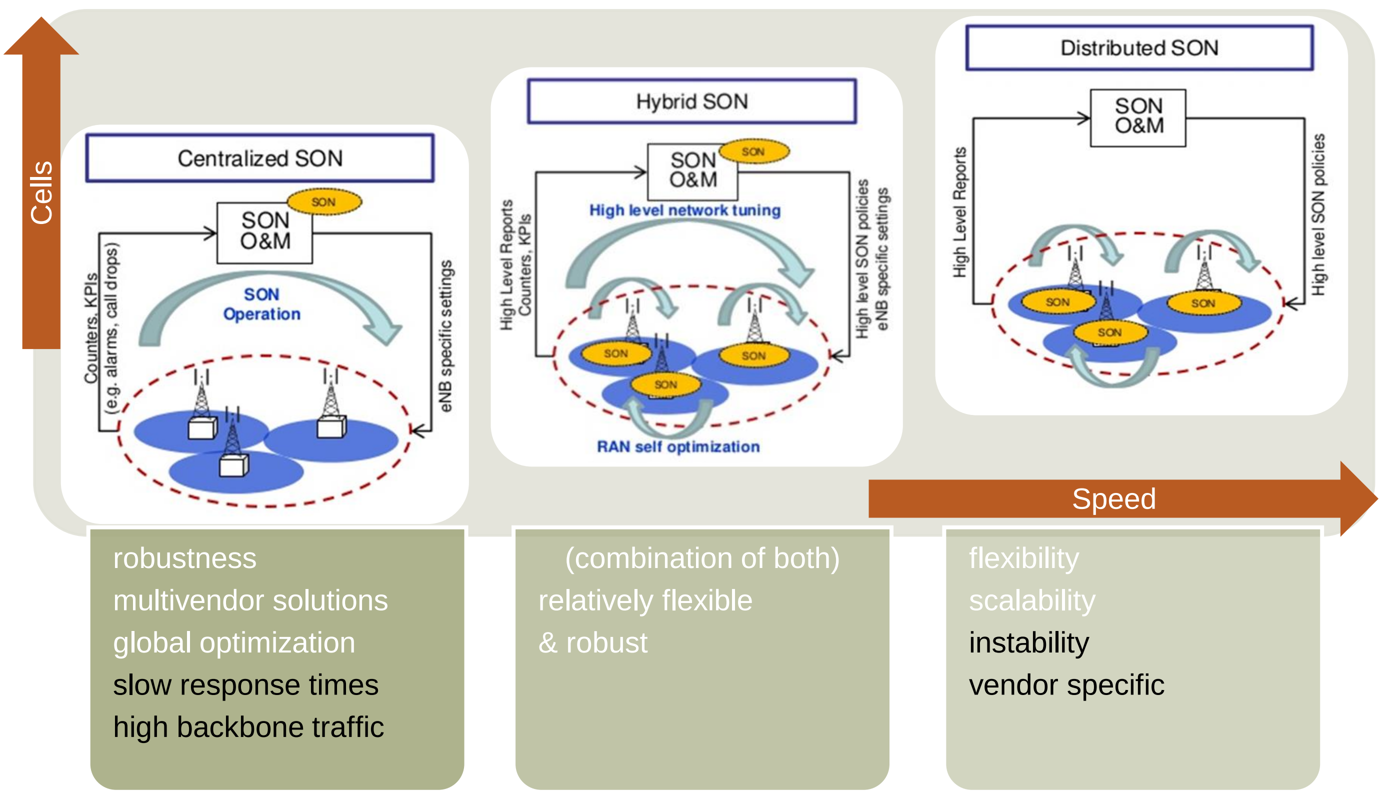

Figure 5: Comparison of the 3 types of SON architecture

SON FUNCTIONS

SON functionalities are commonly divided into three sub-categories: Self-configuration, Self-Optimization and Self-Healing (ETSI 3GPP, 2018) with a given SON function possibly belonging to more than one of these categories. Figure 6 captures the three functions of SON.

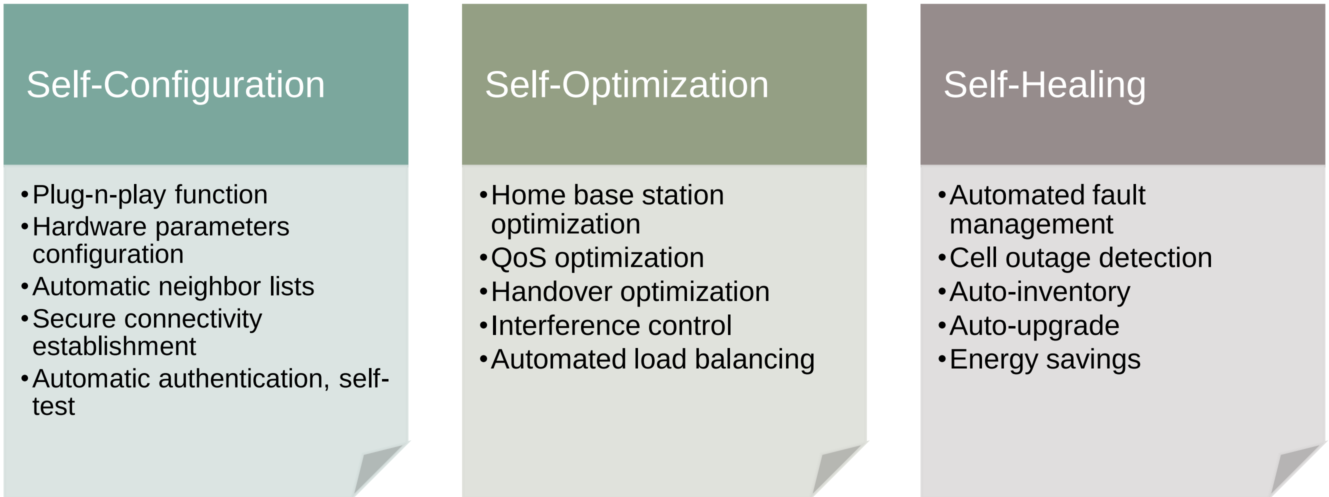

Figure 6: SON functions

There are potential conflicts when SON functions simultaneously share the same network parameters. Possible resolutions to avoid this is to set up a coordination mechanism or design them to be mutually exclusive (Kumar, 2016).

Self-Configuration

The addition of a new site or the introduction of a new service or network feature generally require an initial (re)configuration of a number of parameters or resource management algorithms. These parameters have to be set prior to operations and before they can be optimized as part of the continuous self-optimization process (Marchetti, Prasad, Johansson, & Cai, 2010).

This is where Self-configuration is introduced, in order to reduce or eliminate the amount of human operator intervention in the overall process of network planning, configuration and deployment and establish a more integral inventory management system that is less prone to human errors (Kamboh, Yang, & Qin, 2017).

Self-configuration functions in networks are carried out by specific SON features, which are very effective in reducing the installation time and handle the new Network Elements added to increase the network capacity (Osterbo & Grondalen, 2012).

One example is the “plug-n-play” feature, when a new Network Element first connects to the network it should be able to automatically establish a connection with the core Network Elements, upgrade to the latest software version, set up the initial configuration parameters, perform a self-test, and set itself to operational mode (Kumar, 2016).

Self-Optimization

Self-optimization refers to the ability of the network to apply intelligent methods in order to determine and update a set of parameters for optimization, e.g. the antenna tilt, the power setting or the packet scheduling (Marchetti, Prasad, Johansson, & Cai, 2010). This function minimizes the Operating Expenditures and improves the Quality of Service.

Following are some noteworthy network features to accomplish Self-optimization (Kumar, 2016):

- Mobility Robustness Optimization (MRO) is crucial to achieve minimum handover failure rates while simultaneously avoiding unnecessary handovers as much possible.
- Mobility Load Balancing (MLB) manages uneven traffic distributions to improve load balancing while also minimizing the handovers and redirections in order to do so.
- Energy Savings can be achieved by deactivating cells that are temporarily not needed, informing the neighboring cells of the deactivation and reactivate them when a request from the neighbors is received
- Minimization of Drive Tests (MDT), which tend to be costly and time consuming and use user equipment instead as probes to obtain detailed information about the performance of the network.

Self-Healing

Self-Healing refers to a collection of SON procedures that enable the network to automatically detect, solve or mitigate problems in order to avoid impact on users and to reduce maintenance costs while noticeably improving Quality of Service and of Experience (Kamboh, Yang, & Qin, 2017).

The self-healing concept could be dissected to two major areas as follows (Osterbo & Grondalen, 2012):

- Self-diagnosis
- Self-healing

Within the functionality of Self-healing threats are initially addressed through continuous performance monitoring, then the specific alarm is triggered. If the threat is possible to correct or minimize, more information is gathered (e.g., measurements, testing results, and so forth), deep analysis is done and the appropriate actions are executed. Once the actual failure has been repaired, all parameters are restored to their original settings (Marchetti, Prasad, Johansson, & Cai, 2010).

ROUTING PROTOCOLS IN SON

All numerous routing protocols for SON share the following key properties (Kumar, 2016).

- Noticeably fast choosing of routes
- Highly reliable packet transmission
- Minimal amount of service information
- Prevention of loops
- Easy detection and recovery of routes
- High performance and scalability

Based on their operation, SON routing protocols are broadly classified into three different types (Jorguseski, Pais, Gunnarsson, Centonza, & Willcock, 2014):

- **Proactive** routing protocols (table driven) –Service messages, containing information relating to any changes in the network topology, are periodically sent across the network. Each node uses these messages to build a routing table with the optimal routes to all the other nodes.
- **Reactive** routing protocols (on-demand driven) - Routes are built for each node if and only when needed and not saved in the table beforehand. A message is broadcasted by the sender to the entire network. The intended receiver transmits a confirmation message back to the sender which he then uses to deduce the optimal route and stores it in the routing table.
- **Hybrid** routing protocols (adaptive) - A combination of the abovementioned routing protocols. A proactive routing protocol is used to build the routing table and a reactive routing protocol is used to select the optimal route. This helps reduce routing table sizes and the volume of service traffic in large networks and is commonly the preferred solution.

In order to choose the optimal route from one node to another, the following metrics should apply (Proskochylo, Vorobyov, & Zriakhov, 2014).

- Packets should undergo least number of hops (distance vector protocols).
- Routes are estimated based on certain parameters like the number of hops, the delay in packet delivery, available bandwidth, etc. (complex metric protocols).
- Geographic location of all the nodes in a network is acquired using Global Positioning System.

CONCLUSIONS

Challenges in SON Implementation

Although SONs are expected to bring huge benefits towards optimizing mobile networks, there are challenges in implementing them in reality. SON functions are mainly rule-based control structures that evaluate some metrics and perform actions based on a set of rules. Specific rules that can respond to each possible scenario in a network or a cell are very complex to design and, in practice, they can only support generic behavior (Mwanje, Schmelz, & Mitschele-Thiel, 2016).

Among the aspects that must be taken into consideration before practical implementation of SON concepts are the following (Marwangi, et al., 2014; Premnath & Rajavelu, 2011)

- **Cross-vendor interworking** –Vendors adopt different SON implementations across different vendor equipment and their respective management systems.
- **Architecture selection** – there is a special deployment need to configure the SON functionalities on each type of architecture which could potentially influence the functional level implementation of SON.
- **Data measurement and processing** – Deciding on the type of measurement data that needs to be collected, as well as the appropriate techniques to be used can be challenging depending on the type and state of the network/system.
- **Computing algorithms availability and application** – Since trial and error method for altering parameters in real network is too risky and requires extra effort, probabilistic approach based on past experiences is used to develop SON algorithms. Application of techniques based on the concepts of game theory, fuzzy logic, neural networks etc. can be challenging, as well as dealing with incomplete, delayed and faulty data.
- **Conflict between parameters and goals** – Some of the different SON functions might have mutually exclusive goals and may simultaneously try to act/optimize the same parameters requiring clear sequencing which cannot always be achieved.
- **Establishment of recovery mechanisms** – Setting options that would successfully revert the network configuration to a pre-determined earlier state, e.g. “Reset to factory defaults”.
- **Avoiding network overload and scalability** – Networks might overload or degrade in performance due to additional load on network equipment. Also, the SON functionalities should be scalable according to the size of the network. The use cases implemented as part of SON functionalities should be scalable while the network evolves and matures.

One approach to address some of the aforementioned challenges is with assistance from a SON Coordinator for the SON functionalities use cases residing across the higher levels of the operator network (see Figure 7).

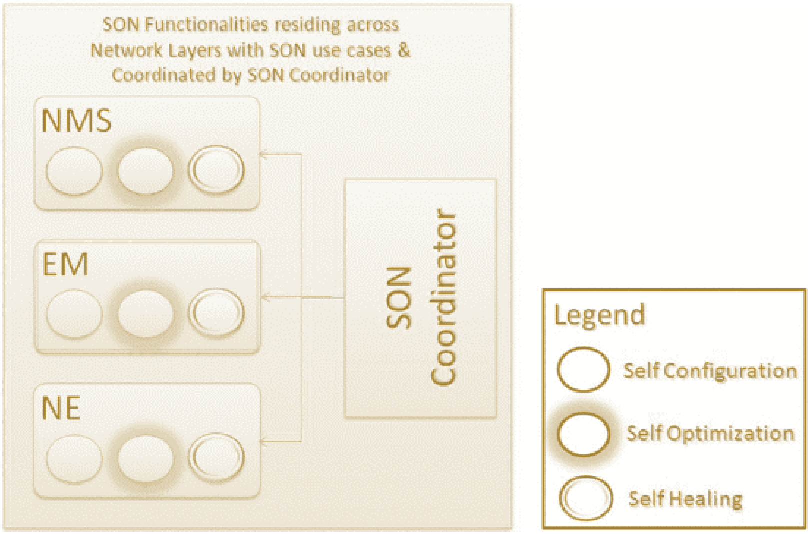

Figure 7: Self Coordinator

The need or gains of SON coordination depend on the SON functions in operation:

- An accurate design of the SON functions may result in few or no dependencies at all
- Fewer numbers of implemented SON functions decrease the potential of operator dependent conflicts

Interworking can be mitigated using SON Coordinator, which could potentially coordinate the information exchange between Network Elements with different vendors using standard web-service based interfaces. Properties such as vendor specific interfaces, data model etc. can be abstracted at SON coordinator level, allowing the information to be successfully exchanged (Premnath & Rajavelu, 2011).

Opportunities and Future Development

Mobile operators and vendors are increasingly focusing on integrating new SON functions to address issues of protection against digital security threats, self-learning through artificial intelligence techniques, compliment to 5G requirements such as handling diverse devices at a massive scale and more. Furthermore, dedicated SON solutions for Wi-Fi and other access technologies have also emerged, simplifying wireless networking in home and enterprise environments.

Below are presented the key findings of a comprehensive market research report and analysis on SON in the 5G Era, carried out last year (MarketResearchNest, 2019).

- Global investments in SON technology, driven by the increasing complexity of today's mobile networks, are expected to grow at a rate of 11% between 2019 and 2022 and by the end of 2022 account for a market worth $5.5 Billion.
- The increasing adoption of SON technology from mobile operators worldwide has brought about vast practical benefits for early adopters – spanning from more than a 50% decline in dropped calls and reduction in network congestion by 80% to more than 30% decrease in OpEx and a 5-10% increase in service revenue.
- SON are playing a pivotal role in accelerating the adoption of 5G networks by facilitating advanced capabilities such as network slicing, dynamic spectrum management or predictive resource allocation.
- To better address the emerging challenges from increased complexity, C-SON platforms introduce a host of state-of-the-art technologies – ranging from artificial intelligence and machine learning techniques to the application of Big Data technologies and the use of alternative data mined with crowd-sourcing tools.
- In addition to SON solutions offered by vendors and third-parties, mobile operator developed solutions are also beginning to emerge.

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