A Survey of Self-Organizing Networks

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Abstract

One of the main new technologies in future generation networks is that of the automation of their organization. These networks are called Self-Organizing Networks (SON). SON functions are responsible for automatically planning, configuring, managing, optimizing and healing a mobile network. Well-designed and efficient SON functions are able to achieve and maintain high levels of network performance by continuously finding improvement patterns that may not be easily distinguishable to an expert. This is done so via the modification of various network parameters and by using rollback algorithms. These operations can be performed efficiently due to the availability of rich statistical models on Key Performance Indicators (KPI), their dependencies on one another and their interactions with each other. However, SON implementation is not easy. SON functions need to be specifically tuned to each individual network. Correct parameters need to be used which comply with the existing network policies. The other major problem in SON is increasing their bandwidth as it results in routing protocols not being able to infer the correct metrics to choose the optimal path. In this paper, we discuss the features and advantages of important SON functions and routing protocols. We also describe ways to improve their efficiency using existing technologies.

Keywords

Self-Organizing Network (SON), SON Coordination (SONCO), Routing Protocols, Wireless Sensor Networks, 3rd Generation Partnership Project (3GPP), Long Term Evolution (LTE), Peer to Peer (P2P), Network Management, Conflict Resolution, Reinforcement Learning, State Aggregation

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1 Introduction

The significant increase in the number of mobile users as well as the amount of online content has caused the demand for high-speed data to rise exponentially. This has played a major role in recent developments in mobile networks. In order to accommodate this growing demand, mobile operators are having to deploy increasingly complex networks [Jorguseski14]. These networks are comprised of multiple radio access technologies, several different cell types and various users, all of whom have different Quality of Service (QoS) requirements. Mobile operators now need to be able to manage these ever-increasingly complex networks efficiently with minimal costs. In order to do this new and existing networks need to be managed with minimal manual efforts. Thus, SON functionalities are essential in future as well as existing networks.

The first technology to make use of SON features was 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE), Release 8. SON functionalities have also been implemented in existing radio access technologies as well such as the Universal Mobile Telecommunication System [Wikipedia1]. The operators' alliance known as the Next Generation Mobile Networks (NGMN) has defined a set of requirements for SON [Asghar12].

The main reason for mobile operators to implement SON is in order to decrease their capital and operating expenditures. However, the benefits from improving network performance and reducing the total capital and operating expenditures should outweigh the costs of implementing and managing SON-related functionalities for mobile operators to consider SON. This goal can be achieved quite easily. SON functions can help decrease the costs in all 3 stages (planning, deployment and operation) of a network life cycle [Jorguseski14]. Figure 1 provides an overview of SON features along with the stages where they are used. We can clearly see from the figure that the operational efficiency of networks will keep increasing as more SON features are implemented.

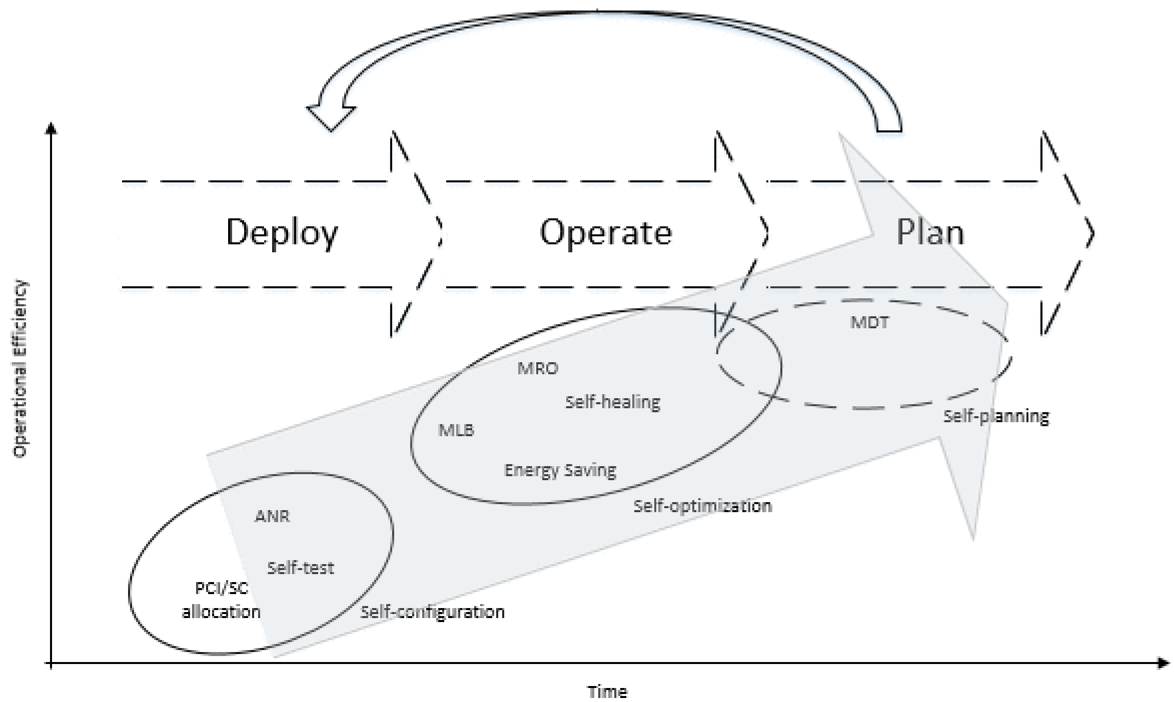

Figure 1: Overview of SON features

In this paper, we discuss the implementation of SON functions and routing protocols. We also describe ways to improve their efficiency using various technologies. Section 2 provides an overview of SON mechanisms in 3GPP LTE. Important existing features as well as future trends are explained. In Section 3, we discuss SON routing protocols. In Section 4, we survey how Peer to Peer (P2P) technologies can be used to improve the efficiency of SON. In Section 5, we address the problem of SON function conflicts. Lastly, in Section 6, we conclude the survey paper with a summary.

2 SON Mechanisms in 3GPP LTE

In the 3GPP LTE network, an operator interacts with the network through the Network Management (NM) system. The NM system uses a standardized interface called Interface-North to interact with the Domain Manager (DM). The DM is responsible for managing all Network Elements (NEs) using a standardized interface called Interface-South. NEs include Evolved Node Bs (eNBs). These are the hardware that are connected to the mobile phone network that communicate directly with mobile handsets [Wikipedia2]. Figure 2 depicts the 3GPP network management architecture.

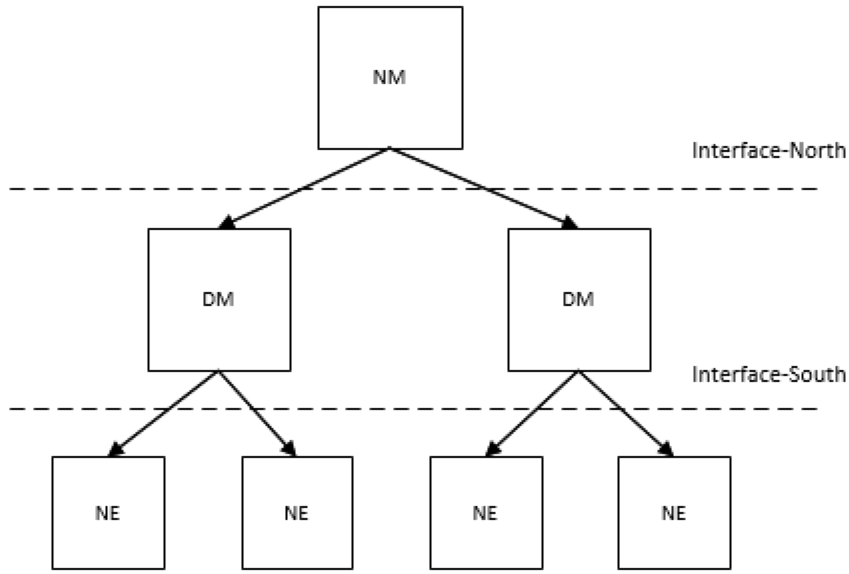

Figure 2: 3GPP Network Management Architecture [Jorguseski14]

SON functions can be classified into different types depending on how they are mapped onto the network management architecture [Jorguseski14]. There are 3 kinds of SON architectures [3GPP1]:

- NM-centralized SON: Centralized policies are defined in the NMs. NE parameters are reconfigured by the NM based on feedback information from NEs.
- Distributed SON: It is implemented in the NEs (commonly eNBs). NEs receive policies from the NM through the DM and provide KPIs to them. Standardized interfaces are used for inter-NE communication.
- Hybrid SON: It is a combination of both NM-centralized and Distributed SON components.

The rest of this section is devoted to describing current as well as future SON features in relation to the network management architecture.

2.1 Current SON Features in 3GPP LTE

The existing important SON solutions in 3GPP LTE up to Release 12, which was completed in early 2015, are described below.

- Self-Configuration: The initial setup of NEs is complicated as a large number of parameters need to be initialized. Automating this process helps save considerable amounts of time and effort. The configuration of these parameters may be handled through the 3GPP Automatic Radio Configuration Data-Handling Function. When connectivity is established the handling function along with any other software upgrade is passed on to the eNB. The eNB performs self-tests and becomes operational upon completing self-configuration.

- Automatic Neighbor Relations (ANR): One of the main configuration and optimization costs for mobile operators has been the manual generation of inter-cell neighbor relations. This is performed via the LTE ANR function in the eNB. However instead of doing it manually, User Equipment (UE) may be used to create and manage neighbor relations automatically. This is done by having an eNB request a UE to decode the neighbor cell system information instead. Due to the large number of UEs in a network this method is significantly faster, more reliable and less expensive than either manual configuration or drive tests.
- Automatic Cell Identity Management: Mobility in 3GPP LTE is handled using Physical Cell Identifiers (PCIs). PCIs are reported to the network by UEs. These PCIs need to be locally unique. When they are non-unique confusion and/or collision can occur. These confusions/collisions can be detected via the UE ANR method described above. The Operations, Administration and Maintenance (OAM) system is a set of functions that monitor network operations. It detects any network faults and measures network performance. The OAM system will initiate a centralized PCI reassignment mechanism when a confusion or collision is detected. It provides a new PCI or a list of PCIs to choose from to the cell based on its neighbor relation information.
- Random Access Optimization: In Random Access, UEs are able to notify their presence to the network. They are also able to establish an uplink time synchronization with the network. In order to optimize the random access channel performance and its estimation, UEs are used to monitor the network. UEs provide a report to the eNB upon completing an access attempt. This can be incredibly beneficial as UEs are able discover radio-related issues which may not be known to the network.
- Mobility Robustness Optimization (MRO): MRO is one of the most important SON features. Minimum mobility failure rates should occur between different LTE networks. At the same time unnecessary handovers should be avoided as much possible. The eNB contains the LTE MRO function. UEs can be used to assist the handover procedure by providing a measurement report to the eNB [Suleiman14]. The eNB uses the report to initiate the handover procedure to the target cell. In the case of a handover failure, the events monitored by UEs and the information from multiple eNBs are combined together in order to detect the root cause. UEs will then try to reestablish connection to the network or switch to idle mode and reconnect later on.
- Mobility Load Balancing (MLB): MLB manages uneven traffic distributions. It also minimizes the number handovers and redirections in order to do so. The eNB contains the LTE MLB function. MLB shares many objectives with MRO. Therefore, the UE MRO method can also be used to improve load balancing.
- Energy Savings: Energy is one of the major expenses in the operation of a mobile network. Energy consumption can be lowered by having eNBs deactivate cells that are temporarily not needed. eNBs can notify their neighbors of this via a deactivation message. A deactivated cell can be reactivated via a cell activation request sent to its eNB from one of its neighboring eNBs.
- Minimization of Drive Tests (MDT): Drive tests have traditionally been used to obtain detailed information about the performance of a radio network. However, they tend to be costly and time consuming. Instead of drive tests UEs can be used as probes to report

measurements of the network. This method is known as MDT and is much less expensive to perform.

- Potential SON Function Conflicts and Resolutions: Different SON functions may conflict if they share the same network parameters at the same time. In order to avoid this a standard coordination mechanism can be set up or different SON function types can be designed to be mutually exclusive.

2.2 Future Trends in SON Features

There are a number of new SON features that are in development. The addition of these new features in future networks will require existing SON and MDT functionalities to be modified and refined. One such important example is Dual Connectivity in regards to Small-Cell Enhancements. The implementation of this feature could result in significant changes to the architecture and the operation of 3GPP LTE. 3GPP-WiFi integration is another such example. In this feature a large number of small cells will be deployed to increase the total system capacity and user throughput. In order to be able to do this, mobile operators will need to automate this deployment so as to keep the costs manageable. Other important features include Network Sharing, Multicast and Broadcast Data Transfer and Device-to-Device Communication.

The Self-Management for Unified Heterogeneous Radio Access Network (SEMAFOUR) is an important European research project. Its aim is to design and develop a unified self-management system. This system will enable network operators to holistically manage and operate complex heterogeneous mobile networks. Its ultimate goal is to create a management system that will enhance QoS, improve network performance and manageability, and reduce operational costs [SEMAFOUR1].

The SEMAFOUR SON system is shown in Figure 3. We can observe that the main new component in the system is the integrated SON management layer. This is comprised of 3 sublayers. The first is the policy transformation and supervision layer which is responsible for converting high level goals to individual SON functions. The second is the operation at SON coordination layer which is responsible for conflict management between different SON functions. Lastly, the multi-radio access technology/ multi-layer SON layer contains functions that will handle future complex mobile-communication networks. The decision support system is responsible for automatically generating recommendations for appropriate network extensions. Recommendations are based on current and optimal KPIs, cost constraints, network traffic predictions and available network extension options [Jorguseski14].

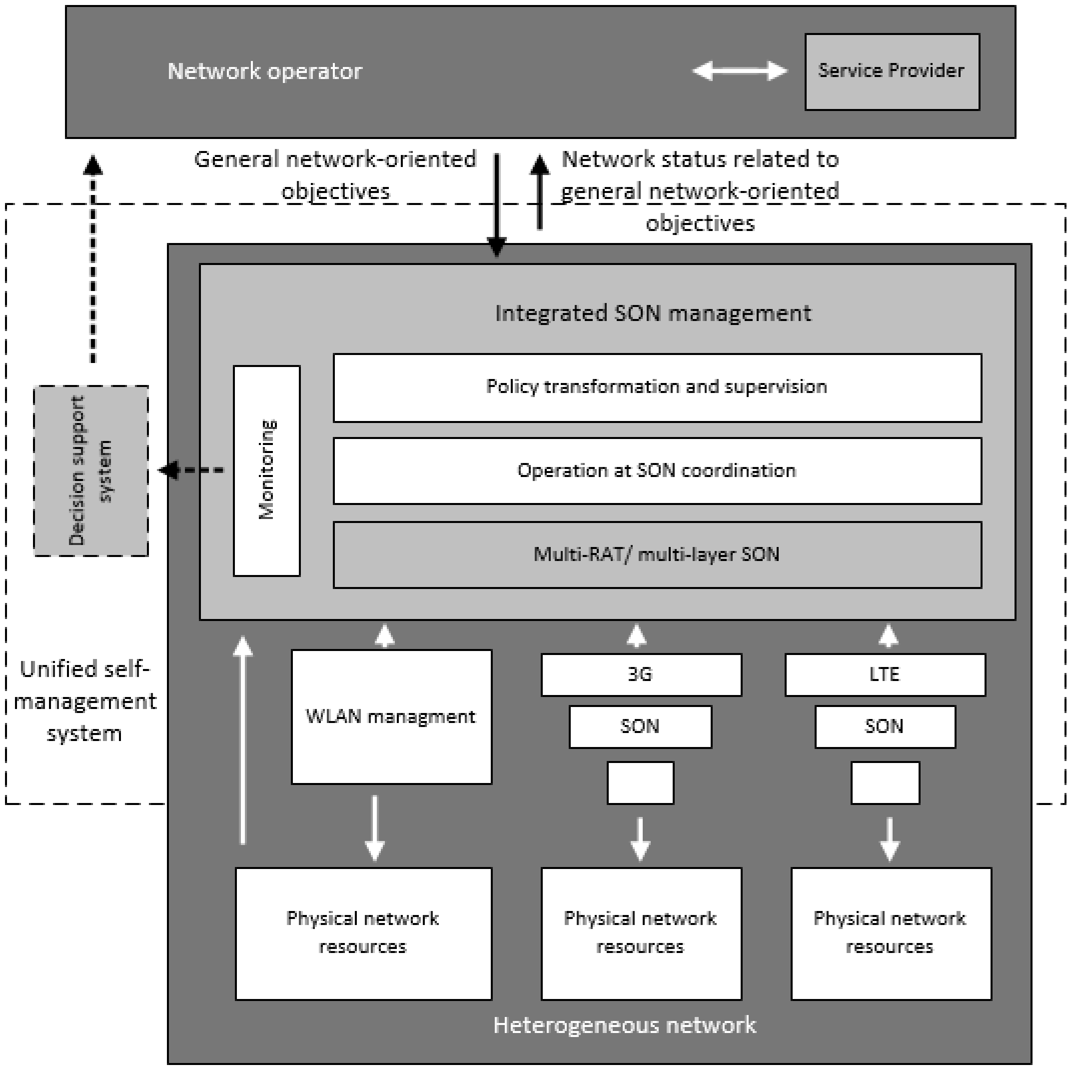

Figure 3: SEMAFOUR SON system [SEMAFOUR1]

3 Routing Protocols in SON

There are many routing protocols for SON. All of these routing protocols share certain key properties.

- Routes are chosen in a short amount of time.
- Packet transmission reliability is extremely high.
- Volume of service information is minimal.
- Loops are prevented.
- Routes can be found and recovered easily.
- Performance and scalability is high.

Based on how they work, SON routing protocols can be broadly classified into three different types [Wireless1].

- Proactive routing protocols: Service messages are sent across the network periodically. These messages contain any information relating to change in the network topology. Each node uses these messages to build a routing table. This table contains the optimal routes to all the other nodes.
- Reactive routing protocols: Routes are built to a particular node only when necessary and not saved in the table beforehand. The sender broadcasts a message to the entire network. The intended receiver transmits a confirmation message back to the sender. The sender uses the confirmation message to deduce the optimal route and stores it in the routing table.
- Hybrid routing protocols: These combine the mechanisms from both proactive and reactive routing protocols. The network is divided into multiple subnets. Each subnet has a proactive routing protocol. However, reactive routing protocol is used between the subnets. This helps reduce routing table sizes in large networks. It also helps reduce the volume of service traffic.

Routing protocols can use the following metrics in order to choose the optimal route from one node to another [Proskochylo14].

- 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. Global positioning system is used in order to acquire this information (geographic routing protocols).

Table 1 gives a comparison between different SON routing protocols.

Table 1: Comparison of SON Routing Protocols [Proskochylo14]

Routing Protocol	Metric	Type
Ad hoc On-Demand Distance Vector Routing	Hop	Reactive
Dynamic Source Routing	Hop	Reactive
Optimized Link State Routing Protocol	Hop	Proactive
Fisheye State Routing	Hop	Proactive
Landmark Routing Protocol	Complex	Hybrid
Zone Routing Protocol	Hop	Hybrid
Hybrid Wireless Mesh Protocol	Complex	Hybrid

The most popular routing protocols are Hybrid Wireless Mesh Protocol, Zone Routing Protocol and Landmark Routing Protocol. All three of these are hybrid routing protocols. These protocols use proactive routing to build the routing table. However, reactive routing is used in order to select the optimal route. Using hybrid protocols is the most efficient way to reduce the total amount of routing traffic in a network. This is because they have the advantages of both reactive and proactive routing protocols.

3.1 A Distributed Approach to Solving Multicast Routing in SON

Multicast routing is very important in SONs. However, due to its NP-Completeness, it is incredibly hard to implement efficiently in high performance networks.

Multicast routing algorithms can be divided into two different types: centralized algorithms and distributed algorithms. Although existing multicast routing algorithms can calculate an approximate solution however, they have significant drawbacks for SON implementation. For example, Kou-Markowsky-Berman is a classic centralized multicast routing algorithm. It can provide an appropriate approximate solution. However, it must know the topology of the entire network to do so. Thus, it is unsuitable for large dynamic networks.

The Distributed algorithm for Optimized SON Multicast Routing is a multicast routing algorithm for SON. It has a dynamic nature to support the dynamic characteristics of SON [Li14]. In this algorithm the information regarding a node is stored in the routing table. This is used to calculate the hops of multicast tree routing.

3.2 Controlled and Self-Organized Routing for Large-Scale Wireless Sensor Networks

Wireless sensor networks are comprised of numerous sensor and sink nodes. Sensor nodes monitor and collect sensory information. Sink nodes transmit the data obtained from sensor nodes to a data server. These networks can be used for a vast variety of applications such as wide-area monitoring. The main advantage of wireless sensor networks is that there is no need for a fixed network infrastructure.

One of the major problems regarding wireless sensor networks is that of routing scalability. As there are a large number of sensor nodes, the exchange of routing information is incredibly costly. It consumes a large amount of energy and bandwidth. In contrast to IP networks, nodes cannot be given unique IDs as it will result in excessive exchanges of routing information.

Self-organization can be used to decrease the amount of routing information exchanged in the network. Nodes use local information in order to choose the next hop. The fact that nodes only use local information results in local near-optimization. However, global network optimization cannot be guaranteed. Therefore, macro-scale network problems can occur. For example, uneven node distributions can cause large concentrations of loads in the network.

In potential-based routing, all nodes have a scalar value which is called potential [Kominami13]. A node calculates its potential based on the potentials of its neighbors, the number of hops to a sink node, its remaining energy or its neighbors' remaining energy. The node selects the next hop based on its potential value as well as that of its neighbors. Data transmitted from a node with a higher potential value to a node with a lower potential value will eventually reach a sink node. Potential-based routing suffers from the above mentioned problems as it is based on self-configuration.

Controlled Potential-Based Routing (CPBR) is a controlled and self-organized routing protocol which addresses these problems [Kominami13]. It is a variation of potential-based routing. A control node is added which is known as the controller. Sink nodes are used as observers. They monitor the network and send reports to the controller. The controller uses these reports to adjust the potential of the sink nodes. This results in the construction of an ideal potential field over the network. CPBR performance is inferior to centralized control performance. This is because all decisions are made locally. In centralized control decisions can be made to optimize the global performance. However, CPBR can address the scalability issues that centralized control suffers from and can reach near optimal performance under optimal conditions.

4 SON Function Conflict Resolution using Reinforcement Learning with State Aggregation

SON functions (like MLB and MRO) help automate network optimization. An instance of a SON function is a single realization of that function. It can govern one or more cells in the network by tuning different network parameters to optimize some KPI. Multiple instances of a SON function or different SON functions can share network parameters in the same time frame. This can cause conflicts between them.

These conflicts can be resolved using a SON Coordination (SONCO) function. This function can govern multiple instances of a SON function and different SON functions so that these conflicts do not occur. Different SON instances and functions do not change the network parameters directly. Instead, they send the SONCO a request to change them and the SONCO decides which request to execute.

There are two main approaches for designing a SONCO function. The first approach treats SON instances as black-boxes. Little to no information is known about the algorithms and inputs used in the SON functions. Conflicts are resolved based on instantaneous network conditions, and the outcome of past decisions are disregarded. An example of this type of approach is a SONCO function which attributes priorities to different SON functions and instances. The second approach treats SON instances as white-boxes. The SONCO function has complete information about the algorithms and inputs used in the SON functions. This approach is very complex to implement. If the SONCO is operator-centric then this approach is not always feasible, especially in a multi-vendor environment [Iacoboaiea14].

SONCO function design can be improved using reinforcement learning with state aggregation. SON functions and instances are treated as black-boxes. However, unlike other SONCO functions based on this approach, the outcomes of past decisions are not discarded. As SON functions are considered as black-boxes there will always be a certain degree of uncertainty relating to the SONCO’s decisions. The decisions may not resolve the conflict completely. This degree of uncertainty needs to be minimized. This is done by using a Reinforcement Learning (RL) framework in which the impact of past decisions is utilized [Iacoboaiea14].

The RL framework uses a centralized value function with a state-space table consisting of all the possible configurations of a set of network parameters to keep track of past decisions. The value function associates a regret parameter with each network configuration. New decisions are made by the SONCO function with the aim of minimizing this regret parameter. The RL algorithm is based on Markov Decision Processes.

The size of the state-space table scales exponentially with the number of cells in the network. For this reason, it is inconvenient to use a centralized value function for large networks. Instead, a distributed value function is used. The size of the state-space table of this function scales linearly with the number of cells.

5 P2P Technologies in Future LTE Self-Organizing Networks

Self-organization and management is becoming increasingly important in LTE networks. However, as SON features were not initially included in the development of LTE, their integration is proving to be complex. P2P on the other hand has had SON functionalities since the very beginning of its development. Therefore, different technologies and algorithms of P2P can be used to improve the efficiency of LTE SON.

There are four major useful technologies of P2P that can be used in LTE SON: architecture selection, resource search algorithm, topology aware and load balancing algorithm [Zhang12].

5.1 Architecture Selection

Each of the three architectures of LTE SON has a corresponding P2P topology. These topologies along with their application and characteristics can be used as reference when constructing a SON. Figure 4 depicts the three architectures of LTE SON and their corresponding P2P topologies.

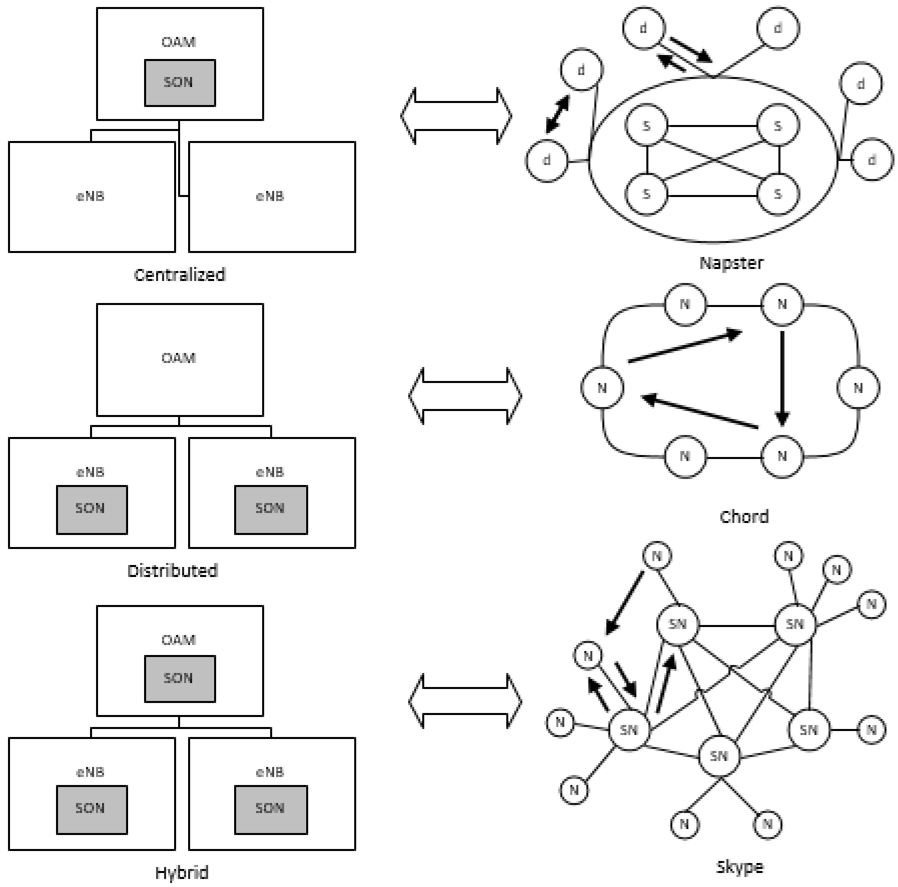

Figure 4: SON architectures and their corresponding P2P topologies [Zhang12]

The centralized topology of P2P can be taken as reference for centralized SON. In centralized SON architecture, all the configuration and optimization resources are located in the OAM. In P2P centralized SON, the indexes of the resources can be stored in the OAM. eNBs can search this index and acquire the resources from other eNBs.

The fully distributed topology of P2P can be taken as reference for distributed SON. In distributed SON architecture all resources are located in the eNB. In P2P distributed SON, eNBs can use Distributed Hash Table search algorithm to search for resources in other eNBs. Information and resources can be exchanged between eNBs.

The semi-distributed topology of P2P can be taken as reference for hybrid SON. In P2P hybrid SON resources are shared between eNBs and super nodes (powerful eNBs or the OAM). eNBs can query and acquire resources from super nodes. The indexes of the resources in eNBs are stored in their super nodes. P2P search algorithms like DHT can be used to search for the resources in the super node. Figure 5 shows how the hybrid SON architecture can be evolved using semi-distributed topology of P2P as a reference.

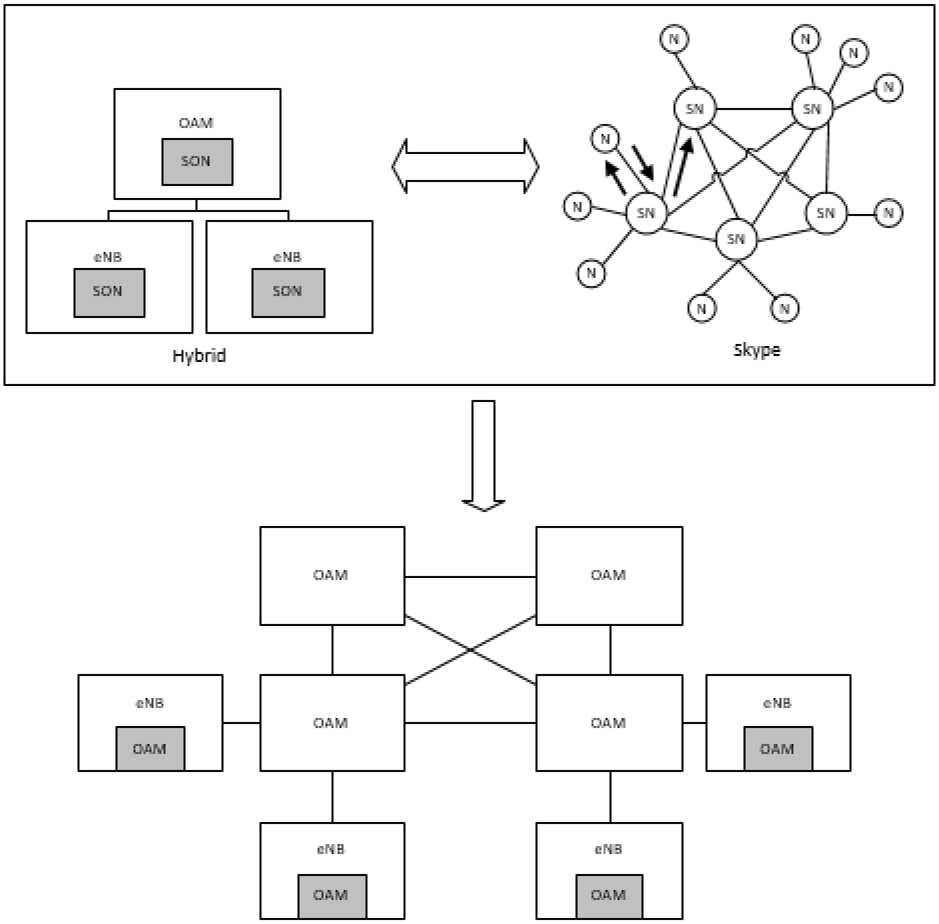

Figure 5: Evolved hybrid SON architecture [Zhang12]

5.2 Search Algorithms

In SON resources are distributed among the nodes. They are not stored in a central system. As a result efficient distributed search algorithms are required to locate resources. Classic P2P search algorithms like Distributed Hash Table and Juxtapose can be used for this purpose with appropriate modifications for SON.

5.3 Topology Aware

In LTE SON monitoring events of eNB joining and leaving the network as well as the setting up of ANR can be done using certain P2P topology aware technologies. For example, instead of using OAM to monitor a node, the successor of a node can be used instead to monitor it like in Chord.

5.4 Load Balancing Algorithms

Adjacent eNBs can be dynamically assigned loads using various P2P load balancing techniques. Information about loads can be shared between eNBs. Structured P2P systems contain load balancing algorithms that can be applied in LTE SON with minimal modifications.

6 Summary

SON and other network automation techniques show the most potential for mobile operators to handle providing ever-increasing performance services while at the same time reducing capital and operating costs. A large number of SON functionalities have been incorporated in 3GPP LTE since Release 8. These functions help facilitate operators in planning, deployment and optimization of complex mobile networks. There is a clear indication that mobile operators are shifting from using manual and static network operations to automated and dynamic ones. As a result, SON has become a key area of research and its standardization is currently ongoing. Technologies and experiences from older concepts can be used to improve and develop SON features. Architectures, search and load algorithms of P2P can be used with appropriate modifications to improve the efficiency of SON. RL can be used in SON function conflict resolution to learn from the impacts of past decisions. In this paper, we summarized the features and the advantages of SON functions and routing protocols. We provide possible solutions on improving SON architecture, routing and function conflict resolution. Topics relating to future developments and research works in SON are also discussed.

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List of Acronyms

SON	Self-Organizing Networks
KPI	Key Performance Indicators
QoS	Quality of Service
3GPP	3rd Generation Partnership Project
LTE	Long Term Evolution
NGMN	Next Generation Mobile Networks
P2P	Peer to Peer
NM	Network Management
DM	Domain Manager
NE	Network Elements
eNB	Evolved Node B
ANR	Automatic Neighbor Relations
UE	User Equipment
PCI	Physical Cell Identifiers
OAM	Operations, Administration and Maintenance
MRO	Mobility Robustness Optimization
MLB	Mobility Load Balancing
MDT	Minimization of Drive Tests
SEMAFOUR	Self-Management for Unified Heterogeneous Radio Access Network
CPBR	Controlled Potential-Based Routing
SONCO	SON Coordination
RL	Reinforcement Learning

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