ISSN No. 0976-5697

Volume 4, No. 4, March-April 2013

International Journal of Advanced Research in Computer Science

RESEARCH PAPER

Available Online at www.ijarcs.info

Self-Organizing-Healing Paradigm for Mobile Networks

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Abstract: Mobile communication has grown rapidly and with this growth comes heterogeneity due to multiple radio access technologies (RAT) and varying network architectures. Networks have become very difficult, complex, time consuming, and costly to manage. The need for operators to overcome these problems triggers this research on Self-Organizing -Healing Networks (SOHNs). More attention is now being focused on Self-Organizing Networks (SONs) by international standardization organizations as one of the key technologies for combating some of these complexities. Our research on SOHN focuses on the following functionalities; Self-organization, Self-configuration, Self-optimization, and Self-healing. Recent researchers have concentrated on self-configuration and self-optimization with little work done in the area of Self-organization and self-healing. This article highlights the four key functionalities, with emphasis on self-organization and self-healing. Furthermore, a self-organizing-healing framework has been proposed, and possible research areas outlined.

Key-words*:* Self-Organization, Self-Healing, Self-Configuration, Mobile Communication Network

I. INTRODUCTION

The introduction of new technologies and services in wireless networks has brought about more complexities in managing such networks. Current trends suggest a future of highly heterogeneous networks as different radio access technologies (RAT) such as GSM, Long Term Evolution (LTE), EDGE, etc, network architectures and transmission solutions will coexist. As expectations of customers on quality of service (QoS) and wider network coverage increase, network solution providers will strive to offer a higher QoS at minimal cost in order to maximize profit. More efficient strategies and algorithms have to be incorporated in order to reduce operational expenditures (OPEX). However, as the number of services, cell types, and technologies grow, so thus complexities in network planning and operation. To overcome these complexities, automation of most procedures in the network is necessary, with a view to having an autonomously managed network. Network optimization therefore becomes very vital in the life cycle of mobile systems. However, most network optimization and fault management procedures are still being done manually at present. An SON is a network that can self-configure, self-optimize, and self-heal [1].

There is need, therefore, for a Self-Organizing-Healing Network (SOHN). Universal deployment of Long Term Evolution (LTE) networks alongside GSM/UMTS/HSPA is forcing network operators to develop SOHN mechanisms in order to stay alive and remain in the competition. Operators are looking for proper strategies and advanced technologies to reduce OPEX of their networks. This has led to various research, investing into the development of newer technologies and more efficient network architectures such as mobility load balancing (MLB) for LTE networks [9, 5].

Again, deployment of small cells in large scale and their interactions with macro cells make the functions of SOHN vital in such huge network operations. The Next Generation Mobile Networks (NGMN) Alliance identified SON as a major design principle for next generation networks [8]. The Third Generation Partnership Project (3GPP) also included SON in its standards as a key element for the deployment of LTE in Release 8, and with enhancements in Releases 9 and 10.

II. FRAMEWORK FOR SELF-ORGANIZING-HEALING NETWORK

The framework of our proposed Mobile Network with self-organization-healed capacity is a wireless communication system with four main functionalities which are as follows:

a. Self-Organization: this involves the network structure (Nodes, Links, Node Capacity, etc.) and the dynamic changes this structure can undergo while in operation.
b. Self-Configuration: this includes functions for network deployment and configuration of its parameters. Because of auto-configuration, network elements can start in an autonomous mode, run setup routines; configure initial parameters, and so on.

c. Self-Optimization: in charge of automatically tuning parameters such as updating list of neighbouring cells, traffic balance, handover, etc. These should be recalculated dynamically according to changes in traffic and network conditions.
d. Self-Healing: this includes functions that can help the network cope with service degradation or disruption, such as fault detection and diagnosis mechanisms for compensation during outage. Fig. 1 compares a network operation with SOHN functionality and a manually managed network.

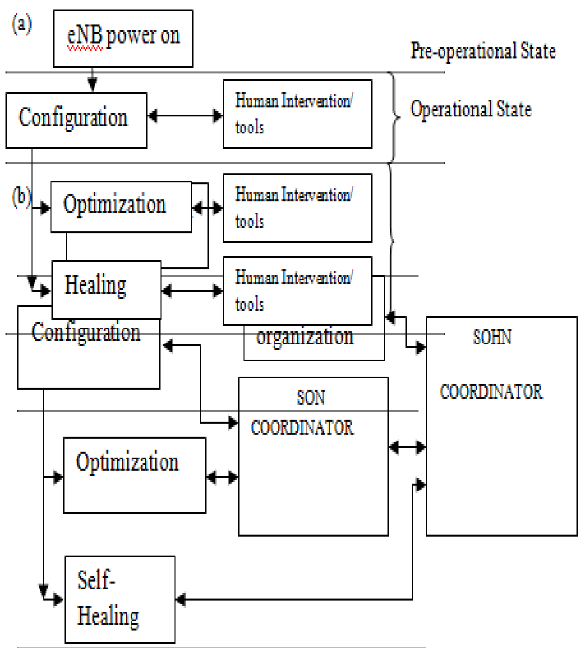

Figure 1: (a) Network operation without SOHN functions (b) with SOHN functions

The self-configuration ability enables fast installation and deployment of future evolved nodeBs (eNBs) which minimizes deployment time and manual management. The newly added eNBs can also be deployed in a plug-and-play approach. Thus, self-configuration is most useful during the pre-operational stages of a wireless mobile network. In terms of comparison, self-optimization techniques such as MLB helps a mobile network to automatically select and make adjustments to system parameters and proper algorithms in order to achieve service coverage and optimal system capacity. Self-organization is therefore an important requirement for the operational state of mobile wireless networks. Lastly, self-healing ensures that operators recover a network when it fails due to one or more unknown reasons. This property is event-driven, and is necessary during system failures.

Recent years has seen concentrated research activity on SONs, especially in the European Union Projects Framework. The ones that have been most meaningful are: FP7SOCRATES [1], FP&E3 [2], and CELTIC Gandalf [17]. However, most of these studies concentrate more on the aspects of self-configuration and self-optimization in SON, with self-healing getting little attention [10, 3]. Contrastingly, finding and resolving faults is a major concern for network operators and vendors. The scarce number of studies in self-healing may be as result of difficulty in defining the most common faults and their main symptoms in mobile communication networks. Literature is scarce and known mostly to some experts who have their own means of identifying and resolving faults based on field experiences. Another possible reason may be the difficulty of evaluating the performance of a self-healing system, since using a simulator to model most of the faults is highly complex and obtaining historical data on faults from live networks is almost impossible. As a result, there only exist incomplete studies on self-healing and the available ones have been as a result of collaborations between vendors, operators, and academia. Additionally, available studies are based on specific scenarios and therefore not all – encompassing.

A cell failure traditionally implied that users in that cell would not receive service until the cause of the fault is located and resolved. Consequently, a large chunk of OPEX is devoted to fault-cause-identification and resolution in current networks. Futuristically by means of self-healing mechanisms, networks will be able to quickly solve their faults autonomously, thus increasing the time for resource utilization. At the same time, users in the “failed” cell will still have access to service as this will be provided by neighbouring cells even though the services may not be at its zenith.

In this article, we present Self-organization, self-configuration, self-optimization and self-healing in mobile networks. An illustration of a self-configuration mechanism for newly added eNBs without a dedicated backhaul interface is provided. A distributed MLB algorithm with low handover cost for LTE networks is evaluated. We then propose a reference model for self-healing which comprises of functions that have been studied in accessible references. This is followed with major challenges researchers are currently facing in the area of self-healing. Lastly, we summarize our findings and conclude our discussions.

A. Function of SON Coordinator:

There are two (2) basic ideas behind SON coordinator, namely:

(a). To perform a low-level coordination of automatically operating SON functions so as to prevent or resolve SON function conflicts
(b). To give control over the SON-enabled system to the human operator, or allow a governance of the SON function behavior based on high-level operator requirements without the need of continuous interaction between human operator and the management system.

The SON coordinator can determine how to deal with conflicting SON functions, for example, whether the optimization of a set of cells should be continued or the changes of cell sizes is related to failure recovery and should therefore be prioritized.

B. Goals of SON Coordinator:

The tasks of a SON function coordinator in a SON are to:

(a). Prevent undesired SON function conflicts
(b). Support required SON function interactions
(c). Enforce management goals as well as operational policies
(d). Ensure a very high efficiency for the overall SON System

Decision trees are usually used to express the decision logic that needs to be applied to respond to a SON function instance execution request. They capture dependencies and interaction of a given function with other deployed functions and also provide a sequence of events for each SON function that need to be evaluated in order to take a coordination decision [14]. A SON function coordinator will use the decision trees and combine them with impact area for the given SON function instances and times to come to a coordination decision.

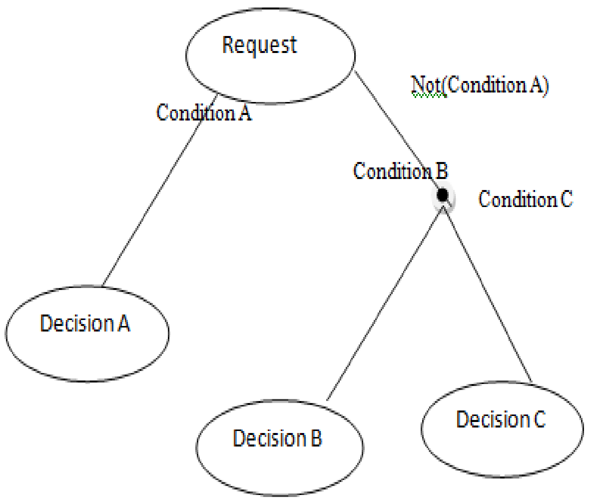

Figure 2: Generic Decision tree for SON function Coordinator

The root of the tree represents the SON function execution request. The decision logic is annotated at the edges between the nodes. This logic forces the SON function Coordinator to perform different types of evaluations:

Check whether one or more SON functions are currently active within the impact area of the requested SON function Evaluate the requested changes whether they are in conflict with previously executed changes to the targeted NEs.

It is sufficient if the coordination function has access to the information on the currently active SON functions affecting the impact area and impact times of the requested function. In case there is no information about SON functions within the impact area of the requested function, the SON function execution is instantaneously acknowledged.

C. Function of SOHN Coordinator:

In addition to the services provided by SON coordinator, SOHN coordinator provides among others the following:

(a). For a communication session the SOHN establish a sub-network that is capable to handle that session.

(b). Based on the above, multiple sub-networks could be established to handle concurrent communication sessions.

(c). The continuous change of state/structure or change on demand that is facilitated by the neural network implementation of the self-organization functionality help to provide alternative routes in the face of failure of some nodes or links.

D. Overview of Self-Organization:

A self-organizing network based on radio communication or any other means of communication is bound to create its own connections, transmission schedules, topology, and routing patterns in a distributed manner. The implementation of self-organization functionality is dependent on neural network paradigm where an instance of a set of input is used to select an appropriate system state for a communication session thus a local hub, gateways, relays, and backbone network may be established. A common drawback for this type of network is the hidden terminal problem.

When the current topology needs to be updated, single or multiple routes are maintained between node pairs. The topology is either updated in respect to route length (path – aware) or energy consumption (energy – aware), with low overheads in terms of discovery, transmission and control, or update messages. A self-healing and optimizing route technique (SHORT) in which the on-demand routes are monitored by nodes to obtain an improved local sub-path could be employed.

E. Overview of Self-Configuration:

Self-configuration process is defined as a process where the newly deployed base stations (eNBs) are configured by automatic installation procedures to get basic parameters and download necessary software for operation [17]. Conversely, self-configuration can also be applicable where failure cases combine with fast failure detection mechanisms to provide automatic failure recovery or compensation mechanisms. Self-configuration happens at the pre-operational state. First, an eNB obtains its IP address and that of the operation, administration, and management (OAM) centre. It is then authenticated on the network after which it obtains an access gateway (aGW). The next step involves the eNB downloading the required software and operational parameters. Lastly, the eNB configures the neighbor list and information about coverage/capacity parameters based on the downloaded information and enters into operational state.

In conventional cellular systems an eNB has two interfaces at the minimum, namely, the air to user equipment (UE) interface and the backhaul interface to the core network. Self-configuration processes use the backhaul interface. The main point of implementing the self-configuration function is how the eNB gets its IP address and connects to the configuration server. Several solutions exist to this problem. The eNB can simply use a Dynamic Host Configuration Protocol (DHCP) or Bootstrap Protocol (BOOTP) agent to obtain its IP address. The DHCP or BOOTP packets can only be transmitted in the same subnet. If available backhaul link routers do not support one or both of these protocols, other schemes are available to choose from. For example, the eNB can be added into a multicast group of routers and a configuration server using the Internet Group Management Protocol (IGMP) [10] and the multicast IP packets receive the configuration information.

This self-configuration procedure is based on the assumption that the eNB has a dedicated backhaul interface (Time Domain Multiplexing or Ethernet) with which it connects to the configuration server.

There may be scenarios, however, where the eNB does not use the backhaul interface to communicate. The possible scenarios could be:

(a). An eNB with a physical backhaul interface is deployed for temporal coverage at a location with no matching interfaces.

(b). An eNB with no dedicated backhaul interface, but the Radio Access Technology hosts the backhaul transmission protocols of eNB as proposed in [3].

Moreover, next-generation cellular systems might come with higher operational frequency thereby resulting in the use of eNB with a higher density as well. This increases the possibility of an eNB with a dedicated backhaul interface. When this happens, the traditional self-configuring solutions cannot work, and may result in the need for a more flexible mechanism. To power the self-configuration process, [4] have proposed the newly deployed eNB to initially boot up in UE mode, and then connect to already configured neighbor eNB to download its configuration parameters and software, before entering operational state. The figure below illustrates the neighbor assisted self-configuration procedure.

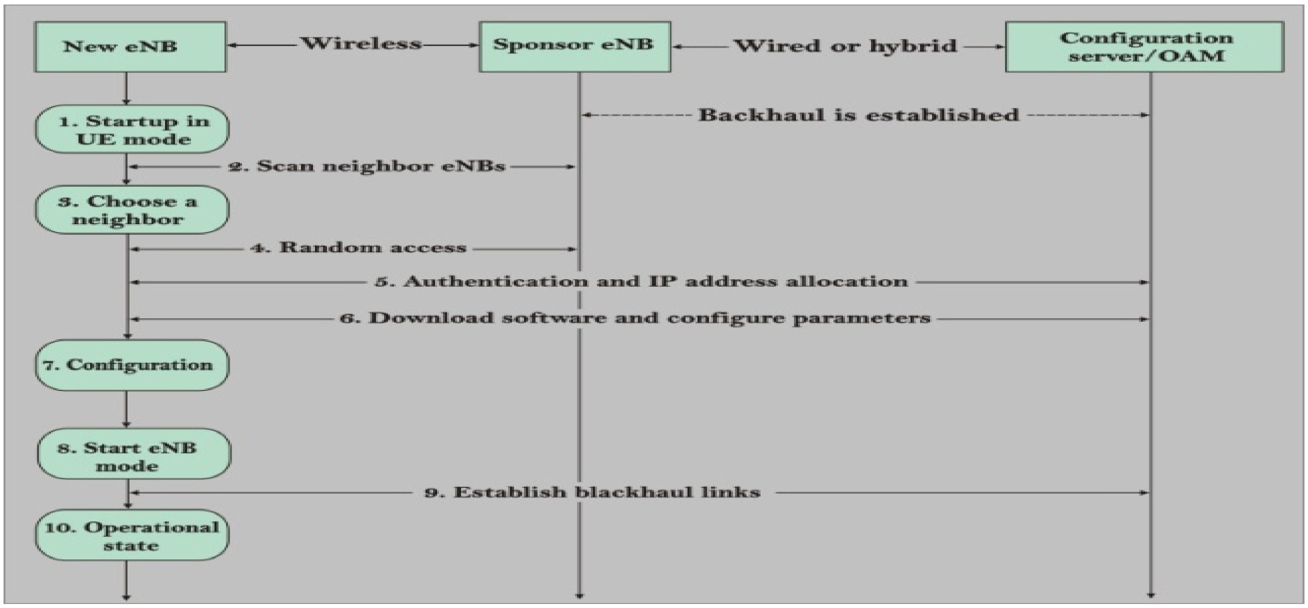

Figure 3: Neighbor eNB assisted self-configuration procedure

Steps:

a. Newly powered eNB starts up in UE mode which doesn't need to be configured
b. The new eNB scans neighbor cells and chooses one of the neighbor eNBs that already has a backhaul link as its sponsor eNB.
c. The new eNB accesses the sponsor eNB by a random access procedure
d. The new eNB sends authentication information to sponsor eNB. The sponsor eNB forwards the authentication request to OAM if it finds that the request is from the new eNB.
e. After the new eNB is authorized, OAM sends the IP addresses of the new eNB, the aGW, and the configuration server to the sponsor which then forwards the IP address to the new eNB
f. The new eNB connects to the configuration server, and then downloads the software and operational parameters
g. The new eNB then installs the software and configure itself
h. The new eNB terminates the UE mode and switches to eNB mode
i. The new eNB establishes backhaul connection with both the neighbor eNB and the core network
j. Self-configuration procedure terminates and the new eNB enters the operational state.

F. Overview of Self-Optimization:

Mobile users and the resultant traffic flow in cellular networks are random, time varying, and unbalanced which makes cell loads to be unequal in a system. A high number of overloaded UEs may exist in some cells, while some other cells have very few UEs which imply that resources are not fully utilized. Resources can be efficiently utilized through optimal network management and planning. However, network practices currently in use have not been able to totally solve the Load Balancing problem in LTE systems, and several factors are responsible for this. First, rapid development of network application and services, and sudden increase in demand for resources make resource shortage a common occurrence. Secondly, the unpredictable nature of traffic flow makes it difficult to plan pre-fixed networks to dynamically adapt to the varying load in a timely manner.

A possible solution to load balancing is the handover process which involves shifting some UE at the borders of overlapping or adjacent cells to less congested cells. This balances the load and improves system performance, though with a heavy trade-off on system resources. The involved UE may experience performance degradation and system delay in the process. Thus, if handover happens frequently, performance improvements gained by the more balanced traffic load cannot compensate for performance loss cause by handovers. [4] have demonstrated how a modified MLB algorithm with penalized handovers can be used to balance unequal load, improve system performance, and minimize the number of handovers that can occur. The algorithm is summarized below:

(a) Each UE computes the weight W(u, c) for each cell c with which it is able to communicate
(b) The greedy algorithm [16] is run to solve the MWM problem approximately based on the weights computed in step 1

(c) If UE is assigned to cell c, which is not the current serving cell, UE(u) hands over toward cell c.

This algorithm can be run as many times as possible at varying frequency and varying time to balance various aspects of the algorithm, such as performance and system overhead.

G. Self-Healing Concepts:

The need for self-healing arises when there is a problem in a cell. Any situation that has a degrading effect on the service is a problem, and there is no standardized way or ways of identifying them. Self-configuring and Self-healing wireless networks implement two (2) major mechanisms, namely; route discovery between node pairs and current topology update. This is done by first detecting link failures followed by optimizing routes obtained through discovery. The discovery can be proactive, in which case routes between any pair of nodes are periodically sought, or on-demand, when only certain routes are required. Different operators use different parameters or measurements; and any measurement whose observed value might help in fault identification is termed a solution.

Self-healing is different from fault management. In 3GPP, the objective of fault management is to detect failures as they occur and to ensure, as much as possible, that they have minimal effect on QoS. Assuming this process happens autonomously, we may then conveniently say that this is self-healing. Even so, there are still differences between these two concepts. Fault management is usually linked to alarms generated by Network Elements (NEs) [7]. NEs use autonomous self-checking procedures, which includes comparing counters to known thresholds in order to generate alarms that point to the faulty NE. self-healing functions encompass more in terms of causes and symptoms, the reasons being that:

(a). Numerous instances abound when an abnormal behavior in a cell is not caused by a NE. for instance, shadowing due to a change in propagation conditions may result in increased number of dropped calls in a given area.

(b). Abnormal behaviours not related to NEs could be as a result of bad parameter definition rather than a fault.

(c). Normally, it is impossible to determine the fault cause from the number of alarms because a single fault may generate multiple alarms, and multiple faults may generate a single alarm. Some alarms may even be activated due to a change or some changes in network conditions rather than a fault. Alarms only identify the fault cause in simple cases [7]

H. Self-healing vs. Self-Optimization and Self-Configuration:

The three functionalities of SON work at different stages of the network and based on the scenario in which they are executed. Self-configuration would operate in the network deployment phase and in the operational phase when reconfigurations are carried out. Self-optimization works when there are no clear problems in a cell. The cell works well; its performance can still be improved. Self-healing would work perfectly well in cells where the cell is degraded or failed. Accordingly, all three SON functions will change network parameters – setting initial configuration for self-configuration, auto-tune cells performing normally for self-optimization, and changing parameters of cells with degraded or failed service for self-healing.

I. A Self Healing Reference Model:

A framework for self-healing is proposed in the figure below. The framework congregates and integrates different functionalities and terms that have been identified independently by network operators and vendors, used in standards, and partly studied by other authors. These functions can be implemented with minimal human inputs.

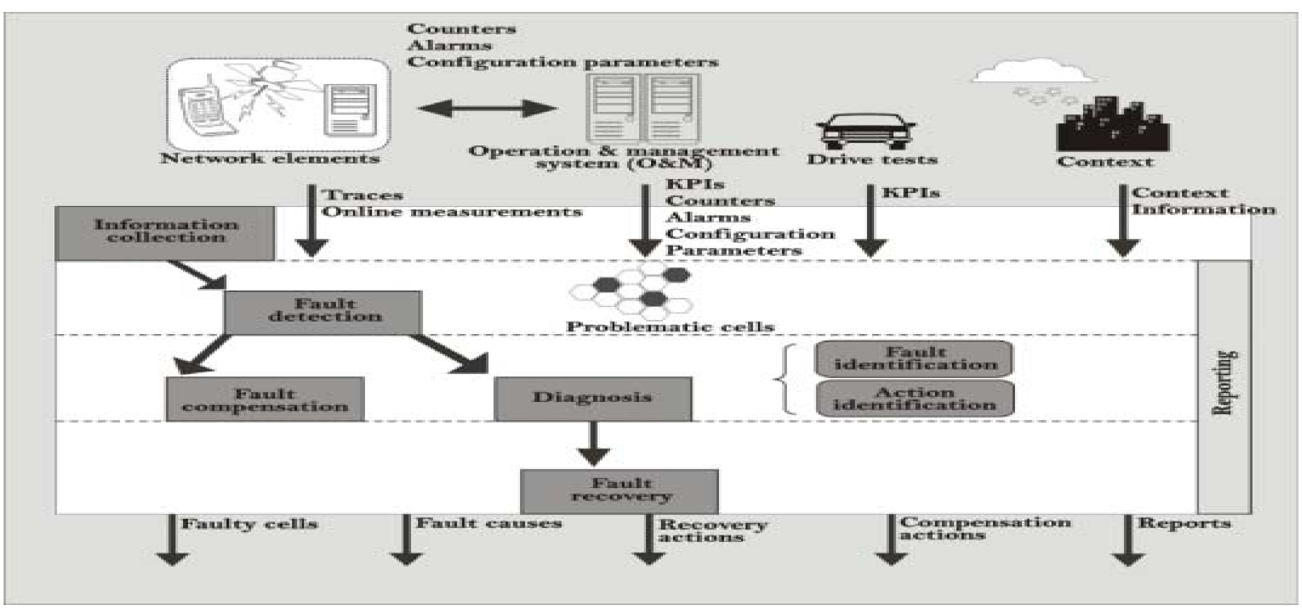

Figure 4: Self-healing Model

a. Information Collection: this is the function responsible for collating input information used by the self-healing process. The more detailed the information is, the faster it takes to identify and resolve the failures. The following are some common information sources used by operators.

b. Configuration parameters: information about the NEs configurations and network resources
c. Alarms: messages generated by NEs when faults occur
d. Network counters: measurements from the NEs transferred intermittently to the Operations and Management System (O&M). Such measurements could be traffic load and availability of resources
e. Mobile traces: information from specific network users
f. Real time monitoring: online measurements of specific items (e.g. traffic load)
g. Drive tests: field measurements related to coverage and interference
h. Key Performance Indicators (KPIs): combinations of other elements used to describe the failure or success rates of most important events
i. Context information: information about the environment or environmental conditions.

All or some of these information sources may be considered. Operators currently use statistics information from the O&M to identify faults.

III. DISCUSSION

There are diverse areas of research and technical challenge in the self-healing functionality of SONs, given the fact that it is the least investigated functionality. Key research areas available in the aspects of self-healing include, but not limited to the following:

A. MULTI-RAT Networks:

A large number of parameters used in self-healing function are dependent on technology of access used. Though many of the available techniques work for all RATs, each RAT has its own fault causes and symptoms as seen in [11] for GSM and in [10] for UMTS. In numerous instances, both the parameters and methods used to implement the self-healing functions will have to be modified to the specific RAT, for example, cell outage compensation in LTE as described in [3]. This implies that new studies will have to be carried out for each new RAT. Again, since all previous references focus on a single type of cell and RAT, self-healing in heterogeneous networks is a key research area.

B. Techniques for Self-Healing Functions:

Only a few methods (e.g. Bayesian Networks for Diagnosis) have so far been proposed for the implementation of each function in self-healing. Many other techniques such as from the fields of artificial intelligence and statistics can still be explored and tested for each function. There are also several problems to be solved for each of these functions. For example, fault compensation methods automatically adjust neighbouring cell parameters can be investigated.

C. Multilayer Networks:

Heterogeneous networks will include several femtocells, relays, and picocells within the macrocell. When LTE and LTE-Aare implemented, dynamic network topologies will have to be managed, since femtocells and relays could be switched off temporarily or moved to other places. The fact that the knowledge of neighbours is only partial complicates the self-healing functionality. Detection and diagnosis should therefore consider all layers as faults in a given layer may be due to problems in another area. Cell outage compensation is also a key research area, since outage in a particular layer may cause another higher layer to provide the service.

D. Sources of Information:

The main input data for fault detection and diagnosis considered in previous references are alarms and KPIs obtained from the O&M. On-line measurements from base stations and user terminals, data from drive tests, and context information are other data sources. Combining these data from different sources and different time-scales to improve diagnosis accuracy is also a key research issue.

E. Combination between Self-Healing and other SON functionalities:

Since real networks are interconnected, some key network parameters are affected by all the three SON functionalities. Though self-healing has been studied independently in existing references, we consider it in conjunction with other functionalities to proffer SOHN, especially self-optimization, because of the following reasons:

a. An incorrect radio parameter, such as low power transmission, is a typical example of a fault case that may cause problems in a cell. Within SON, self-optimization is responsible for tuning the network parameters in order to achieve optimum network operation. There wouldn't be a problem with bad parameters in the first place if self-optimization was perfect. Since it is not perfect, and even optimized parameters can have incorrect values if not properly coordinated. Once a fault has been identified by the self-healing process as being caused by a bad parameter, self-healing should collaborate with self-optimization algorithms affecting that parameter.
b. Fault compensation normally modifies parameters that are also tuned by self-optimization algorithms (e.g. handover parameters, power, and antenna tilt). A joint strategy between self-healing and self-optimization is therefore considered in our pursuit of SOHN implementation.

IV. CONCLUSION

While SON has been identified as one of the key technologies for minimizing OPEX in future wireless networks, Our SOHN attempt to mitigate all factors working against Network's optimum performance. In this article, we have attempted to unify the concepts of SON, combine self-organization, self-healing to other functionalities to peep into the future mobile networks that can self-exist (SOHN). Most of the work in self-healing has been carried out in the framework of European research projects, such as SOCRATES. Articles are limited, and even the available ones emphasize on specific aspects of self-healing. In SON, the first operational state is known, the configuration/ reconfiguration of the state happened in the course of operation, when a fault is detected. In Our proposed SOHN, the incorporation of self-organization technique based on neural network ensures that the state at the onset is not known and is chosen based on the set of inputs (internal and external). Hence the best or optimal system state is chosen autonomously during operation, thus the likelihood of error occurrence is reduced.

Since there has not been much work done in this research area, the research potential is huge. The most vital technical challenges have been presented in this article.

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