Self-Optimizing Networks in 3GPP Release 11:
The Benefits of SON in LTE

October 2013

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1 INTRODUCTION

1.1 GOALS OF THIS WHITE PAPER

In today's mobile wireless networks, many network elements and associated parameters are manually configured. Planning, commissioning, configuration, integration and management of these parameters are essential for efficient and reliable network operation; however, the associated operations costs are significant. Specialized expertise must be maintained to tune these network parameters and the existing manual process is time-consuming and potentially error-prone. In addition, this manual tuning process inherently results in comparatively long delays in updating values in response to the often rapidly-changing network topologies and operating conditions, resulting in sub-optimal network performance.

The recent deployment of LTE to address the growing data capacity crunch, has highlighted the need and value of self-organizing capabilities within the network that permits reductions in operational expenses (OPEX) during deployment as well as during continuing operations. Self-optimizing capabilities in the network will lead to higher end user Quality of Experience (QoE) and reduced churn, thus allowing for overall improved network performance. Self-Organizing Networks (SON) improve network performance, but in no way replace the wireless industry's important need for more spectrum to meet the rising mobile data demands from subscribers.

This paper is an update of the paper published in 2011, *Self-Optimizing Networks: The Benefits of SON in LTE*, that addressed the rationale for SON and the description of SON features in 3GPP Releases 8, 9 and 10. This paper also focuses on the SON use cases that play an important role in the operation of multi-vendor Heterogeneous Networks comprising of macro and metro cells. Multi-vendor aspects of these SON use cases are addressed in detail. Various architecture options and tradeoffs as it relates to the implementation of SON use cases for multi-vendor HetNets are described as well.

2 3GPP EVOLUTION AND SON

2.1 LTE SON HIGH-LEVEL SCOPE AND TIMELINE

3GPP initiated the work towards standardizing self-optimizing and self-organizing capabilities for LTE in Release 8 and Release 9. The standards provide network intelligence, automation and network management features in order to automate the configuration and optimization of wireless networks to adapt to varying radio channel conditions, thereby lowering costs, improving network performance and flexibility. This effort continued in Release 10 with additional enhancements in each of the above areas and new areas allowing for inter-radio access technology (I-RAT) operation, enhanced inter-cell interference coordination (e-ICIC), coverage and capacity optimization (CCO), energy efficiency and minimization of operational expenses through minimization of drive tests.

Figure 1 provides the standardization timelines for the different 3GPP LTE releases, throughout which SON capabilities have been developed and enhanced.

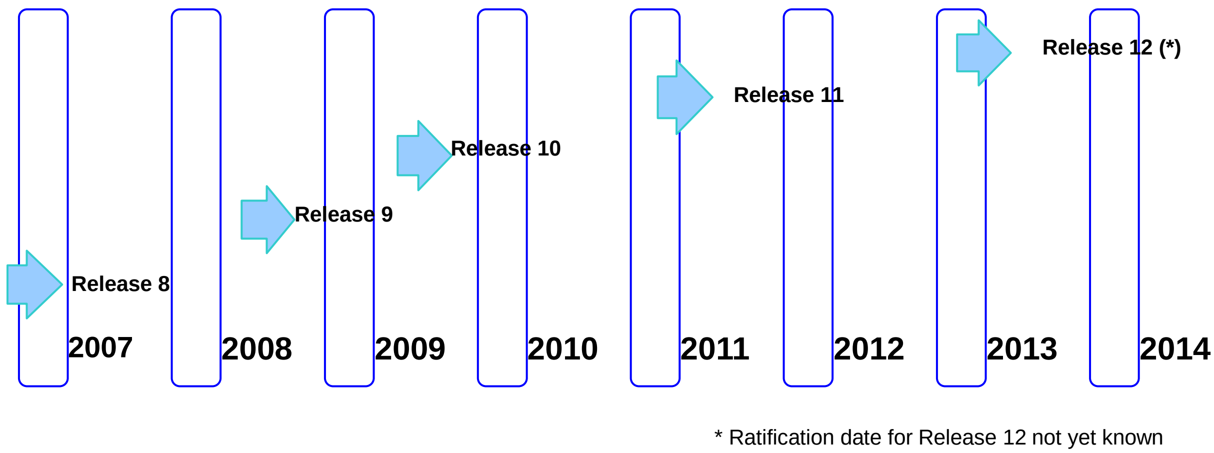

Figure 1. 3GPP LTE Specifications Timelines.

A key goal of 3GPP standardization has been the ability to support Self-Organizing Networks (SON) features in multi-vendor network environments. Therefore, a significant part of the SON standardization has been devoted to defining the appropriate interfaces to allow exchange of common information which can then be used by each SON algorithm. The SON specifications have been built over the existing 3GPP network management architecture defined over Releases 8, 9, 10 and 11. These *management* interfaces are being defined in a generic manner to leave room for innovation on different vendor implementations. In addition to specifying the interfaces, 3GPP has defined a set of LTE SON use cases and associated SON functions.[1] The standardized SON features effectively track the expected LTE network evolution stages as a function of time, following expected commercial network maturity. As such, in Release 8, SON functionality focused on procedures associated with initial equipment installation and integration to support the commercial deployment of the first LTE networks, also known as 'Enhanced Node Base Station (eNB) self-configuration'. These procedures included:

- Automatic Inventory
- Automatic Software Download[2]
- Automatic Neighbor Relation (ANR)[3]
- Automatic Physical Cell ID (PCI) assignment[4]

Following this reasoning, in Release 9 SON functionality focused on the operational aspects of already commercial networks, in particular key aspects related to network optimization procedures. The Release 9 standardization scope included these additional use cases:

- Mobility Robustness/Handover optimization (MRO)
- Random Access Channel (RACH) Optimization
- Load Balancing Optimization
- Inter-Cell Interference Coordination (ICIC)

Release 10 provides a richer suite of SON functions for macro and metro networks overlaid on and interoperating with existing mobile networks. It includes enhancements to existing use cases and definition of new use cases as follows:

- Coverage & Capacity Optimization (CCO)
- Enhanced Inter-Cell Interference Coordination (eICIC)

- Cell Outage Detection and Compensation
- Self-healing Functions
- Minimization of Drive Testing
- Energy Savings

Release 11 provides enhancements to the following features:

- Automatic Neighbor Relations
- Load Balancing Optimization
- Handover Optimization
- Coverage and Capacity Optimization
- Energy Savings
- Coordination between various SON Functions
- Minimization of Drive Tests

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of each of the features and their respective benefits.

The SON standards are a work in progress and SON-related functionality will continue to expand through the subsequent releases of the LTE standard, Release 11, 12 and beyond, to cover all key aspects related to network management, troubleshooting and optimization in multi-layer, multi-RAT and heterogeneous networks.

2.2 SON DEVELOPMENTS IN NGMN

In 2006, a group of operators created the Next Generation Mobile Networks (NGMN) Alliance with the objective to provide business requirements to the new technologies being developed. In practice, NGMN recommendations provide guidance to the technical standards being developed for LTE, indicating the key use cases that are most important for carriers' day to day operations. These use cases have been identified by the operators as the typical tasks that will be performed by their engineers in their day-to-day operations; therefore, a better system of integration and automation would result in a more efficient utilization of the operator resources, both material (spectrum, equipment, etc.) and human (engineering time).

NGMN's first white paper included high-level requirements for Self-Optimization Network strategies[5], and sometime later a concrete set of use cases was defined, covering multiple aspects of the network operations including planning, deployment, optimization and maintenance[6].

NGMN's Top (P-OPE) Recommendations (Sep 2010), Sec. 4.2.3 provided the following generic use cases for Radio Access Network (RAN):

- Automatic optimization of coverage and capacity related parameters in dependency of related Key Performance Indicators (KPIs) and thresholds
- Automatic optimization of Quality of Service (QoS) and Grade of Service (GoS) related parameters (i.e. adaption of scheduling and / or RACH parameters) in dependency of related KPIs and thresholds
- Automatic optimization of mobility and handover related parameters (i.e. cell individual offsets, down tilts, Event A related parameters) in dependency of related KPIs

- Automatic optimization of cells or services in outage based on an unambiguous detection of this outage

Table 1 lists the top 10 use cases indicated by NGMN, many of which have already been introduced in the 3GPP standards.

Table 1. NGMN Use Cases.

1	**Plug & Play Installation**
2	**Automatic Neighbor Relation configuration**
3	**OSS Integration**
4	**Handover Optimization**
5	**Minimization of Drive Tests**
6	**Cell Outage Compensation**
7	**Load Balancing**
8	**Energy Savings**
9	**Interaction home/macro BTS**
10	**QoS Optimization**

For SON functions based on northbound interface (Itf-N), the NGMN recommendations have set the general goal of out-of-the-box interoperability between Operation Support System (OSS)/ Business Support System (BSS) and the Network or Element Management System (EMS), based on open interfaces, which would also allow for 3rd party software integration. In 3GPP, the NGMN top OPE recommendations were taken as the guideline for development of SON specifications where SA and RAN Work Groups were strongly involved.

Some recent developments in Next Generation Mobile Networks (NGMN) related to heterogeneous networks are outlined below:

> The NGMN Project Small Cells has been launched in 2013 with the objective to define scenarios, use cases, system architecture and functional requirements for the fast and efficient introduction and operations of Small Cells. The work-streams of the project activity will deal in particular with the aspects of Wi-Fi integration, cost efficient deployment, operational issues, multi-vendor deployment and backhauling for Small Cells[i].

[i] "NGMN Alliance Pushes for New Work Program", Press Release 11.3.2013.

The "multi-vendor deployment" work-stream[ii] of the project has the general objective of solving potential interoperability issues in multi-vendor small cells or HetNet deployments with a particular focus on SON features.

The Project Small Cells is working closely with Small Cell Forum to ensure that work in both organizations is closely aligned.

3 KEY LTE SON FEATURES, RELEASE 11 SON UPDATES AND MULTI-VENDOR ISSUES

3.1 BASE STATION SELF-CONFIGURATION

The deployment of a new network technology is a major investment for any service provider. The objective of the Self-Configuration SON functionality is to reduce the amount of human intervention in the overall installation process by providing "plug and play" functionality in the eNBs. Self-Configuration is a broad concept which involves several distinct functions that are covered through specific SON features, such as Automatic Software Management, Self Test and Automatic Neighbor Relation configuration.

There have been no updates to the self configuration features after Release 10. The reader should refer to the 4G Americas *Benefits of SON* white paper released in 2011 for a description of the feature and its benefits.

3.2 AUTOMATIC NEIGHBOR RELATION (ANR)

One of the more labor-intensive areas in existing radio technologies is the handling of neighbor relations for handover. It is a continuous activity that may be more intense during network expansion but is still a time-consuming task in mature networks. The task is multiplied with several layers of cells when having several networks to manage. With LTE, one more layer of cells is added and the development of small cells further increases the number of neighbor relations; thus optimization of neighbor relations may be more complex. Even with the best methods at hand, due to the sheer size of large radio networks – with several hundred thousands of neighbor relations for a single operator – it is a huge undertaking to maintain the neighbor relations manually. Neighbor cell relations are therefore an obvious area for automation, and Automatic Neighbor Relation (ANR) is one of the most important features for SON. To explore its full potential, ANR must be supported between network equipment from different vendors. ANR is, therefore, one of the first SON functions to be standardized in 3GPP.[7]

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of ANR features and its benefits.

[ii] http://www.ngmn.org/workprogramme/small-cells.html

3.2.1 RELEASE 11 UPDATES TO ANR

Prior to Rel-11, focus was on E-UTRAN ANR. Rel-11 ANR focuses on the management aspects of ANR for UTRAN and IRAT ANR, specifically defining the following SON use cases in the context of UTRAN Automatic Neighbor Relation (ANR), including:

- Intra-UTRAN ANR
- UTRAN IRAT ANR from UTRAN to GERAN
- UTRAN IRAT ANR from UTRAN to E-UTRAN

In addition to UTRAN ANR, Rel-11 has addressed management aspects for E-UTRAN IRAT ANR, including:

- ANR from E-UTRAN to GERAN
- ANR from E-UTRAN to UTRAN
- ANR from E-UTRAN to CDMA2000

3.2.2 MULTI-VENDOR ANR

Self-Organizing Network capabilities have been defined in the 3GPP standards since Release 8, considering that different vendor entities would coexist in the same network. In practice, most of the LTE deployments to this date are implemented using the same infrastructure vendor to supply all the entities involved in SON processes: eNodeB, Mobility Management Entity (MME) and OSS. However, in the cases where a multi-vendor deployment has been selected, several practical issues have been noticed that prevented some of the SON algorithms to function properly. Given the multi-vendor nature of HetNet deployments, it is anticipated that similar issues will be observed in those cases. These situations can be avoided with proper Interoperability Tests (IOT) in some cases, and better definition of standard signaling in others.

The proliferation of HetNets will present some challenges to the proper automatic neighbor definition, given the increasing number of nodes in the network which will contribute to confusion between cells and possibly to ever increasing neighbor lists. Furthermore, there may be additional challenges in case there are multiple vendors in the same geographical area.

Figure 2 illustrates the most typical multi-vendor case, in which the eNode-B from vendor A will be connected to the MME from vendor A and will be interacting with vendor B eNBs.

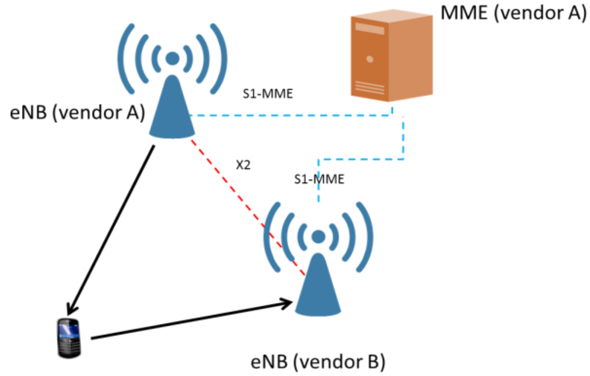

Figure 2.

In this configuration, there may be possible IOT issues to be solved when the RAN and MME vendors are different. Those IOT issues are even more challenging in the case of eNBs from two different vendors, as described in Figure 2, during the execution of Automatic Neighbor definition these entities need to be able to communicate in order to properly setup the X2 interface between the source and the target eNode-B that has been detected by the UE. Figure 3 illustrates the scenario, together with the expected steps.

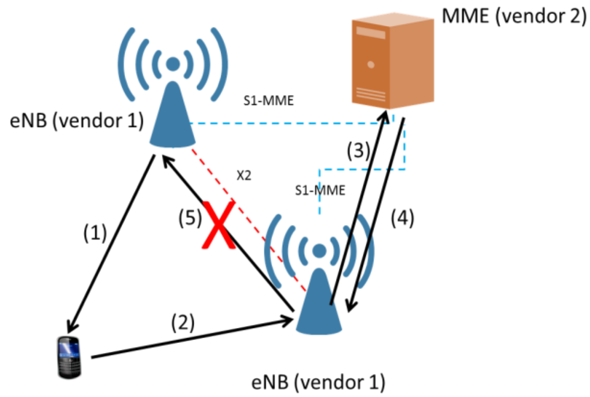

Figure 3.

The expected steps are as follows:

1. The UE detects a new sector (1) and reports it back to the serving cell (2), who asks the UE to read and report the new cell's CGI
2. The source eNB requests information about the target eNB, including IP address, that is necessary to establish the new X2 interface (3)
3. The MME helps provide the required information to the target eNB (4)
4. The source eNB communicates with the target eNB to establish the X2 interface (5). Then both eNBs exchange relevant information (PCI, GCI, TAC, PLMN-id and frequency) to define each other's as neighbors.

When different vendors are used for eNB and MME there is a possibility of lack of proper exchange of information between these entities. This can lead to a failure to establish the X2 connection. .

3.2.2.1 MULTI-TECHNOLOGY ISSUES OF ANR

Inter-System ANR, or IRAT ANR will create one-way neighbors between the small cell and the underlying system (GSM/UMTS or CDMA). Given that there is no O&M interaction between the small cell and the underlying system, ANR specific problems such as neighbor consistency, conditioned on the way neighbor relations between LTE and 3G are updated, may be expected from this kind of deployment.

3.3 PCI PLANNING

In order for the UEs to uniquely identify the source of a receiving signal, each eNB is given a signature sequence referred to as Physical Cell ID (PCI). Based on the LTE specification of the physical layer detailed in 3GPP TS 36.211-840, there are a total of 504 unique physical layer cell identities.

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of the PCI features and its respective benefits.

3.3.1 MULTI-VENDOR PCI ASSIGNMENT

The assignment of the Physical Cell Identity (PCI) is one of the first SON techniques that have been tested and deployed in commercial networks. This feature comprises two different use cases, one when a eNB is deployed and activated for the first time, in which case there is a planning function involved during the Self-Configuration stage and a second use case, that runs continuously when the network is operational, and whose objective is to optimize the performance and resolve possible PCI collisions. To support this second use case, e-NodeBs usually have a mechanism to detect collisions and alert their OSS of this situation. When a PCI collision occurs in an operational network, normally this will be resolved by a centralized entity that will consider the overall PCI allocation in the problematic area, and will reassign the codes to minimize collisions.

The PCI assignment needs to be coordinated between different RAN vendors in border areas, and especially in HetNet deployments. In the case of HetNets, it is expected that small cells from one vendor will coexist within the macro coverage area of a different vendor. The simplest way to avoid conflicts between vendors is to partition the PCI space into macro/pico/femto ranges. Given the large amount of available PCIs (504) this solution is likely to be feasible in the short to medium term.

As traffic increases and small cell deployments expand, there may be a need for inter-vendor coordination during PCI optimization. In such situations, the standards provide procedures to facilitate the coordination between these entities over the X2 interface, to allow one of the vendors to “take over” the assignment of PCIs for all sectors in one specific area.

3.4 LOAD BALANCING

Load Balancing refers to the process whereby similar network elements that are intended to share traffic, share the load. The similar network elements can be anything from packet gateways to MMEs to base stations and sectors. In LTE, MME pools are expected to share user traffic load across different MMEs as load increases, while eNBs may have RRM functions that share/offload traffic to neighboring cells in order to increase system capacity. As a result, different real-time algorithms at different nodes can simultaneously provide Load Balancing of user traffic per network element as required. Additionally, long-term traffic behavior of each node can be monitored so that traffic may be “directed” a-priori by a centralized entity in the network. For instance, this could be a desirable feature for markets where periodic or scheduled concentrations of users regularly occur (e.g. sporting events, conventions, daily commutes, etc.).

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of load balancing features and its respective benefits.

Mobility Load Balancing is a specific Load Balancing technique that due to its close interaction with the Mobility Robustness Optimization (MRO), use case is treated in the corresponding section.

3.4.1 RELEASE 11 UPDATES TO LOAD BALANCING OPTIMIZATION

3GPP Rel-11 has defined the following targets or the combination of the following targets to be used for load balancing: Radio Resource Connection (RRC) establishment failure rate related to load, E-RAB setup failure rate related to load, RRC Connection Abnormal Release Rate Related to Load, E-RAB Abnormal Release Rate Related to Load and Rate of failures related to handover.

3GPP has defined additional specific load balancing related performance measurements for use in SON, including: the number of failed RRC connection establishments related to load; the total number of attempted RRC connection establishments; the number of E-RAB setup failures related to load; the total number of attempted E-RAB setups; the number of abnormal RRC connection releases related to load; the total number of RRC connection releases; the number of E-RAB abnormal releases related to load; the total number of E-RAB releases; the number of failure events related to handover; and the total number of handover events.

3.5 MOBILITY ROBUSTNESS / HANDOVER OPTIMIZATION (MRO)

Mobility Robustness Optimization (MRO) encompasses the automated optimization of parameters affecting active mode and idle mode handovers to ensure good end-user quality and performance, while considering possible competing interactions with other SON features such as, automatic neighbor relation and load balancing. Incorrect handoff parameter settings can negatively affect user experience and waste network resources due to handoff and radio link failures (RLF). While handoff failures that do not lead to RLFs are often recoverable and invisible to the user, RLFs caused by incorrect handoff parameter settings have a combined impact on user experience and network resources.

In addition to MRO, intra-frequency Mobility Load Balancing (MLB) objective is to intelligently spread user traffic across the system’s radio resources in order to optimize system capacity while maintaining quality end-user experience and performance. Additionally, MLB can be used to shape the system load according to operator policy, or to empty lightly loaded cells which can then be turned off in order to save energy. The automation of this minimizes human intervention in the network management and optimization tasks.

There are multiple approaches towards load balancing for MLB. One of the approaches is described here and other approaches may exist that supplement this approach.

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of MRO features and its benefits, including a detailed description of the various Hand Over (HO) failure scenarios and the standardized messaging available over X2.

3.5.1 RELEASE 11 UPDATES TO MOBILITY ROBUSTNESS OPTIMIZATION

3GPP Rel-11 has specified two options for the location of the SON algorithm for HO parameter optimization, namely, in the eNB(s), and in the element manager through which the parameter changes are executed in the eNBs.

3GPP Rel-11 has specified a HO Parameter Optimization Monitor Function to be used for monitoring the handover parameter optimization (e.g., monitoring related performance counters or alarms), and a HO Parameter Optimization Policy Control Function to be used for configuring the handover parameter optimization policies.

3GPP Rel-11 also specified the collection of the following HO-related performance measurements from the source and / or target eNB which can be useful in detecting HO-related issues on the cell level: the number of RLF events within an interval after handover success; the number of unnecessary handovers to another RAT without RLF and specific performance measurements related to handover failure (number of handover events, number of HO failures, number of too early HO failures, number of too late HO failures, number of HO failures to wrong cell and number of unnecessary HOs to another RAT). Problem scenarios are identified based on UE measurements, Performance measurements, and event capture and analysis.

3.5.2 MULTI-VENDOR MRO AND MOBILITY LOAD BALANCING (MLB)

Even in a multi-vendor setting, the MRO/MLB algorithms must be able to detect changes to the handoff environment and loaded conditions and as a result determine an appropriate course of action to optimize network performance.

3.5.2.1 MOBILITY LOAD CONDITIONS

A loaded condition could occur when the maximum number of users per cell limit is reached and admission control starts blocking new users coming into the network. Ideally, the scheduler should be able to allocate the required Physical Resource Blocks (PRBs) for each service that requires a certain quality of service. When more and more users join the network and take up the PRB resources, at some point after hitting MLB thresholds limits, the system must take a proactive action and start to redirect users to other cells. MLB load conditions thresholds (e.g. normal, lightly loaded and loaded) can be implemented and used to take preventive action prior to reaching a loaded condition.

In a multi-vendor environment, the operator must make sure that the MLB triggers are set similarly in different vendor's network. When offloading users to another cell, the congested cell must also take target cell load into account. The cell load among neighbors can be shared over X2 interface between eNBs. The MLB information exchanged over X2 can be used directly by MLB algorithm in the target eNB in a distributed architecture or sent up to a central entity in a centralized architecture to take further action.

3.5.2.2 MULTI-VENDOR MRO/MLB IN DISTRIBUTED ARCHITECTURE

In distributed architectures, further treated in Section 4, the MRO/MLB algorithms reside within the eNB and load information is exchanged among eNBs via X2 interface. This makes the MLB/MRO parameter available at the neighboring eNB faster. Operators can take full advantage of SON features, optimize the handoff, load parameters and make quicker decisions before the network reaches a loaded condition. However, the distributed SON algorithm works best when implemented in a vendors own network. These proprietary solutions can significantly reduce the signaling load and the latency to exchange MRO/MLB information between eNBs in a distributed architecture.

The standard outlines MRO/MLB procedures, but vendors often modify these algorithms to differentiate. The 3GPP specifications outline what the vendor must share. Additionally, the operator can enforce synchronization of parameters settings on a different vendor's network; however, network critical data and proprietary MRO/MLB algorithms is something vendors may not be willing to share with each other.

Another complication in distributed MLB for multi-vendor environment is the lack of IOT testing among vendors. In a HetNet environment with a mix of macro and small cells, it takes a significant amount of effort and collaboration among vendors to perform IOT testing to make sure their MRO/MLB implementation can work and to enhance the network performance. The lack of IOT testing can have disastrous effects on network performance. The vendors must perform IOT testing prior to going commercial on a live system. The operators will not be willing and cannot afford to let their network be a field test for vendors to test their SON capabilities. To reduce failures due to incompatibilities, the operators will require increased training for operations personal. It is important that vendors provide a common user experience by providing the same CLI or GUI interface across network elements. It will require careful monitoring of KPIs to minimize risks and ensure a smooth operation of the network.

For multi-vendor MRO/MLB, the goal is reduction in OPEX. To accomplish that, operator may choose third party solutions. To take advantage of MRO/MLB, all parties involved must participate in a collaborative way to fine tune the operator's network. The vendors must agree on a set of rules and requirements for mobility parameter optimization and traffic steering during congestion. The vendor must adhere to a fair rule to offload UEs from one network/technology to another.

3.5.2.3 MULTI-VENDOR MRO/MLB IN CENTRALIZED ARCHITECTURE

In a centralized architecture, further analyzed in Section 4, the algorithms are executed at the network management level. Commands, requests and parameter settings data flow from the NMS to the EMS, while measurement data (KPIs), data streams and different reports flow in the opposite direction.

Between the eNBs, the SON info, such as the exchange of Mobility Change Request/Ack messages, handoff/RLF reports, etc., is shared over X2 interface and the data is sent up from the EMS to NMS. The main benefit of this approach is that the MRO/MLB algorithms can utilize information from all parts of the network into consideration. This means that it is possible for the operator to jointly optimize MRO/MLB parameters for the entire network, even if the network is comprised of multiple vendors. Also, centralized solutions can be more robust against network instabilities caused by the simultaneous operation of proprietary SON functions that have conflicting goals. Since the control of all SON functions is done centrally, they can easily be coordinated. Third party MRO/MLB solutions are possible, since functionality can be added at the NMS and not in the EMS where vendor specific solutions could be conflicting.

The disadvantages of centralized architecture are the delay in its response time and a single point of failure. Timing is very critical for MRO/MLB optimizations and to avoid RLF. The network must adapt to frequent changes in MRO/MLB parameters on the fly. The delay in updates could have negative impacts on overall system performance.

Another disadvantage of centralized architecture is increase in signaling traffic, since the data needs to be sent up from different network nodes to the centralized network management system. In a HetNet environment with more and more small cells from 3rd party vendors, managing the MRO/MLB updates from different nodes that result in additional data traffic will be a significant challenge and will consume resources.

3.5.2.4 MULTI-VENDOR MRO/MLB IN HYBRID ARCHITECTURE

In hybrid architectures, further evaluated in Section 4, some MRO/MLB optimization is done at the EMS while other functions are centrally controlled at NMS. An example would be when an eNB is introduced into the network. It will take some time for neighboring eNBs to learn about the new eNB and to share load or handoff parameters. Since most of MRO/MLB algorithms do not work well until there is sufficient data to make smart decisions, the initial default MRO/MLB parameters could be managed by NMS. Later updates to MRO/MLB parameters can be made when more data is available as part of UE measurement and info is exchanged over X2 interface between nodes. The hybrid architecture control would provide an oversight to the distributed algorithms and if needed, could intervene as required to provide configuration parameter adjustments and in some cases even a full reset. However, like the other two solutions, hybrid solutions also face the challenge of maintaining different interface extensions and extra signaling load.

3.6 RANDOM ACCESS CHANNEL (RACH) OPTIMIZATION

The configuration of the random access procedure has a critical impact on end-user experience and overall network performance. The Random Access Channel (RACH) optimization entity is specified to reside in the eNB. Performance measurements related with RACH optimization include: distribution of RACH preambles sent and distribution of RACH access delay.

A poorly configured RACH may increase access setup time and access failures, impacting call setup delays. With optimal random access parameter setting, maximum end-user experience can be obtained. This is achieved by reaching the desired balance in the radio resource allocation between random accesses and services while at the same time avoiding the creation of excessive interference. To keep the RACH optimized for all cells during varying conditions, the optimization can be repeated periodically or run continuously.

Support for SON based automatic RACH optimization is introduced in 3GPP Release 9 specifications TS 36.300 and TS 36.331 and is discussed in TR 36.902.

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader is referred to that white paper for a description of RACH features and its benefits.

3.7 INTER-CELL INTERFERENCE COORDINATION (ICIC)

The reuse of one cellular network frequency (reuse-1) is characterized by mutual interference between cells. Given the orthogonal nature of intra-cell transmissions, the source of interference in LTE is inter-cell interference. Within the OFDM and SC-FDMA based LTE system interference has to be coordinated on the basis of the physical resource blocks (PRBs). The ability to schedule users over variable portions of the carrier bandwidth allows for inter-cell interference coordination techniques to be utilized which can shape the interference in frequency.

Inter-Cell Interference Coordination (ICIC) involves the intelligent coordination of physical resources between various neighboring cells to reduce interference from one cell to another. Each cell gives up use of some resource in a coordinated fashion to improve performance especially for cell edge users which are impacted the most by inter-cell interference.

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of ICIC features and its respective benefits.

3.7.1 RELEASE 10 ICIC ENHANCEMENTS

Release 10 has introduced the Enhanced ICIC (eICIC) as an interference mitigation technique to enhance the operation of heterogeneous networks. Overlaying small cells within the coverage area of the macro cell is an attractive solution for cell splitting. Firstly compared to a macro cell, small cells are much easier to deploy and do not require all the infrastructures associated with the deployment of a macro site. Secondly small cells due their smaller coverage area allow for a much more geographically precise traffic offload thereby creating significantly less interference into the system. However a co-channel deployment of heterogeneous networks presents interference issues and scenarios that are quite different from a typical macro only network.

In a macro only network a UE is typically served by the strongest cell (i.e. the cell with the highest RSRP). However in a heterogeneous network due to the large difference between the transmit power levels of the macro cells and the small cells; this approach is not always desirable. Particularly when the small cell is deployed close to the macro cell it is often desirable of a UE to associate with the pico cell in-spite of it being weaker than the macro cell. When a UE associates with a cell other than the strongest cell, it is called a Cell Range Expansion (CRE). As shown in Figure 4, without the usage of CRE pico cells in certain scenarios, the small cell will not be able to offload any traffic from the macro cell.

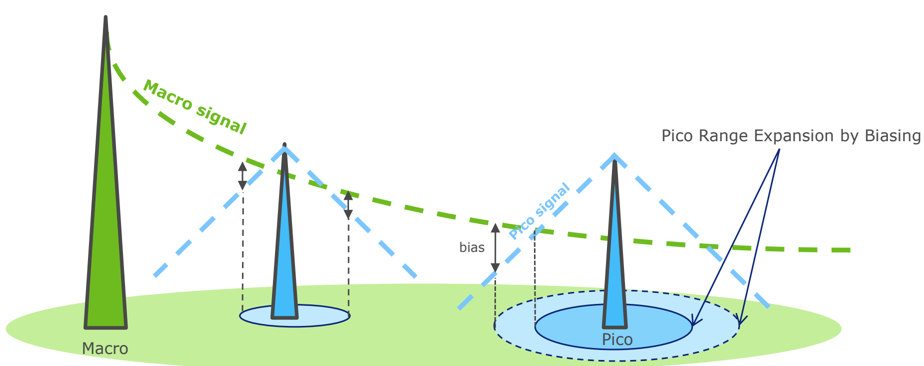

Figure 4. Cell Range Expansion of Pico Cells.

The UEs in the CRE region experience a particularly poor SINR due to strong interference from the macro cell. Depending on the CRE bias the SINR in the CRE region can be significantly worse. In Figure 5 the distribution of SINR of the pico cell users is shown. As expected with a larger CRE bias the pico cell's ability to offload traffic from the macro cell improves albeit at the cost of a poorer SINR distribution, particularly for the UE's in the CRE region.

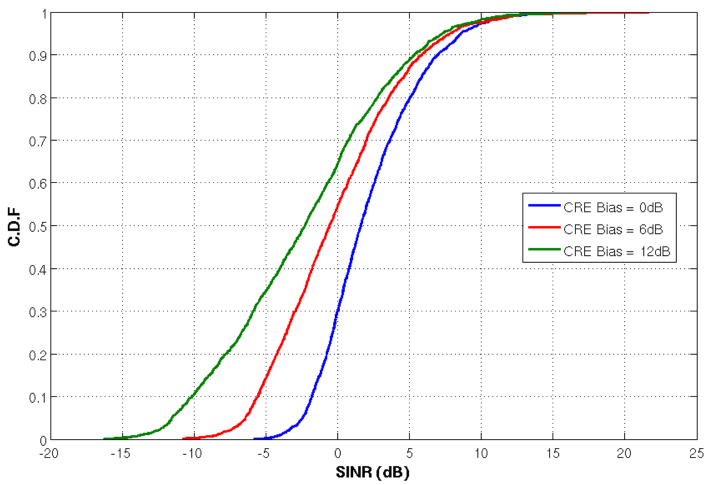

Figure 5. SINR distribution of UEs associated with small cell.

In order to mitigate this particular interference scenario, enhanced Inter-Cell Interference Coordination (eICIC) was introduced in Release 10 of LTE specification. The key concept behind eICIC is the idea of an Almost Blank Sub-Frame (ABS) wherein a cell is not allowed to schedule any transmission on the PDSCH (physical downlink shared channel) or the PDCCH (physical downlink common channel). In the context of heterogeneous networks the ABS is a tool that can be used to mitigate the effect of the interference from the macro cell to the small cell UEs that happen to be in the CRE region. Since small cells are able to offload a certain amount of traffic, the macro cell can give up a certain percentage of the frames as ABS frames. These ABS frames can then be used by the small cells to schedule the UEs in the CRE region. Even though the CRE bias allows the small cells to offload UEs from the macro cell, without the usage of ABS, the small cell will not be able to provide any significant data rate to these UEs. In Figure 6 the improvement in the cell edge data rate of the small cell UEs by using eICIC is shown. These results are based on a system level simulation of an LTE network at 2.0 GHz in an urban environment with 500m inter-site-distance. Other parameters and assumptions used for these simulations are consistent with section A.2 of 3GPP document TR 36.814.

Even though during ABS no transmission is scheduled on the PDSCH and PDCCH, due to legacy reasons, other channels such as the PSS, SSS, PBCH, paging channel (PCH) and cell specific reference signal (C-RS) still need to be transmitted. This is the reason these frames are called *Almost* blank sub-frames. For very large CRE bias (>12dB) the interference from these channels and C-RS can become significant thereby requiring additional interference cancellation technique at the receiver to operate under such large CRE bias.

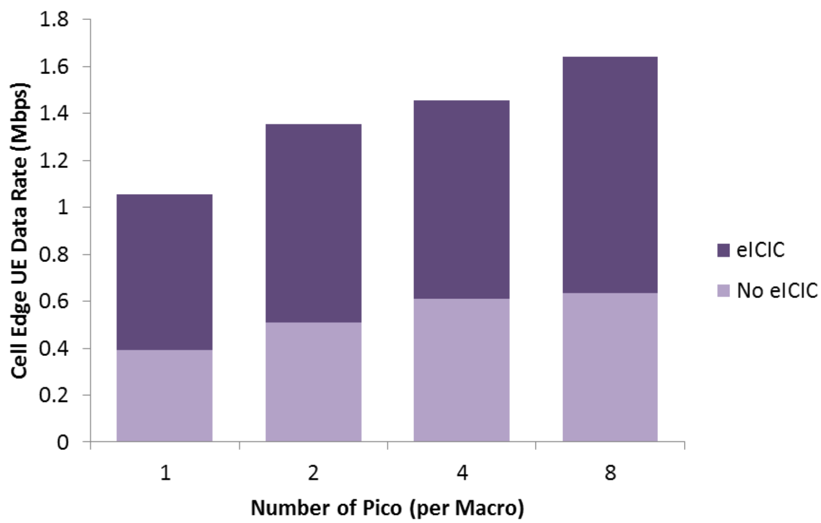

Figure 6. Cell edge data rate improvement with eICIC.

In order for eICIC to work, timing synchronization is required between the small cell and the macro cell. In the case of small cells, it is not possible to depend on the availability of GPS since many of them are deployed below the clutter or indoor. In this case the small cell would depend on a timing signal on the S1 or X2 interface over the backhaul network. This could be somewhat challenging in the multi-vendor deployment.

The design of eICIC and ABS is intended to provide a high degree of flexibility. In order to ensure the effectiveness of this interference coordination in the time domain; a certain degree of coordination is required between the macro cell and the small cell. The ABS frame pattern has a periodicity of 40 msec, which is the lowest common multiple of the 10 msec frame duration and the 8 msec HARQ periodicity. In order for eICIC to operate effectively both the macro cell and the small cells should be made aware of the ABS pattern. Although it is not mandatory it is common practice to let the macro cell determine the ABS frame pattern and indicate it to the small cells. This can be done over the X2 interface where the macro cell determines the ABS frame pattern and relays it to the small cells. Another possibility is to have a central SON entity determine the optimum ABS frame pattern and relay it to both the macro cell and the small cell.

Even though the Rel-10 LTE specification defines the messages and signaling over the X2 interface it is left up to the implementation to determine whether this is done in a distributed fashion or in a centralized fashion. This requires a certain degree of coordination between the macro cell, the small cell and the centralized SON entity. This could be a potential challenge in a multi-vendor environment where each of these entities could be supplied by a different vendor. In order to lower the complexity of this problem and identify a few potential solutions, it makes sense to break this problem into different stages, each with an increasing degree of complexity. In the following sections, two representative phases are explained; static eICIC and dynamic eICIC.

3.7.1.1 STATIC EICIC

In this case, the ABS frame patterns for the macro cell (and or small cell) and the CRE bias can be statically configured by the central OAM. This requires a certain degree of inter-operability between the eNodeBs (macro cell and small cell) with the OAM, but that is a requirement for any Heterogeneous network irrespective of whether eICIC is used.

3.7.1.2 DYNAMIC EICIC

Even though most of the studies and analysis of heterogeneous networks is done using a static eICIC technique in a real world deployment, we expect the static eICIC to be of limited benefit. In a real network, the offered traffic is dynamic in both a geographical and temporal sense. It is fairly common to see a large shift in traffic patterns and volume over the course of the day in a given network. Therefore in a mature deployment of eICIC, the optimization of parameter set depends on a number of factors varying over time and therefore we expect the configuration of the ABS frame patterns to be dynamic.

In this case the right choice of ABS frame pattern and CRE bias is based on the optimization of some metric. An effective choice of metric should take into account the data rates experienced by the UEs, as well as various other things such as the total amount of traffic in their buffer as well as the QoS requirements of the various bearers. This can be very similar to the metrics used by a time-frequency OFDMA scheduler albeit operating at much larger time scales. Some commonly used metrics in this case are:

$$\mu_1(\theta) = \sum_{n=1}^{N} Q_n B_n r_n(\theta)$$

$$\mu_2(\theta) = \prod_{n=1}^{N} Q_n B_n r_n(\theta)$$

$$r_n(\theta) = \theta \tilde{r}_{n,ABS} + (1-\theta)\tilde{r}_n \text{ for small cell UE}$$

$$r_n(\theta) = (1-\theta)\tilde{r}_n \text{ for macro cell UE}$$

Where N is the number of UEs, θ is the percentage of ABS frames on the macro cell. Also Q_n, B_n, and $r_n(\theta)$ are the QoS weight, total number of bits in the buffer and average data rate (as a function of the ABS frame fraction θ) for the n^{th} UE.

The first metric μ_1 tries to maximize a weighted sum of the data rates and the second metric μ_2 tries to maximize a weighted product of the data rates (or equivalently, sum of log rate) of all the UEs. The first metric provides the highest overall throughput, however, at the cost of the fairness since it penalizes the macro users in favor of the small cell users. On the other hand, the second metric provides a much better control of the fairness across all users. An example of this can be seen in Figure 7 which plots the overall aggregate system throughput as a function of data rate of the macro cell UEs. The parameters and assumptions used for the purposes of these simulations are consistent with case 1 as described in section A.2 of 3GPP document TR 36.814.

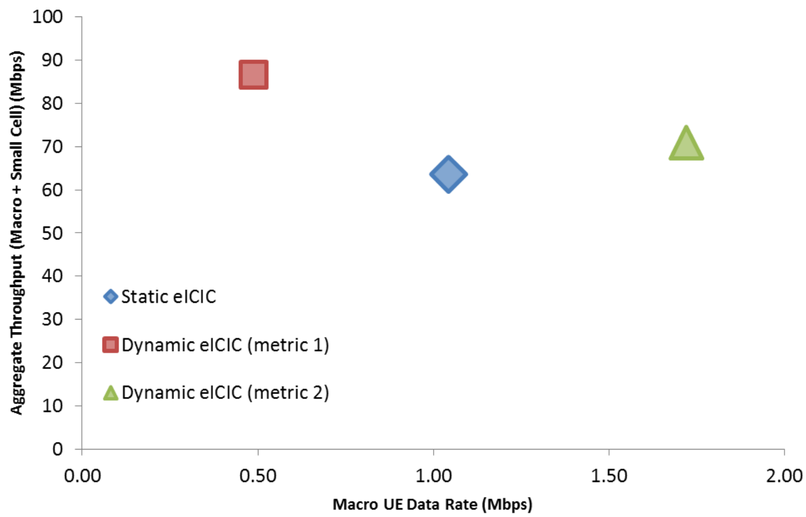

Figure 7. Static vs. Dynamic eICIC.

3.7.2 MULTI-VENDOR EICIC ISSUES

Dynamic eICIC can be implemented using either a centralized architecture or a distributed architecture. In a centralized architecture the control is done using the northbound interface and the controlling entity typically resides outside the RAN. On the other hand in a distributed architecture the control is done based on the X2 interface and the controlling entity resides within the RAN and can be implemented within one of the macro eNodeB that acts as a controlling node. Both of these solutions have their pros and cons in a multi-vendor environment.

1. **Centralized Architecture**: As mentioned previously in the centralized architecture the controlling entity resides outside of the RAN and the northbound interfaces can be used for the flow of information and control. Since the control entity is outside of the RAN in a centralized architecture dynamic eICIC can only operate at time scales much larger than the time scales of RRC signaling and re-configuration. Typical time scales involved in this case are in order of several minutes. However due to the centralized nature of this control it is possible to derive an optimum solution that is suitable for the entire large scale network and not just one cluster at a time. Since X2 interface is not involved in this case it makes inter-operability much easier. However a certain degree of inter-operability testing is still required since it is more than likely that controlling entity in the SON and the eNodeB are manufactured by different vendors and moreover the complexity over the Itf-N needs to be addressed.
2. **Distributed Architecture**: In a distributed architecture the control of the eICIC can reside within the RAN thus allowing for the dynamic eICIC to operate at much smaller time-scales. However unlike the centralized case it is difficult for the control entity to have a view of the entire network and therefore the solution is optimized for each eICIC-cluster thus causing border effects between the clusters. A typical cluster can consist of one or more macro eNodeB along with all the pico eNodeBs in the coverage area of the macros. Due to its distributed nature this architecture requires a certain amount of information exchange between the clusters on the X2 interface. This makes it harder to implement in multi-vendor environment. The X2 interface does allow for 'vendor specific' messages but it can be a

challenging task to make that happen across different vendors. Within the distributed architecture the dynamic eICIC algorithm can be divided in different sub-categories depending on the amount of information exchange done to compute the optimal solution.

a. **<u>Full Inter-Cluster Information Exchange:</u>** In this case all the eICIC-clusters exchange all the information (such as the metric $\square_1$ and $\square_2$ described earlier) needed to compute the optimal eICIC parameters. It can be shown that in the limit this solution can in theory approach the optimality of the centralized algorithm, albeit at the cost of a rather large load on the X2 interface.

b. **<u>No Inter-Cluster Information Exchange:</u>** In this case there is no exchange of information between the eICIC-clusters and as a result it is quite possible that parameters such as ABS frame percentage can be significantly different in adjacent clusters. This edge effect makes this solution less optimal although the load on the X2 interface is low since the information exchange is only within a cluster.

c. **<u>Partial/Quantized Inter-Cluster Information Exchange:</u>** In this case the eICIC-clusters exchange only partial information instead of the full information needed for the dynamic eICIC computation. One example could be that each cluster simply shares its choice of optimum ABS frame percentage with every other cluster. The signaling load required for such an exchange is considerably lower than the previous case albeit at the loss of optimality of this solution. For truly distributed eICIC architectures this might be the best choice from an implementation point of view since it achieves a tradeoff between performance and X2 load associated with signaling and information exchange.

Within the multi-vendor scenario, there is a specific case of macro eNodeB provided by one vendor and pico eNodeB provided by a second vendor. In this specific case, the inter-vendor interworking challenges can be alleviated by adopting a macro controlled approach, which allows the inter-cluster coordination interaction to occur within the macro eNodeBs using a common set of objective functions (e.g. sum or product of rates). The pico eNodeBs can report their loading information to the macro eNodeBs using standardized X2 messages, and wait for ABS configuration commands from the macro eNodeB, also using standardized X2 messages.

In a multi-vendor environment a centralized eICIC scheme controlled by a SON entity in the network is a much more practical solution, even though it might lack the dynamic agility of a distributed architecture. The centralized schemes for eICIC have a slower reaction time compared with distributed X2 based schemes.

3.8 ENERGY SAVINGS

Mobile network operators are increasingly aiming at decreasing power consumption in telecom networks to lower their OPEX and reduce greenhouse emissions with network energy saving solutions for long term sustainable development. With the expected deployment of large numbers of mobile network radio equipment, in the form of Home NB/eNBs, OPEX reduction becomes even more crucial.

Energy consumption is a significant part of an operator’s OPEX. OPEX reduction can be accomplished by designing network elements with lower power consumption and temporarily shutting down unused capacity when not needed. Power amplifiers consume a significant portion of the total energy consumption in a wireless network.

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of energy savings features and its benefits.

3.8.1 RELEASE 11 UPDATES TO ENERGY SAVINGS

3GPP Rel-11 has spelled out the importance of Energy Savings Management for Network Operators to look for means to reduce energy costs and protect the environment.

OAM of mobile networks can contribute to energy saving by allowing the operator to set policies to minimize consumption of energy, while maintaining coverage, capacity and quality of service. The permitted impact on coverage, capacity and quality of service is determined by an operator's policy.

3GPP Rel-11 has defined two energy saving states for a cell with respect to energy saving namely: n*otEnergySaving* state and *energySaving* state.

Based on the above energy saving states, a full energy saving solution includes two elementary procedures: energy saving activation (change from *notEnergySaving* to *energySaving* state) and energy saving deactivation (change from *energySaving* to *notEnergySaving* state).

When a cell is in an energy saving state it may need neighboring cells to pick up the load. However, a cell in *energySaving* state cannot cause coverage holes or create undue load on the surrounding cells. All traffic on that cell is expected to be drained to other overlaid/umbrella cells before any cell moves to *energySaving* state.

A cell in *energySaving* state is not considered a cell outage or a fault condition. No alarms should be raised for any condition that is a consequence of a network element moving into *energySaving* state.

Criteria for the *energySaving* state is defined in 3GPP namely: degree of energy saving effect, controllability from the network, and service availability.

The various Energy Savings Management (ESM) concepts can apply to different RATs, for example UMTS and LTE. However, 3GPP has specified that some of these ESM concepts may be limited to specific RATs and network elements, and specific solutions may be required for them.

In Rel-11, three general architectures that are candidates to offer energy savings functionalities are described, namely: distributed, network management centralized, and element management centralized. Energy savings management use cases such as the cell overlay use case and the capacity limited network use case, are described in detail. Requirements for element management centralized energy savings and distributed energy saving are specified. Coordination between energy saving and cell outage is addressed.

3.8.2 MULTI-VENDOR ENERGY SAVINGS MANAGEMENT

The value of energy savings management (ESM) for network operators is addressed by 3GPP Rel-11, which provides means for reducing energy costs while simultaneously protecting the environment. The mobile network OAM can contribute to energy saving by allowing the operator to set policies for minimizing energy consumption, while maintaining coverage, capacity and quality of service. The permitted tradeoff between coverage, capacity and quality of service is therefore set by the operator's policy.

3GPP Rel-11 defines two energy-saving states for a cell: *notEnergySaving* state and *energySaving* state. Based on these two states, a full energy-savings solution includes two elementary procedures: energy-saving activation (i.e., change from *notEnergySaving* to *energySaving*) and energy-saving deactivation (the reverse transition). When a cell undergoes energy-savings activation, it may need neighboring cells (including overlay or umbrella cells) to pick up the load – it cannot cause coverage holes or create undue load upon the surrounding cells. As an *energySaving* activation is a conscious decision, it thus should not be considered a cell outage or trigger any fault conditions. Defined criteria for the *energySaving* state are: the degree of energy savings effect, controllability from the network, and service availability.

Rel-11 further describes three general architectures that are candidates for offering ESM functionality: distributed; network management centralized; and element management centralized. Each of these architectures introduces different multi-vendor interoperability aspects in order to assure the proper coordination to perform the energy savings actions discussed above. This requires standardized and/or interoperable interfaces between the eNBs, EMS and NMS that may come from different vendors, as well as coordination between energy savings SON algorithms that may reside in each of these network elements.

3.9 CELL OUTAGE DETECTION AND COMPENSATION

Cell Outage Detection and Compensation provides automatic mitigation of eNB failures especially in the case where the eNB equipment is unable to recognize being out of service and has therefore failed to notify OAM of the outage. Detection and Compensation are two distinct cases that cooperate to provide a complete solution:

Cell Outage Detection typically combines multiple separate mechanisms to determine whether an outage has occurred. This is needed to detect the latent fault case, often described as 'Sleeping Cell', where OAM is unaware of the issue. If a cell continues transmitting but does not accept RACH access or hand-ins, it will simply generate interference. The most immediate mitigation available is to stop that cell from transmitting. OAM aspects are addressed in detail in 3GPP 32.541.

Cell Outage Compensation techniques are generally only applied after standard soft recovery techniques have failed to restore normal service. Cell Outage Detection uses a collection of evidence and information to determine that a cell is no longer working correctly. Detection includes active notification to cover the generalized case in which OAM is aware of the fault.

The work in this paper is based on prior work done in the 4G Americas *Benefits of SON* white paper released in 2011 that addresses the SON features in Releases 8, 9 and 10. The reader should refer to that white paper for a description of Cell Outage Compensation features and its respective benefits.

There have been no updates in Release 11 as it pertains to Cell Outage Detection and Compensation.

3.10 COVERAGE AND CAPACITY OPTIMIZATION (CCO)

3.10.1 MODIFICATION OF ANTENNA TILTS

A typical operational task in wireless networks is to design and optimize the network according to coverage and capacity. Traditionally, this has been performed based on measurements from the network and using theoretical propagation models in planning tools. It requires extensive data collection from the network including statistics and measurements, such as using extensive drive tests. In current networks, while this task has been semi-automated with the help of Automatic Cell Planning tools, this method is still largely based on measurement estimations. Therefore their results are not very accurate. Furthermore, running such tools is a cumbersome task that requires a significant preparation on the operator side to compile all necessary data inputs, create optimization clusters, and then implement the changes in the network.

Coverage and Capacity Optimization (CCO) has been identified as a key area in 3GPP as a self-optimization use case for SON, which will complement traditional planning methods by adjusting the key RF parameters (antenna configuration and power) once the cells have been deployed. This method will permit the system to periodically adjust to modifications in traffic (load and location) in addition to any changes in the environment, such as new construction, or new cells being put on air.

The CCO function should work on a rather long time-scale in the order of days or weeks to capture and react to long-term changes in physical environment, load imbalance, and UL/DL mismatch. Sufficient data should be collected for accurate observation and estimation of CCO performance. The CCO standardization is addressed in 3GPP Rel-10 and will continue to be addressed in Rel-11 and beyond.

The CCO use case is defined in RAN *(*3GPP TR 36.902).

The reader is referred to the 4G Americas 2011 *Benefits of SON* white paper that describes the specified CCO scenarios.

3.10.2 RELEASE 11 UPDATES TO COVERAGE AND CAPACITY OPTIMIZATION (CCO)

In Rel-11, symptoms of capacity and coverage optimization problems, namely, coverage hole, weak coverage, pilot pollution, overshoot coverage and DL and UL channel coverage mismatch are addressed in detail. Inputs for the identification of the problem scenarios, namely, UE measurements, performance measurements, alarms and other monitoring information (e.g. trace data) are described.

UE measurements are sent within UE measurement reports and they may indicate the capacity and coverage problem. Rel-11 has specified that a tradeoff between capacity and coverage needs to be considered. Capacity and coverage-related performance measurements collected at the source and/or target eNB can be useful in detecting capacity and coverage-related issues on the cell level. Minimizing Drive Tests (MDT) or HO-related performance measurements may be used also in detecting capacity and coverage related issues on the cell level. Alarms, other monitoring information, for example trace data; can be correlated to get an unambiguous indication of capacity and coverage problems. Parameters to be optimized to reach capacity and coverage optimization targets are defined, namely, downlink transmit power, antenna tilt and antenna azimuth.

Logical Functions for CCO, namely CCO Monitor Function and CCO Policy Control Function, to be used for configuring the capacity and coverage optimization policies are defined in Rel-11. Options for the location of the centralized CCO SON algorithm are defined namely in the element management or in the network management layer. Performance measurements related with CCO are specified including: maximum carrier transmit power and mean carrier transmit power.

3.10.3 MULTI-VENDOR CCO

Within Rel-11, several symptoms of capacity and coverage problems that can be addressed through optimization are described in detail: e.g., coverage holes; weak coverage; pilot pollution; overshoot coverage; and DL and UL channel coverage mismatch.

Input data for identifying these problem scenarios include: UE measurements; performance measurements; alarms; and other monitoring information (e.g., trace data). For instance, call drop rates may give an initial indication of the areas within the network that have insufficient coverage, while traffic counters could be used to identify areas with capacity problems. Specific procedures include the capability to collect connected and idle mode UE measurements at the eNB via call trace procedures. Based upon these collected data, the network can identify coverage and/or capacity issues, and take actions in order to optimize the performance (e.g., through a different tradeoff between coverage and capacity). Typical cell parameters that can be optimized to reach the desired capacity and coverage optimization targets include downlink transmit power, antenna tilt, and antenna azimuth.

Logical functions for CCO, namely CCO Monitor Function and CCO Policy Control Function, to be used for configuring the capacity and coverage optimization policies are defined in Rel-11. Options for the location of the centralized CCO SON algorithm are defined namely in the element management or in the network management layer. Performance measurements related with CCO are specified including: maximum carrier transmit power and mean carrier transmit power.

Like in the case of Energy Savings, the ability to support CCO in a multi-vendor deployment requires the interfaces and/or interoperability between, EMS and NMS network elements and SON algorithms to coordinate the up/down-tilting between antennas of different eNBs to achieve the desired coverage/capacity optimization. Since CCO requires this coordination amongst a cluster of cells, there has been particular focus in 3GPP on insuring the necessary performance measurements for CCO are made available for centralized SON approaches (i.e. NMS based).

3.11 INTERFERENCE OVER THERMAL CONTROL

The manner in which each cell sets the value of P_0 and α, and average cell-specific mean interference targets, that are useful for setting UE SINR targets are not specified in 3GPP standards. Since the choice of parameters results in a suitable mean interference level at every cell above the noise floor, this problem of setting the cell power control parameters is referred to as IOT control problem. Clearly, aggressive (conservative) parameter setting in a cell will improve (degrade) the performance in that cell but will cause high (low) interference in neighboring cells. It should be noted that the problem statement in this section is applicable to homogeneous as well as heterogeneous networks with the later exhibiting exacerbation of the issues presented here to the embedding of the small cells.

Since the fractional PC scheme and its parameters are cell-specific, its configuration lies within the scope of a SON framework. Broadly speaking, a SON-based solution should be capable of adapting the parameters based on suitable network measurements, to the latest traffic/interference conditions.

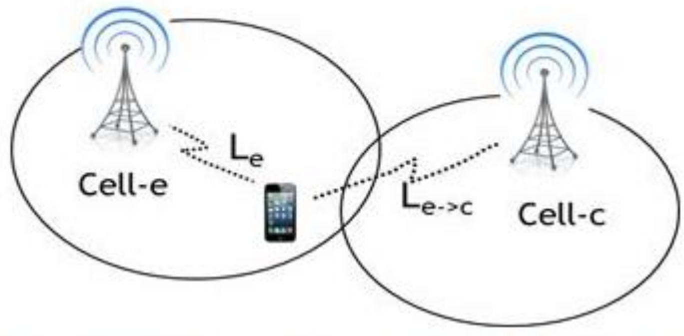

Figure 8. Uplink Interference Scenario and Path-loss / Cross-Loss notation.

In reference to Figure 8, the uplink interference scenario is depicted where a UE served by the cell-e causes interference to cell-c that is a factor of L_e and$L_{e\to c}$. L_e is the path loss towards the serving cell and $L_{e\to c}$ is the path loss towards the neighboring cell. The task of the SON algorithm is to assign for each cell of interest the optimal pair (P_0,α) having observed the joint distribution of ($L_e, L_{e\to c}$), the marginal distribution towards the cell of interest, traffic statistics such as occupancy of interfering resource blocks in each cell and load information such as number of active UEs.

It can be shown, that the uplink IOT optimization can be engineered as a convex problem with a social utility maximizing objective function, as a function of the log-SINR of each UE. Significant gains can be expected depending on the deployment scenario. Figure 9 shows the performance of one optimization scheme (denoted as LeAP) in the figure against a network-wide fixed alpha assignment and P0 assigned such that the nominal SINR UE distribution is above a certain threshold (typically 0dB).

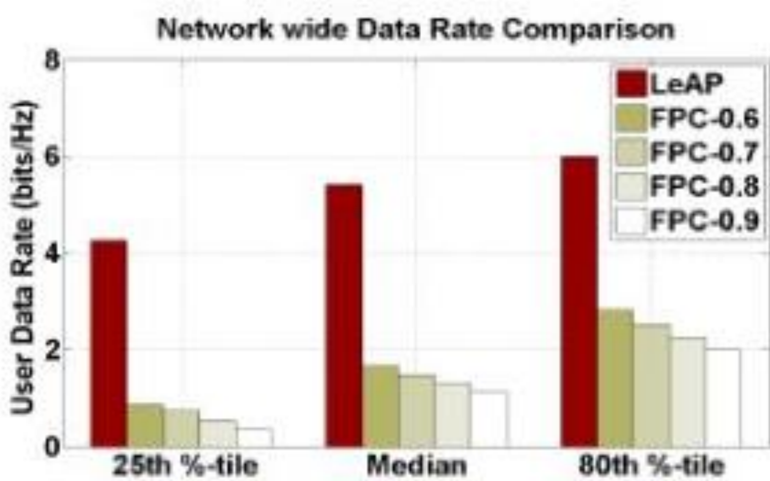

Figure 9. IOT Optimized (LeAP) vs. fixed alpha Heterogeneous Network (HTN) – NYC deployment assumptions.

3.11.1 MULTI-VENDOR ISSUES

The aforementioned statistics are inputs and easily retrievable for single vendor networks. If cells e and c in Figure 8 belong to the different vendors, the inputs must be reported to, and statistics calculated by, centralized entities. In the case where the inputs are not reported or retrievable, the IOT optimization scheme will be dependent on the UE and network capability to support 3GPP MDT as well as UE trace standards.

Based on the issues identified and results of this section, the IOT control could be a potential candidate for standardization activity in the SON work item in 3GPP.

4 SON ARCHITECTURE ALTERNATIVES

The specification covering the SON overview[15] identifies three different architectures for SON functionality: Distributed; Centralized; and Hybrid as shown in Figure 10.

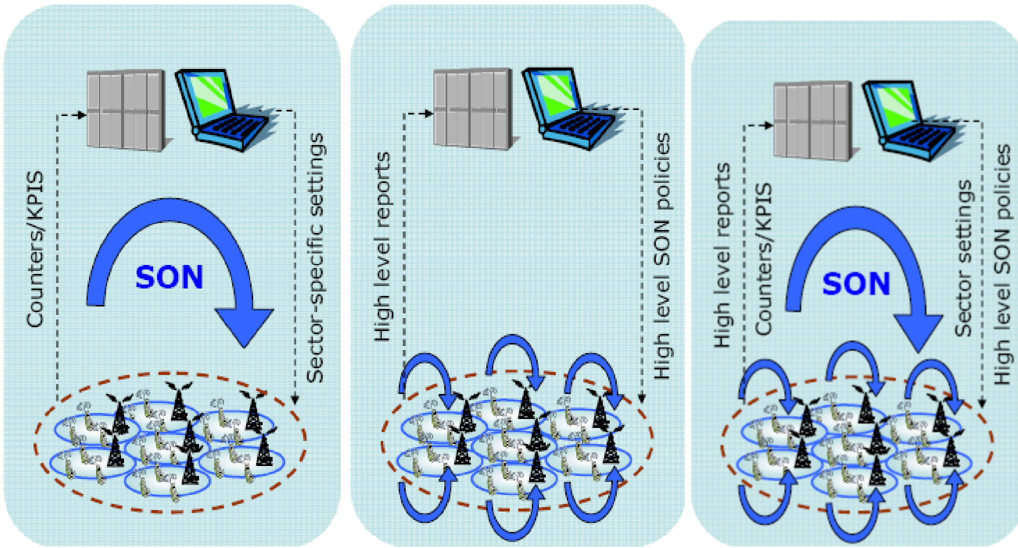

Figure 10. Different SON architecture approaches: Centralized (left), Distributed (center) and Hybrid (right).

In a centralized architecture, as shown in Figure 11, SON algorithms for one or more use cases reside on the Network Management System or on a separate SON server that manages the eNBs.

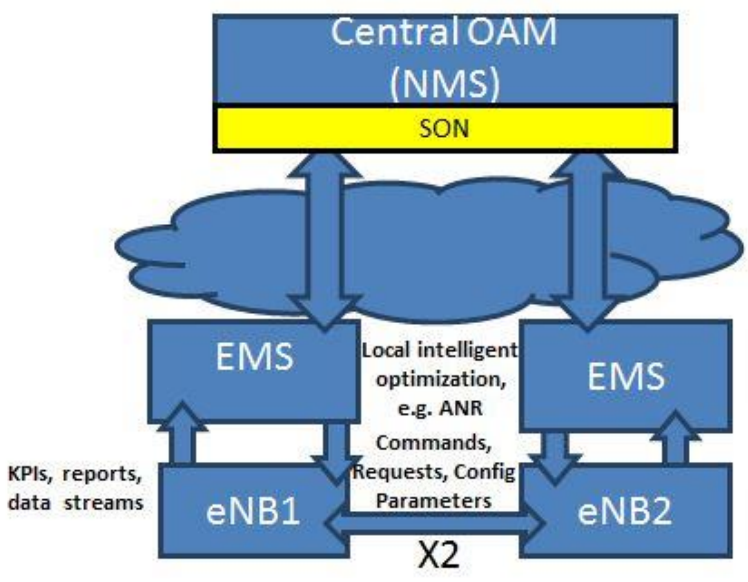

Figure 11. Example of a Centralized SON Architecture Realization.

The output of the SON algorithms namely, the values of specific parameters, are then passed to the eNBs either on a periodic basis or when needed. A centralized approach allows for more manageable implementation of the SON algorithms. It allows for use case interactions between SON algorithms to be considered before modifying SON parameters. However, active updates to the use case parameters are delayed since KPIs and UE measurement information must be forwarded to a centralized location for processing. Filtered and condensed information are passed from the eNB to the centralized SON server to preserve the scalability of the solution in terms of the volume of information transported. Less information is available at the SON server compared to that which would be available at the eNB. Higher latency due to the time taken to collect UE information restricts the applicability of a purely centralized SON architecture to those algorithms that require slower response time. Furthermore, since the centralized SON server presents a single point of failure, an outage in the centralized server or backhaul could result in stale and outdated parameters being used at the eNB due to likely less frequent updates of SON parameters at the eNB compared to that is possible in a distributed solution.

There are three key time intervals associated with Centralized SON.

- The Collection Interval is the period during which statistics are collected and uploaded. This is also the smallest available granularity for data analysis. This interval is most likely determined by the vendors OAM statistics throughput limitations. Most Network Management solutions would typically support a five minutes interval.
- The Analysis Interval is the time period considered in the decision process for parameter adjustment. It is beneficial to consider more than a single collection interval in the analysis. While the latest collection interval should have the greatest impact on the analysis, the output should be damped to take into account results from previous intervals.
- The Change Interval is the period between changes applied to the network by SON. System performance constraints may limit the number of cells for which changes are applied at any given time. This could result in Change Intervals that do not align directly with the Collection Intervals. These limiting factors don't always apply, but centralized solutions either need to have vastly over provisioned processing and networking capability, or intelligent change management.

In a distributed approach, SON algorithms reside within the eNB's, thus allowing autonomous decision making at the eNBs based on UE measurements received on the eNBs and additional information from other eNBs being received via the X2 interface. A distributed architecture allows for ease of deployment in multi-vendor networks and optimization on faster time scales. Optimization could be done for different times of the day. However, due to the inability to ensure standard and identical implementation of algorithms in a multi-vendor network, careful monitoring of KPIs is needed to minimize potential network instabilities and ensure overall optimal operation.

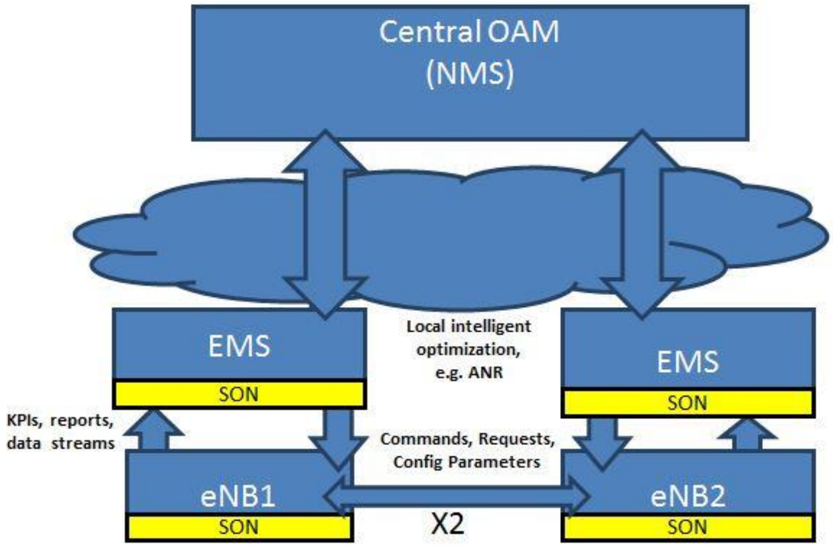

Figure 12. Example of a Distributed SON Architecture Realization.

In practical deployments, these architecture alternatives are not mutually exclusive and could coexist for different purposes, as is realized in a hybrid SON approach shown in Figure 13.

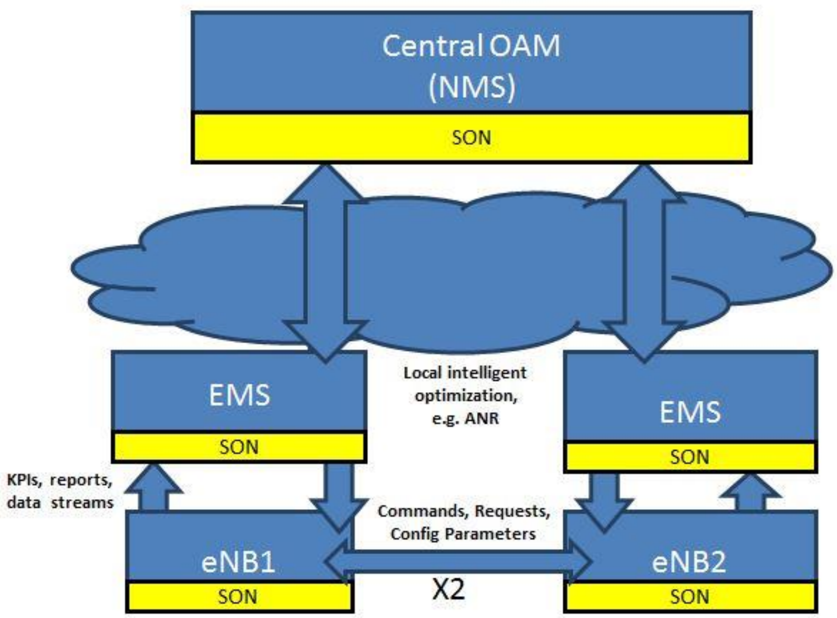

Figure 13. Example of a Hybrid SON Architecture Realization.

In a hybrid approach, part of a given SON optimization algorithm is executed in the NMS while another part of the same SON algorithm could be executed in the eNB. For example, the values of the initial parameters could be done in a centralized server, and updates and refinement to those parameters in response to the actual UE measurements could be done on the eNBs. Each implementation has its own advantages and disadvantages. The choice of centralized, distributed or hybrid architecture needs to be decided on a use case by use case basis depending on the information availability, processing and speed of response requirements of that use case. In the case of a hybrid or centralized solution, a practical deployment would require specific partnership between the infrastructure vendor, the operator and possibly a third party tool company. Operators can choose the most suitable approach depending upon the current infrastructure deployment.

4.1 MULTI-TECHNOLOGY APPROACHES IN MULTI-VENDOR HETEROGENEOUS NETWORKS (HTN)

There are many possible configurations with a mixture of cell types. While many configurations will support multi-vendor solutions, mixed-vendor solutions may potentially suffer due to a lack of coordination and cooperation between the nodes. We can distinguish two broad solution types in accommodating multi-vendor multi-technology deployments:

- *Uncoordinated Solutions:* The simplest configurations are when the Macro layer is mostly uncoordinated with the small cell layers. While these configurations may be initially the easiest to deploy, they may lack in many key areas such as OA&M integration, Mobility Performance and interference mitigation schemes. Uncoordinated solutions may be necessary in most cases where multi-vendor solutions are applied.
- *Coordinated Solutions:* Coordinated solutions allow for improved performance and functionality between multiple layers and nodes in the network. Macro and small cell nodes can all coordinate with each other. Both all-in-one RBSs and distributed nodes can all coordinate with each other as shown in Figure 14.

The coordination schemes selected will be based on the interconnect quality whether it is high or low latency interconnect.

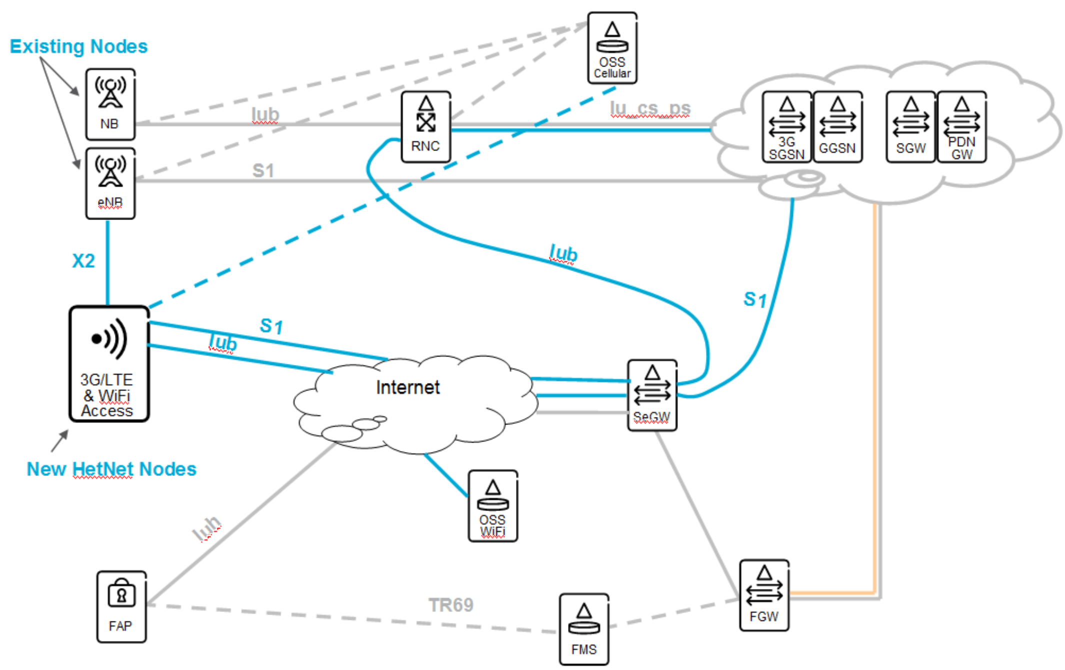

Figure 14. Coordinated Network Architecture.

There are many examples where coordinated networks offer improvements over uncoordinated networks:

- Shared Cell Approach
- Carrier Aggregation based e-ICIC
- Power Balancing and Range Expansion
- Almost Blank Subframes
- Load Balancing
- Mobility Improvements
- OAM Integration

In a coordinated network, many of the above SON use cases and functions can be implemented based on X2 with the benefit of real time actions. For uncoordinated networks, those functions might have to be realized with a centralized approach due to the lack of IOT between vendors X2 implementation.

4.2 MULTI-VENDOR SON ARCHITECTURES

4.2.1 SON USE CASES AND FUNCTIONS BASED ON X2

SON functions based on X2 rely on distributed SON algorithms where decisions are made locally at eNBs in consultation with neighboring eNBs. Due to their distributed nature, these SON algorithms scale well with network growth and densification. Distributed SON solutions benefit from direct UE feedback to the eNB for functions such as RACH optimization, MRO and ANR. The role of the OAM in the X2 based SON model is to set performance targets and configure boundaries within which the distributed SON functions can operate.

Several X2 based SON functions are enabled by the standards, and are described in more detail in the subsequent sections. An X2-based implementation for other use cases such as eICIC and RACH optimization are also viable.

4.2.1.1 DEPENDENCIES IN MULTI-VENDOR X2 SOLUTIONS

The X2 interface plays a vital role in several SON use cases; this section discusses the X2 specific issues when eNBs from different vendors are connected via an X2 interface. We explore two aspects of multi-vendor interworking over X2.

1. Interpretation of X2 messages and fields by the receiving eNB
2. Need for inter-vendor alignment of eNB internal algorithms to generate and process X2 messages

4.2.1.2 X2 INTERWORKING FOR PCI PLANNING

The PCI Planning function relies on the eNB detecting PCI conflicts, and either reporting the conflicts to OAM or resolving the conflicts locally. The detection of PCI conflicts can rely on a variety of options, one of which relies on the X2 interface:

(a) UE ANR for eNB1 to detect conflict between eNB2 and eNB3

(b) Information about a neighbor list of another eNB received over X2

(c) Network listening function at eNB if available

Given the large pool of PCIs in LTE, the probability of PCI collision is typically small as shown in 3GPP contribution R1-092350. Once a PCI conflict is detected, it is generally enough to select a new random PCI that avoids all known conflicting PCIs. However, there may be a small probability of such algorithms not converging and PCI collisions not being resolved, for example due to different implementation details among vendors. To prevent inter-vendor PCI conflicts, one simple approach is to partition the PCI space between the different vendors. Such a technique is commonly used for UMTS femtocells to separate their PSCs from macro cells.

A more X2 specific aspect of inter-vendor working relies on the Neighbor Information IE in the ENB CONFIGURATION UPDATE message. If eNB1 receives this message from eNB2, it may learn of a PCI conflict with eNB3, where eNB3 is a neighbor of eNB2. The role of the sender of this message (eNB2) is to include the Neighbor Information IE whenever a new neighbor (eNB3) is added to the neighbor relation table at the sender, and to remove the Neighbor Information IE when a neighbor is removed from the neighbor relation table at the sender. The role of the receiver of this message is to declare a collision in case a PCI is seen in the Neighbor Information IE that is the same as the PCI of a serving cell in the eNB. After a collision is declared, a new PCI is selected by randomly picking a PCI that avoids the known PCIs being used in neighbor cells.

4.2.1.3 X2 INTERWORKING FOR ANR

The ANR function is responsible for automatic discovery of neighbors and their addition to the neighbor relation table (NRT) under OAM guidance. The X2 interface, as such, does not play any role in the discovery of neighbors for possible addition to the NRT. However, the ANR function may result in the establishment of X2 with a newly discovered neighbor.

The inter-vendor X2 dependency for proper operation of the ANR feature is the ability to dynamically setup and manage X2. No dependency beyond this is foreseen.

ANR determination of neighbors is based on UE reporting signal strength from a neighboring cell. If the serving cell has not seen this neighbor before, it should request the UE to perform System Information Acquisition for the neighbor, and then add this neighbor to its Neighbor Relation Table. The addition to the Neighbor Relation Table does not depend on the vendor of the neighbor and the serving cell being the same.

Optionally, the discovery of a new neighbor results in an X2 setup request. For this to work properly, X2 IOT between the vendors is required. In the absence of X2 IOT, this request may be denied, and appropriate implementation is needed to prevent unnecessary retries.

4.2.1.4 X2 INTERWORKING FOR ENERGY SAVINGS MANAGEMENT

The energy savings feature is designed to be used in an environment with a “coverage layer” of eNBs overlaid on top of a ‘capacity layer’ of eNBs. The energy savings function involves two broad steps

1. A cell in the capacity layer can decide to deactivate its radio transmissions based on loading being identified as low, and notify its neighbors via an X2 Configuration Update.
2. A cell in the coverage layer can determine that extra capacity is needed, and request the activation of a cell in the capacity layer by an X2 Cell Activation Request.

The classification of which eNB belongs to which layer is not explicitly specified in the standard, but the X2 functions for energy savings assume that a certain classification has already been performed and notified to the eNBs. In particular, the eNB is informed via OAM whether it has the ability to [Section 22.4.4.3, 36.300] to deactivate itself and whether it has the ability to request activation of a specific neighbor.

The inter-vendor dependency for the X2 procedures is associated with the internal thresholds used by the capacity layer eNB and the coverage layer eNB to perform their decisions. For example, in the case of inconsistent behavior between two eNBs, it is possible to have race conditions where a cell deactivates immediately followed by a request for activation, followed by the cell deactivating again. The proper implementation of OAM guidelines, as defined in [Section 22.4.4.3, 36.300] to perform the deactivation and activation procedures is important to prevent such race conditions.

With X2 IOT, this SON use case could work given the exchange of load information across X2 and across carriers through the backplane. Without X2, no load information is exchanged, so the metro would not know the loading of the macro to figure out if it should turn off. The decision to turn on would have to be done via a central entity.

4.2.1.5 X2 INTERWORKING FOR CCO

X2 based CCO function is not defined in the 3GPP standards.

4.2.1.6 X2 INTERWORKING FOR MLB

Load balancing needs to be responsive to dynamic traffic variations as load moves between cells, and is well suited to a distributed architecture due to the dynamic nature of the feature. The Mobility Load Balancing feature over X2 involves the following process.

1. Cell learns the load of neighbor cells via X2 information exchange (Load Report). Details about the content of this report are in 2011 SON 4G Americas White paper on SON.
2. Cell determines its own load.
3. Based on this information, the cell determines whether load balancing with respect to a specific neighbor is required.
4. If required, the cell proposes load balancing to the neighbor (X2 Mobility Change Request).
5. If the neighbor accepts the request, the load balancing is performed.

In order to perform load balancing, the participating cells should use Cell Individual Offsets to adjust the handover boundaries between the cells.

In a multi-vendor environment, the following issues must be addressed.

- The Load Report message in the first step includes some IEs that are left to vendor implementation, such as the HW load and Composite load. This implementation uncertainty makes it difficult for the receiving node to interpret the message. Note that other IEs such as radio resource usage are well defined in the standard.
- The triggers and objective function for load balancing are left to implementation. For example, in case the load balancing on GBR and non-GBR flows points to opposite actions, it is up to implementation to pick the appropriate load balancing recommendation. In multi-vendor

scenarios, requests generated by a cell can be frequently rejected by its neighbor due to different load balancing triggers.

4.2.1.7 X2 INTERWORKING FOR MRO

The Mobility Robustness Optimization function allows eNBs to learn about different types of handover failures with respect to individual neighbors, and subsequently adjust handover parameters to reduce these failures. The types of handover failures are described in 2011 SON 4G Americas White paper on SON, and there is signaling support in the standard to enable the eNB to learn the nature of handover failures. Note that other metrics, such as ping-pong rate may be taken into account in addition to handover failures.

The distributed SON function within an eNB is responsible for determining which parameters changes are required. Some of these parameter changes may need to be confirmed with neighbor eNB using the X2 Mobility Change Request message, but there are many parameters such as Time to Trigger that can be changed without coordination with the neighboring eNB.

In a multi-vendor environment, the following issues must be considered:

- The detection of handover failures (too early, too late and wrong cell) involve X2 signaling between eNBs and the basic signaling has to go through IOT
- In case handover parameters are modified with coordination among cells via X2 Mobility Change Request, the IOT requirements increase and some guidelines are needed to ensure stable operation of the request/response process. This issue can be simplified

4.2.2 SON USE CASES AND FUNCTIONS BASED ON NORTHBOUND INTERFACES

4.2.2.1 3GPP MANAGEMENT REFERENCE MODEL

A number of management interfaces in a PLMN were identified; among them the most important are:

- Type 2 between the Element Manager (EM) and the Network Manager (NM)
- Type 1 between the Network Elements (NEs) and the Element Manager (EM)

The 3GPP management specifications focus on Type 2 and to a lesser extent on Type 1 management interfaces.

For Type 2, there is an option that the Element Manager functionality may reside in the NE in which case this interface is directly from NE to Network Manager. These management interfaces are given the reference name Itf-N and are the primary target for standardization. Figure 15 shows location of Centralized NM-based SON functions within the Management reference model of 3GPP (TS 32.101). It is located at the NM (Network Manager) level and operates through Itf-N Type 2 interface. The Element Manager (EM) translates read / write operations at the Itf-N to corresponding actions at Type 1 interface. In typical implementation of Centralized NM-based SON, the NE can be RNC or eNodeB. For reference, Figure also shows the location of Distributed SON in case of LTE.

As denoted in Figure , typically DM (EM) are supplied by same vendor as the NE. This is why the Type 1 interface can be proprietary. Centralized NM-based SON can be supplied by the RAN vendor, but there are also 3rd party suppliers of the Centralized SON. It is clear from the architecture that Centralized NM-based SON is naturally capable of managing a multi-vendor network.

Further details of Type 1 and Type 2 interfaces can be found below.

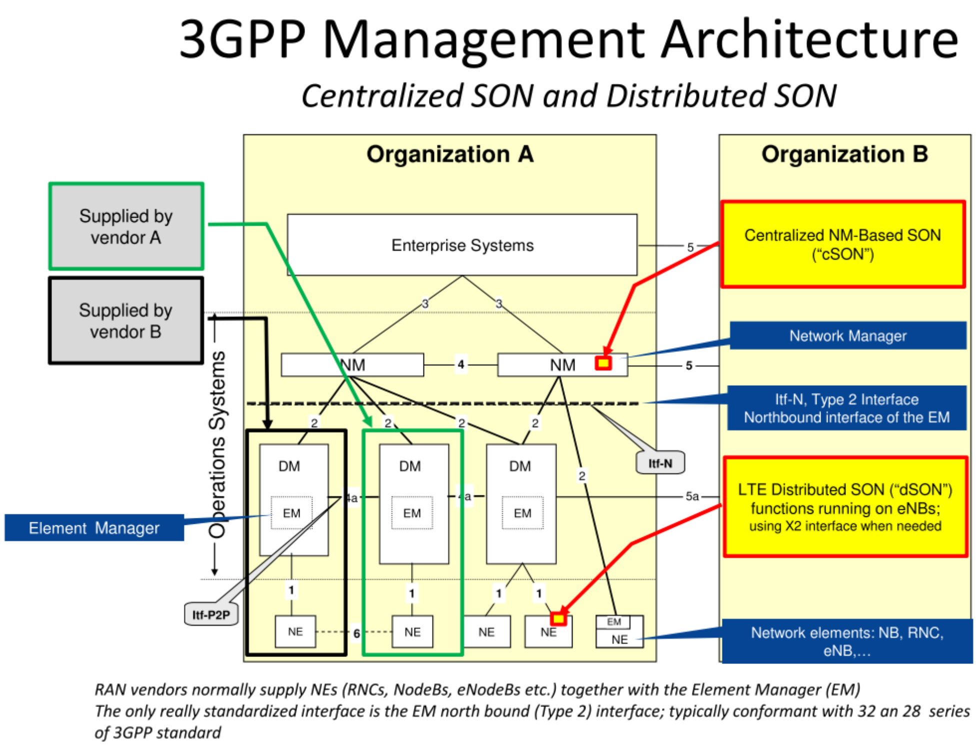

Figure 15. 3GPP Management Reference Model.

4.2.2.2 FUNCTIONAL ARCHITECTURE

Figure 16 depicts an example of a functional service-oriented architecture that represents the various services needed to support a multi-vendor deployment. Other functional mappings and architectures are possible. We limit the discussion in this section to the data and control components.

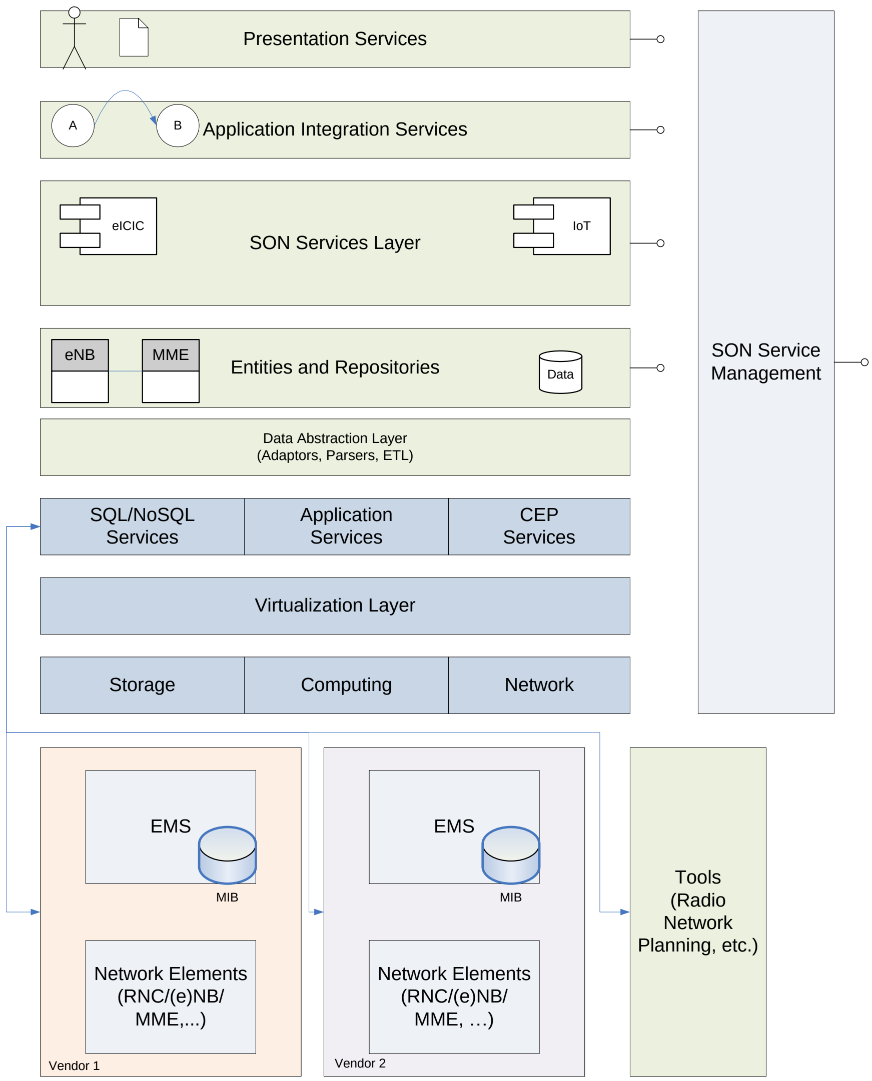

Figure 16. Example of Functional Multi-Vendor Integration Architecture.

4.2.2.3 DATA INTEGRATION ARCHITECTURE

3GPP has defined Northbound Interface (NBI) specifications that define information schemas and information transmission formats between the EMS and the OSS applications. These are known as the Integration Reference Points (IRPs) in Figure 17, but the implementations are still far from being compliant to standards.

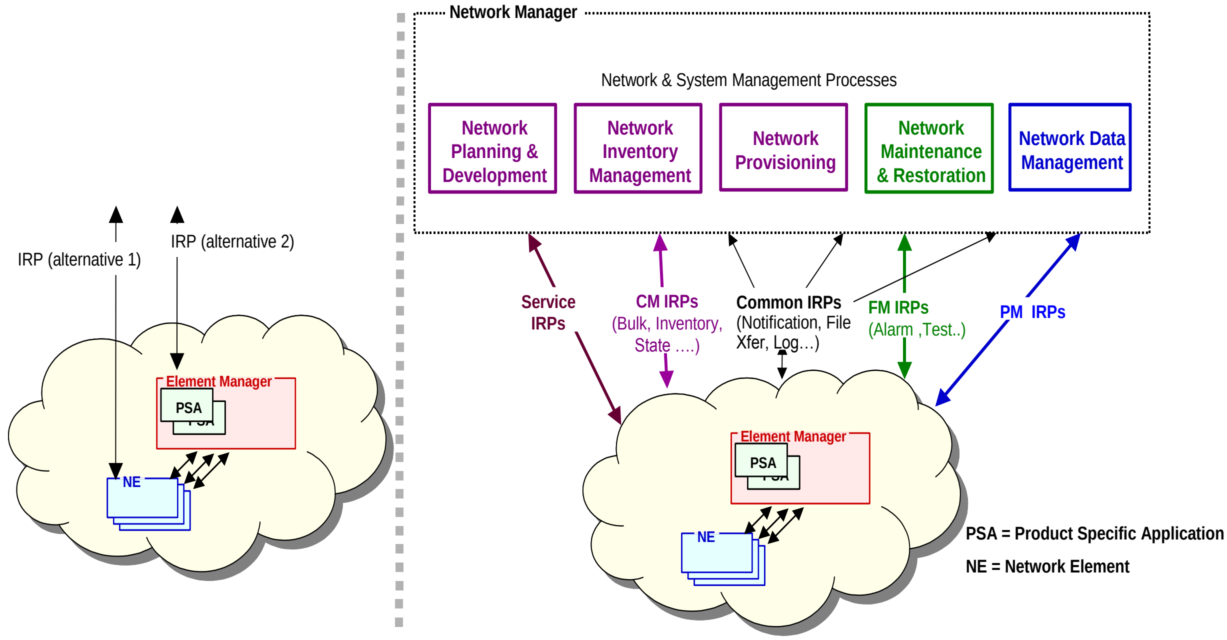

Figure 17. Application Integration Reference Points.

In addition, in the network element level, proprietary implementations of Minimization of Drive Tests (MDT) and UE call trace data dominate and hinder the utility from such data sources without integration. In conclusion, although the standards are there, at least for native 3GPP technologies, the reality forces architects to consider *overlaying* all proprietary data silos and controls with integration functions in the OSS.

There are two categories of sources of data that need to be integrated: OLTP databases / data warehouses that store KPIs for subsequent batch processing; and MDT, UE/Cell trace data for near real time (event) processing.

Today's information models used for non-real time as well as near-real time network data are a mixture of vendor-specific and 3GPP information elements. Further, the information model is specific to the technology (UMTS, LTE). Most EMS vendors expose APIs that allow the retrieval and the setting of information elements and execution of workflows that can propagate the parameters down to the network elements. As described later, the data adaptation layer (DAL) must be able to invoke such APIs especially when vendor-specific objects in the EMS/NE databases need to be retrieved.

The path towards integrated information models that started in the higher OSS/BSS layers could *expand to the EMS layer and the network elements*. There are two major trends that help transition to a more open and therefore easier service-oriented delivery model for SON: the emergence of Network Function Virtualization (NFV) and the cloud as the service delivery platform of choice; and the realization that big-data and IT is an absolute requirement to be competitive with the other internet players. Network management interfaces are an immense source of data, the utility of which extends beyond RAN performance and SON.

4.2.2.4 SCHEMA INTEGRATION AND DATA ABSTRACTION LAYER (DAL)

The DAL exposes data services to the applications and in this respect includes (s)ftp clients, parsers, topic subscribers and publishers, data adapters and several Extract Transform Load (ETL) workflows for both batch and near real time data processing. It can create and update suitable for the use-case data cubes in OLAP warehousing servers and invokes Complex Event Processing (CEP) queries to generate specific events that the applications need.

DAL is controlled by Data Syndication Services (DSS) that reside in the services layers. DAL receives configuration information from the service management application such as: database connection strings; file server addresses; all the information needed to connect to the data sources; and must support three types of data sources across vendor boundaries. The three types of data include: data stored in the *OLTP* servers of EMS systems; *file*-based data generated at the network element level; and *event*-based data generated at the network elements.

4.2.2.5 SEMANTIC INTEGRATION ISSUES

It is the function of the DAL to integrate the various schemas exposed by the vendors. It is next to impossible to *automate* such integration today for information elements such as KPIs that may be semantically similar but have the freedom to a different implementation. For example, a HO success rate KPI may have the same XML tag and same semantics, but vendors may have the freedom to account for race conditions differently.

In conclusion, although the integration of simpler information elements (e.g. RSRP fields) is also simpler to mechanize and implement, the integration feasibility of more complicated schemas is conditioned today on bilateral or multilateral data integration agreements facilitated by operators.

4.2.2.6 GENERAL CONCEPTS OF SELF-OPTIMIZATION

A self-optimization functionality will monitor input data such as performance measurements, fault alarms, notifications, etcetera. After analyzing the input data, optimization decisions will be made according to the optimization algorithms. Finally, corrective actions on the affected network node(s) will be triggered.

According to this concept, the NM portion of Self-Optimization Monitoring and Management Function performs necessary monitoring and limited interaction capabilities to support an automated optimization, as well as related IRP Manager functionality.

3GPP specifications also define the following functions that are addressing the corresponding SON use cases:

- Automatic Neighbor Relations Function
- Load Balancing Function
- Interference Control Function
- Coverage and Capacity Function
- RACH Optimization Function
- Hand Over Optimization Function

Figure 18 shows many-to-many 'mesh' relationship between SON functions and network parameters.

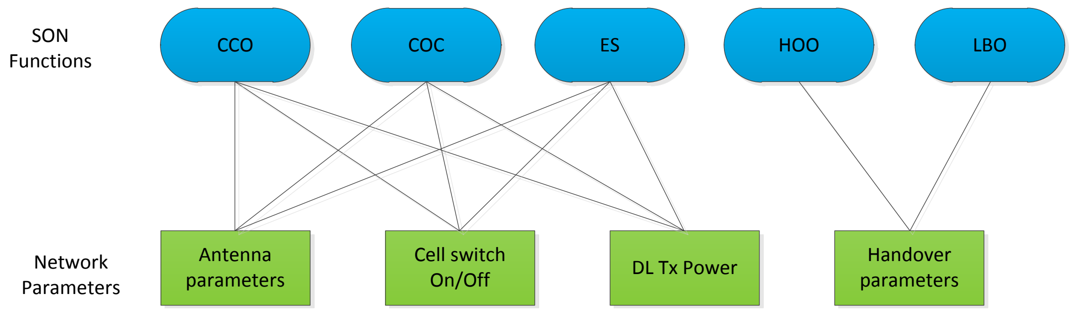

Figure 18. 'Mesh' relationship between SON functions and network parameters.

Itf-N interface specifications provide for a wide variety of information sources (measurements, alarms, traces, etcetera) and managed OAM parameters, which allow for a variety of SON functions that can be implemented at the NM layer. It is important to note that design of Centralized SON requires high tolerance to failures and accurate analysis of cost / performance issues to avoid overloading of the centralized SON controller.

4.2.2.7 TYPE 1 INTERFACE

TS 32.101 in Annex A defines valid 3GPP Management-application-layer-protocols as:

- CORBA IIOP
- NETCONF
- SNMP
- SOAP

The valid Management-application-layer-protocols for bulk and file transfer are:

- FTAM
- FTP
- TFTP
- SFTP (secure FTP).

The valid Management-application-layer-protocol for Home NodeB Management Interface Type 1 and Home eNodeB Management Interface Type 1 is:

- TR-069

The valid Management-application-layer-protocols for bulk and file transfer for Home NodeB Management Interface Type 1 and Home eNodeB Management Interface Type 1 are defined in TR-069.

Note: There is a difference between the concepts of HNB/HeNB in 3GPP (meaning Home HNB/HeNB servicing indoor Femto cells) and the more general concept of Small Cells that might include Micro cells and Pico cells and can be indoor or outdoor. See details in TS 25.104, Sec. 4.2 Base station classes.

4.2.2.8 ITF-N TYPE 2 INTERFACE

Most of 3GPP SA5 SON related specifications (series 32 and 28) address certain aspects of Itf-N Type 2 interface. Use cases and functional entities are outlined in the TS 32.522 according to requirements in TS 32.521.

4.2.2.9 INTEGRATION REFERENCE POINT (IRP) CONCEPT

3GPP is using concept known as Integration Reference Point (IRP). This concept and associated methodology is described in the documents TS 32.103 and 32.150. Specification of every IRP covers a set of operations and notifications for a specific telecom management domain such as alarm management, configuration management, etcetera.

The concept of IRP is closely related to the concept of IRPAgent and IRPManager. IRPAgent encapsulates certain subset of network element functions. IRPManager is a user of IRPAgent(s) and it interacts directly with the IRPAgent(s) using IRP(s). From the IRPManager's perspective, the IRPAgent behavior is only visible via the IRP(s).

4.2.2.10 IRP CATEGORIES

According to TS 32.103, there are three categories of IRP specifications:

- Interface IRPs
- NRM IRPs
- Data Definition IRPs

A Data Definition IRP provides common data definitions, referenced by specifications of Interface IRPs and NRM IRPs. Interface IRPs operate on entities modeled by NRM IRPs. For example, operations defined in Basic CM IRP are used together with E- UTRAN NRM IRP to support E-UTRAN configuration management function.

Specifications of each IRP are partitioned into Requirements-level, IS-level and SS-level specifications which is similar to partitioning of protocol specifications into Stage 1, 2 and 3.

- The "Requirements-level" intends to provide conceptual and use cases definitions for a specific management interface aspect as well as defining subsequent requirements for this IRP
- The "IS-level" provides the technology independent specification of an IRP
- The "SS-level" finally provides the mapping of IS definitions into one or more technology-specific Solution Sets e.g. CORBA.

The following sections outline several important IRPs as well as corresponding groups of 3GPP specifications.

Table 2 provides a list of the most important IRPs and the corresponding 3GPP specifications.

Table 2. Important IRP categories.

Specifications	**IRPs**	**Notes**
32.64x	UTRAN NRM IRP	The UTRAN NRM IRP defines an IRP through which an IRPAgent can communicate Configuration Management information to one or several IRPManagers concerning UTRAN specific network resource, by reusing relevant parts of the Generic NRM IRP in 32.62x series.
32.76X	E-UTRAN NRM IRP	The E-UTRAN NRM IRP defines an IRP through which an IRPAgent can communicate Configuration Management information to one or several IRPManagers concerning E-UTRAN specific network resource, by reusing relevant parts of the Generic NRM IRP in 32.62x series.
32.77X	HNS NRM IRP	The HNS NRM IRP defines an IRP through which an IRPAgent can communicate Configuration Management information to one or several IRPManagers concerning Home NodeB Subsystem specific network resource, by reusing relevant parts of the Generic NRM IRP in 32.62x series.
32.78X	HENS NRM IRP	The HeNS NRM IRP defines an IRP through which an IRPAgent can communicate Configuration Management information to one or several IRPManagers concerning Home Enhanced NodeB Subsystem specific network resource, by reusing relevant parts of the Generic NRM IRP in 32.62x series.
32.52X	SON POLICY NRM IRP	The SON Policy NRM IRP defines an IRP through which an IRPAgent can communicate Configuration Management information to one or several IRPManagers concerning Self-Organizing Networks Policies. Currently the following SON use cases are supported by this NRM IRP: • SON Self-Optimization Management (requirements determined by TS 32.521) • SON Self-Healing Management (requirements determined by TS 32.541) • Energy Saving Management (requirements determined by TS 32.551)

4.2.2.11 PM MEASUREMENTS AND TRACES

This section describes major types of RAN and CN performance measurements, traces and MDT. Any of them can be used as an input to NM-based Centralized SON algorithms.

4.2.2.12 RAN PERFORMANCE MEASUREMENTS AND KEY PERFORMANCE INDICATORS

Table 3 outlines most important IRPs of this type.

Table 3. Performance Measurements and Key Performance Indicators.

Specifications	IRPs	Notes
32.425	E-UTRAN Performance Measurements	The purpose of this specification is to define performance measurements specific to an E-UTRAN network. The standardized measurements result in comparability of measurement data produced in a multi-vendor network.
32.43x	PM File Format	This set of specifications describes the general semantics of performance measurement result and collection. It defines the report file format, report file conventions, and the file transfer procedure.
32.451	E-UTRAN KPI's	This specification defines requirements (business level requirements, specification level requirements and use case descriptions) related to KPIs for E-UTRAN.
32.452	HNB Performance Measurements	The purpose of this specification is to define performance measurements specific to Home NodeB Subsystem (consists of HNB and HNB-GW). The standardized measurements result in comparability of measurement data produced in a multi-vendor network.
32.453	HeNB Performance Measurements	The purpose of this specification is to define performance measurements specific to Home enhanced NodeB Subsystem (consists of HeNB and optionally HeNB-GW). The standardized measurements result in comparability of measurement data produced in a multi-vendor network

Table 4 lists measurements related to the Core Network.

Table 4. Core Network performance measurements.

Specifications	IRPs	Notes
32.406	PS core Performance Measurements	The purpose of this specification is to define performance measurements specific to Core Network Packet Switched Domain in a UMTS network or combined UMTS/GSM network. The standardized measurements result in comparability of measurement data produced in a multi-vendor network.
32.407	CS core Performance Measurements	The purpose of this specification is to define performance measurements specific to Core Network Circuit Switched Domain in a UMTS network or combined UMTS/GSM network. The standardized measurements result in comparability of measurement data produced in a multi-vendor network.
32.426	EPC Performance Measurements	The purpose of this specification is to define performance measurements specific to an EPC network or combined EPC/UMTS/GSM network. The standardized measurements result in comparability of measurement data produced in a multi-vendor network.

4.2.2.13 TRACE SPECIFICATIONS

There are two ways of using the trace feature:

1. Signaling-based activation
2. Management-based activation

In the case of signaling-based activation, configuration of the Trace Session starts from the Core Network and then 'trace parameters propagation' is applied, meaning that the Core Network devices (e.g. HSS) configure and activate trace at other devices, down to the RAN.

Management-based activation is always applied to one specific network element, typically a RNC or eNB. The so-called cell trace feature is a particular case of the management-based trace. In this scenario the trace is activated at a specific cell or a group of cells.

Trace session can be configured to collect certain events on certain interface. The collected trace data is stored at the Trace Collection Entity (TCE) which can be a separate device identified (e.g. by its IP address).

Trace Control & Configuration – 32.422

This specification describes the mechanisms used for the control and configuration of the Trace functionality at the EMs, NEs and UEs. It covers the triggering events for starting/stopping of subscriber/UE activity traced over 3GPP standardized signaling interfaces, the types of trace mechanisms, configuration of a trace, level of detail available in the trace data, the generation of Trace results in the Network Elements (NEs) and User Equipment (UE) and the transfer of these results to one or more EM(s) and/or Network Manager(s) (NM(s)).

Trace Data Definitions – 32.423

This specification describes Trace data definition and management. It covers the trace records content, their format and transfer.

4.2.2.14 MINIMIZATION OF DRIVE TEST (MDT)

Traditional drive test procedures to determine coverage for various locations is expensive in terms of staff, time and equipment needed. Since data can be obtained only for those locations where the drive test is conducted, there is limited measured information for actual user distribution and their mobility and application mixes. Lack of information from within buildings leads an operator to make assumptions about building path loss that may not correlate to the actual building path loss in a given region. Finally, a manual correlation and post processing of drive test data with network parameters including transmit power, antenna azimuth/tilt/gain is needed in order to derive meaningful information.

Due to the various above limitations, using drive tests for network optimization purposes is expensive, thus it is desirable to develop automated solutions including involving UEs in the field to reduce the operator costs for network deployment and operation. The concept of Drive Test (DT) substitution is to use actual UE data to substitute for DT to help measure coverage versus position, etcetera. In addition, UE data can, in some areas, improve upon conventional DT by helping measure dropped calls versus position. Furthermore, coordinated acquisition of UE and network data provides significant potential for surpassing DT in a more fundamental way. 3GPP has concluded that it is feasible to use control plane solutions to acquire the information from devices. This information, together with information available in the radio access network can be used for Coverage and Capacity Optimization. In fact, because MDT allows tracing of UE's operations for both UTRAN and E-UTRAN, it is a prime data source for multi-vendor SON. This includes CONNECTED state ("Immediate MDT") and IDLE state ("Logged MDT"). MDT functionality is specified in TS 37.320. MDT Trace can accumulate the following data:

- M1: RSRP and RSRQ measurement by UE
- M2: Power Headroom (PH) measurement by UE
- M3: Received Interference Power measurement by eNB (a cell measurement)
- M4: Data Volume measurement separately for DL and UL, per QCI, by eNB.
- M5: Scheduled IP Throughput, separately for DL and UL, both per RAB per UE and per UE by eNB

Reporting and logging can be configured as follows:

For M1:

- Periodic
- Serving cell becomes worse than threshold; event A2
- Event triggered periodic; event A2

- Reception of event triggered measurement reports according to existing RRM configuration for events A1, A2, A3, A4, A5, A6, B1 or B2. It is FFS whether this applies to Signaling-based MDT or only for Management-based MDT

For M2:

- Provided by the UE according to RRM configuration; collected when available

For M3, M4, M5 (when available):

- End of measurement collection period

Two parallel solutions have been developed for MDT:

- Area-based MDT, where the UE measurement data is collected in a certain area where the area is determined by a set of UTRAN/E-UTRAN cells or a set of Location Area/ Routing Area/Tracking Area
- Subscription-based MDT, where the UE measurement data is collected for one specific subscriber or equipment

For Area-Based MDT, the MDT trace is activated by the management system. The management system communicates with eNB/RNC directly in the cells where the MDT needs to be activated. The radio nodes are using the RRC protocol over the Uu interface to communicate further with UEs to start the measurement collections in the UE.

For subscription-based MDT, activation of the MDT trace also is started by a command from the management system. In this case the session targets a single particular subscriber identified by IMSI or one specific user equipment identified by IMEI. Therefore activation goes first to the Home Subscriber Server (HSS) database. The HSS propagates the parameters of the session further to the radio network via the core network entities (MME/ SGSN). If the UE moves to another cell, collection of the UE data transitions to that cell following the UE.

The trace information is accumulated in the node called TCE (Trace Collection Entity) in format defined in TS 32.423. The IP address of TCE is configurable along with other trace parameters which provides for additional flexibility.

4.2.2.14.1 RELEASE 11 UPDATES TO MINIMIZATION OF DRIVE TESTS

Rel-11 has described the general principles and requirements guiding the definition of functions for Minimization of Drive Tests as follows:

1. MDT mode. There are two modes for the MDT measurements: Logged MDT and Immediate MDT.
2. UE measurement configuration. It is possible to configure MDT measurements for the UE logging purpose independently from the network configurations for normal RRM purposes. However, in most cases, the availability of measurement results is dependent on the UE RRM configuration.
3. UE measurement collection and reporting. UE MDT measurement logs consist of multiple events and measurements taken over time. The time interval for measurement collection and reporting is decoupled in order to limit the impact on the UE battery consumption and network signalling load.

4. Geographical scope of measurement logging. It is possible to configure the geographical area where the defined set of measurements shall be collected.
5. Location information. The measurements can be linked to available location information and/or other information or measurements that can be used to derive location information.
6. Time information**.** The measurements in measurement logs should be linked to a time stamp.
7. UE capability information. The network may use UE capabilities to select terminals for MDT measurements.
8. Dependency on SON. MDT solutions should be able to work independently from SON support in the network. Relationships between measurements/solution for MDT and UE side SON functions should be established in a way that re-use of functions is achieved where possible.
9. Dependency on Trace. The subscriber/cell trace functionality is reused and extended to support MDT. If the MDT is initiated toward to a specific UE (for example, based on IMSI, IMEI-SV, etcetera), the signalling-based trace procedure is used, otherwise, the management-based trace procedure (or cell traffic trace procedure) is used. Network signalling and overall control of MDT is described in Rel-11.

The solutions for MDT should take into account the following constraints:

1. UE measurements. The UE measurement logging mechanism is an optional feature. In order to limit the impact on UE power consumption and processing, the UE measurement logging should rely as much as possible on the measurements that are available in the UE according to radio resource management enforced by the access network.
2. Location information. The availability of location information is subject to UE capability and/or UE implementation. Solutions requiring location information should take into account power consumption of the UE due to the need to run its positioning components.

Rel-11 has defined detailed mechanisms for Management Based Activation, Trace Parameter Propagation, and Trace Record Collection in the case of signalling-based activation.

Rel-11 has included QoS verification use cases beyond the coverage use cases addressed in Rel-10. The MDT data reported from UEs and the RAN may be used to verify Quality of Service, assess user experience from RAN perspective, and to assist network capacity extension.

4.2.2.14.2 MULTI-VENDOR MDT

The Minimization of Drive Test (MDT) feature is also possibly susceptible to failure when different vendors are utilized. This feature is very useful to support network operators in their performance analysis and troubleshooting functions, since it can provide detailed trace information about one particular UE, including Layer 3 messages, radio information, etcetera.

The trace information is captured by various entities:

- By the device: in logged mode, when the unit is in idle mode and no trace information is sent back to the network
- By the eNB: when the device is in active mode, the eNB will collect the measurements sent by the UE
- By the MME: this unit collects MME trace messages. The information captured by the MME will permit the MDT utility to decode the NAS portion of the traces collected at the RAN.

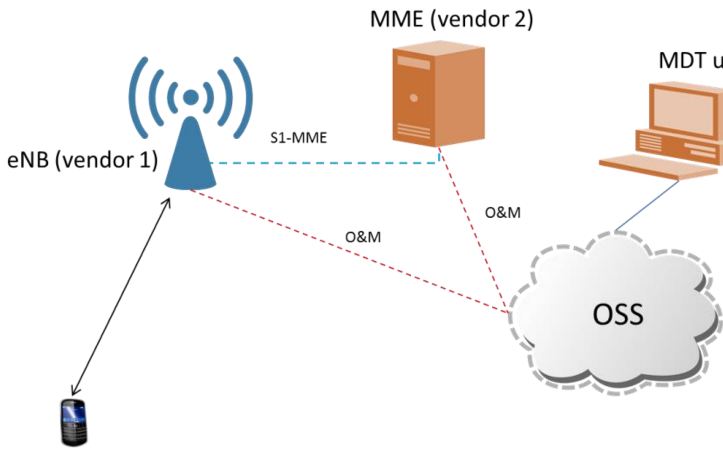

Figure 19. Multi-vendor MDT Scenario.

In order to properly present the UE trace, a software tool is required to collect, decode and correlate the traces from the eNodeB and the MME. Such tool can be part of the OSS of one of the vendors, or provided by a third party company. In a multi-vendor case, as shown in Figure 19, when vendor A supplies the RAN, and vendor B the MME, the MDT utility that resides in the OSS of vendor A may not able to receive the MME part of the trace from that UE, therefore missing important event information about the call. This situation could be avoided with a better standard definition of the interaction between these entities and the OSS for this particular use case.

4.2.3 SELF-OPTIMIZATION FUNCTIONS BASED ON ITF-N

4.2.3.1 LOAD BALANCING FUNCTION

4.2.3.1.1 LOAD BALANCING IN IDLE STATE

Load balancing in IDLE STATE is optimization of the cell (re)selection process with the goal to have IDLE UEs camped in the most suitable cells. Suitability of the cell for certain category of UEs depends on their expected demand; so that when demand for resources is created the network will not need to redirect the UE to another cell. This technique provides for optimal distribution of load created by the IDLE UEs when they switch to CONNECTED state and request network resources.

Implementation of this technique is based on the fact that normally a UE camps on a cell if the minimum signal quality conditions are met. The quality conditions are based on thresholds broadcasted by the Base Station. If the quality of signal drops below the lower threshold, the UE is expected to search for another cell. Being in IDLE state, the UEs do not communicate with the Base Station and therefore the Base Station has no knowledge of their presence. The only way to control camping on the cell is to modify cell reselection priorities, offsets and thresholds. This control is statistical by nature. Itf-N interface provides access to full set of parameters that control IDLE state camping.

4.2.3.1.2 LOAD BALANCING IN CONNECTED STATE

Centralized SON can estimate load at the eNB using such parameters as DL/UL PRB utilization values that normally are available over OAM interface. To fix the problem the SON manager can use parameters that control handovers between the eNB and neighbor cells. These parameters can be set over Itf-N interface.

First of all, there is a group of parameters that control E-UTRA measurement reporting events A1- A6 defined as follows:

Event A1: Serving becomes better than absolute threshold;

Event A2: Serving becomes worse than absolute threshold;

Event A3: Neighbor becomes amount of offset better than PCell;

Event A4: Neighbor becomes better than absolute threshold;

Event A5: PCell becomes worse than absolute threshold1 AND Neighbor becomes better than another absolute threshold2.

Event A6: Neighbor becomes amount of offset better than SCell.

Examples of these parameters: cellIndividualOffset, hysteresis

Normally UEs perform and report measurements of the signal strength and signal-to-interference ratio for signals from the serving cell and from neighbor cells. For LTE, these are RSRP and RSRQ. Similar measurements for UTRAN RSCP, Ec/No are performed by a LTE UE on UTRAN neighbor cells. Configuration of measurements is performed by RRC layer of the eNodeB.

Actual handover preparation procedure normally starts when the signal measurements reported by the UE go below certain thresholds. The threshold can be defined for RSRP or RSRQ or both; normally it can be configured per neighbor over the OAM interface provided by the vendor of eNB. Using these parameters, the Centralized SON can increase probability of edge UEs to be handed over to certain neighbor eNB. It is important also to modify accordingly the corresponding thresholds at the neighbor eNB to avoid ping pong situation.

4.2.3.2 INTERFERENCE CONTROL FUNCTION

For interference control the following parameters can be used:

- Transmit power control
- Selection of PHY parameters (PCI, scrambling code etc.)
- Tilt control

Some vendors provide also for capabilities of setting certain frequency reuse patterns in DL and UL; in this case the corresponding parameters normally are available over the OAM interface. These parameters include specification of subcarrier sets and transmit power arrangements applied to communication with certain categories of UEs (e.g. edge UEs). There are multiple schemes known as FFR (Fractional Frequency Reuse) and SFR (Soft Frequency Reuse), etcetera.

4.2.3.3 COVERAGE AND CAPACITY OPTIMIZATION FUNCTION

MDT is a powerful source of information for Coverage and Capacity Optimization function. The MDT trace allows collections of measurements by multiple UEs, optionally combined with location data. Then the SON manager will be able to create and maintain a virtual map of the network domain with all details of coverage, with path loss matrix calculated for every given location for every eNB etc.

To influence the coverage and capacity situation, all interference control parameters (section 4.2.3.2) are applicable as normally cell capacity strongly depends on interference generated by neighbor cells. The RSRP and RSRQ measurements help identification of coverage holes. In many cases there is a tradeoff between coverage and capacity; Centralized SON architecture allows for proper management of this tradeoff.

4.2.3.4 HANDOVER OPTIMIZATION FUNCTION (MOBILITY ROBUSTNESS OPTIMIZATION)

MRO targets the following: minimize call drops and Radio Link Failures related to handover, optimize cell selection and reselection for UEs in IDLE state, and minimize unnecessary handovers. Some of these targets form a tradeoff. MRO feature is also tightly bound to CONNECTED state load balancing where handovers are used for more uniform distribution of load among eNBs. Centralized SON architecture allows for proper management of these tradeoffs.

In LTE, RLF does not necessarily imply call (connection) drop, however RLF event signals a certain degree of coverage problems. Statistics of both drops and RLFs is important for selection of proper remedy.

To detect problems resulting in RLF, the SON manager can also use RLF traces collected by the network. Actual execution of handover is controlled by the condition when the signal measurements reported by the UE go below certain RSRP or RSRQ threshold. To fix RLF problems, the SON manager can modify these thresholds over the OAM interface.

The same information can be used in optimization of Inter-RAT mobility, particularly for the case of CS Feedback (CSFB) when a LTE terminal requesting a voice service, is handed over from LTE network to collocated UTRAN network.

4.2.4 SON USE CASE INTERACTIONS AND WORKFLOW MANAGEMENT

4.2.4.1 SON INTERACTIONS

3GPP Rel-11 has identified and called out conflicts or dependencies between SON Functions.

Conflict may happen when two or more SON Functions try to change the same network configuration parameter. For example, there would be a conflict when one SON Function tries to increase the value of one configuration parameter while the other SON Function tries to decrease the value of the same configuration parameter. Another typical conflict example is Ping-Pong modification of one configuration parameter between two or more SON Functions.

Dependency means the behavior of one SON Function may have influence on other SON Functions. For example, CCO function may adjust the Neighbor Relation (NR) due to coverage optimization, and then the changed NR will have an influence on Handover Parameter Optimization function.

SON Coordination means preventing or resolving conflicts or negative influences between SON functions to make SON functions comply with an operator's policy.

For coordination of SON Functions whose outputs are not standardized, 3GPP has defined how the Integration Reference Point (IRP) manager uses standardized capabilities to set the SON Function(s) targets, and where needed their weights. For coordination of SON Functions whose outputs are standardized, the context of optimization coordination is FFS. 3GPP has addressed the coordination between SON functions below Itf-N and CM operations over Itf-N. Examples of conflict situations are specified in Rel-11.

3GPP Rel-11 has called out the fact that in a real network, it is possible that centrally managed operations via Itf-N and several SON Functions below Itf-N are running at the same time, and they may try to change the same parameters during a short time period. So coordination is needed to prevent this kind of conflict. If coordination between multiple SON Functions is necessary, 3GPP has identified a function referred to as a SON Coordination Function that will be responsible for preventing or resolving conflicts. The SON Coordination Function may be responsible for conflict prevention, conflict resolution, or both in parallel.

To prevent conflicts between the SON Functions, 3GPP has specified that the SON Functions may ask the SON Coordination Function for permission before changing some specific configuration parameters.

As a basis for decisions, the SON Coordination Function will typically use the following inputs received from the SON Function(s), such as: which SON Functions are modifying configuration parameters (including information about vendor, release etcetera); the time duration for how long the configuration parameter should *not* be interfered with ("impact time"); the state of SON functions; the SON targets, which are the justification for the configuration change; and possible impact of a parameter change on other objects ("impact area"). Additional information, such as the state of certain managed objects, possible impact of the parameter change on Key Performance Indicators, priority of SON functions, and SON coordination policies, is also specified.

The mode of operation between the SON Coordination Function and the SON Function, as well as the role of the SON Coordination Function in the detection and attempts to resolve the conflicts, are specified in Rel-11.

4.2.4.2 WORKFLOW MANAGEMENT

Workflows are one implementation approach for representing the SON Coordination Function interaction with the SON Functions. Although this section refers to centralized architectures, similar workflow management approaches can be used in hybrid architectures as well. In SON system implementations, workflows are executed between the EMS and network elements. The system is engineered to maintain (persist) each stage's state and be able to revert back to the previous stage if error conditions occur. For example, in managing the optimal configuration of a parameter, SON applications may initiate a workflow at the EMS to collect required for the use case data. The EMS uses PM interfaces to return the required data as well as other aperiodic procedures such as initiating UE call trace functionality. The workflow proceeds with the SON application running optimization algorithms on the returned data and transitioning to another stage where it instructs the EMS to use CM procedures and configure the network element(s) with the optimal parameters.

In multi-vendor networks, multiple EMS systems that must participate in such workflows are involved. For example, in HTN networks the EMS system that oversees the small cell layer and the macro layer are different group of servers. A SON application such as eICIC implemented by a centralized architecture, must invoke both EMSs to be able to set optimal parameters. It will need to invoke the EMS of the macro layer to configure the ABS patterns as well as the offloading bias values towards the small cell layer and the EMS of the small cell layer to set up the retaining bias values towards the macro layer. Managing workflows across vendor boundaries requires *a common controlling entity as well as a common control scheme or policy.* A supervisory entity is usually called *control policy manager* to distinguish the specific task at hand.

With this section we have concluded on the two foundational pillars of a centralized multi-vendor SON implementation: data and control. With data we have unified the schemas involved within the Data Access Layer (DAL) and with control we have unified the means that the vendors can exchange control messaging to comply to the underlying policy and facilitate a distributed multi-vendor execution environment.

4.2.5 PRESENTATION INTEGRATION AND DATA VISUALIZATION

SON features simplifies the network management tasks resulting in OPEX reduction and improved network quality. Although, Operators require automation (SON features), they still want to keep the control and understand the SON feature activities in their network.

SON visualization tools are essential for the operator to analyze SON activity and performance in the radio network to validate the performance improvement of the radio network brought about as a result of SON. It provides visibility of SON algorithm behavior, its reliability and performance. Key requirements of SON visualization are:

- Multidimensional view of SON activity and network KPIs
- Provides visibility of SON activity in the network
- Speeds up fault detection and resolution
- Avoids complex and time consuming manual verification of network configuration changes

4.3 SON IN THE DEPLOYMENT OF MULTI-VENDOR LTE HTN

Networks are becoming increasingly heterogeneous with the deployment of macros, picos and femtos, multiple technologies that may come from sometimes from multiple vendors. Several parameters need to be fine-tuned, sometimes over a wide range of timescales. Accordingly, the automation of parameters (and hence SON) becomes increasingly more relevant in the deployment of HetNets to help minimize slow, manual parameter optimization. This section details the various aspects of HetNets and thus motivates the need for SON.

The HetNets deployment scenarios can be defined based on the access mode of the small cells and whether small cells are deployed in dedicated or shared carrier. These HetNets scenarios will be discussed in following subsections.

There are several approaches to increase the capacity of the network:

- Improve the capacity of each macro layer cell.
- Increase the density of cells in the macro layer.
- Complement the macro layer with low power nodes, thereby creating a heterogeneous network.

These approaches are shown in Figure 20.

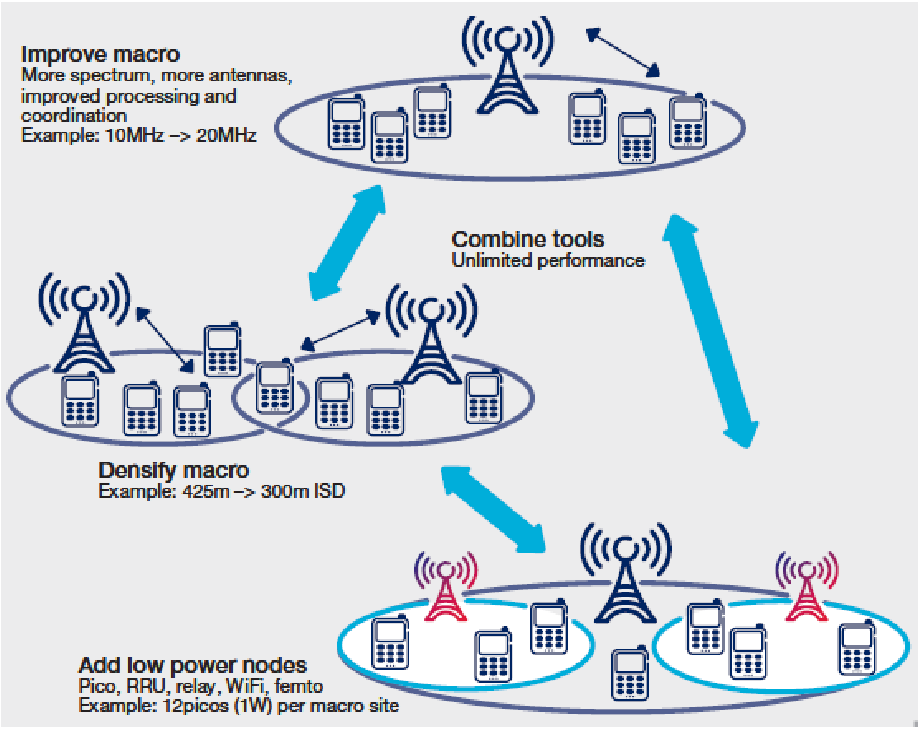

Figure 20.

The capacity of existing macro sites can be enhanced through the addition of more spectrum, more antennas, and advanced processing within and between nodes. These are attractive ways to increase capacity and data rates since they alleviate the need for new sites.

By doubling the spectrum, data volumes for the DL approximately double. In the UL, however, increasing spectrum does not necessarily improve the capacity. This condition is referred to as power limitation. The UL data rates are limited by the lower transmit power of UEs relative to the power of the eNB. Thus UEs in poor channel conditions are unable to take advantage of the additional spectrum.

Another approach is to increase the density of the macro network. With this approach, the network performance is insensitive to traffic location within the cell. By doubling the number of macro sites, the DL capacity of the network is approximately doubled, while the DL capacity per site remains more or less the same. The UL capacity of the network is more than doubled since users become less power limited, have better capacity per site and twice as many sites. Also, the UL data rates for cell edge users are increased significantly.

Complementing the macro networks with low power nodes has been considered as way to increase capacity for some time now. This approach offers very high capacity and data rates in areas covered by the low power nodes. Performance for users in the macro network improves if low power nodes can service a significant number of hotspots and coverage holes. Deploying low power nodes can be challenging, however, depending on the physical location from which traffic is generated. In addition, due to the reduced range of low power nodes, more of them are required. Overcoming these challenges requires proper design and integration of the low power nodes.

The way to meet future capacity demand is by combining all three approaches: improving the macro layer; densification of the macro layer; and adding pico nodes. How these approaches are combined and in what order depends on the existing network, targeted volumes and data rates, and technical and economical feasibility of each approach.

The small cells can be supplied by vendors different from the macro cell supplier in a given area. In addition, small cells from multiple vendors may be deployed in the same market as neighbors to each other. Therefore it is important for SON to work across multiple vendors in these scenarios so that small cells are properly managed and integrated with macro networks.

4.3.1 OPEN AND HYBRID ACCESS SCENARIOS

An open access small cell provides services to any subscriber with the normal PLMN membership or roaming. A small cell in open access mode does not broadcast any CSG (Closed Subscriber Group) identity and does not perform any kind of CSG-based access control.

A hybrid access small cell is accessible as a CSG cell by UEs which are members of the CSG and as a normal cell by all other UEs. A hybrid cell is identified in such a way that it broadcasts a CSG identity but no (or FALSE) CSG indicator. Therefore, for UEs who are not the members of the CSG or who are CSG-unaware, a hybrid cell can be accessed in exactly the same way as an open access cell. Moreover, a hybrid cell can offer preferential services to users which are part of its CSG over non-CSG users.

Open and hybrid access small cells can be deployed indoors or at macro cell edge to expand network coverage. They can also be deployed in hotspots to improve network capacity. They can be installed by operators or a third party such as building owners in an unplanned manner. Small cells benefit greatly from self configuration and optimization enabled by HetNets SON framework.

Future networks need dense deployment of open-access small cells to achieve huge network capacity. The deployment leverages existing premises and backhaul and greatly reduces Capital Expenditure (CapEx) and Operational Expenditure (OpEx). Good SON implementations enable simple plug-and-play deployment of dense small cells in an unplanned manner that will provide both indoor and outdoor coverage. In this new model, small cells are deployed in a variety of venues such as:

- Offices and residences (from single-family homes to high-rise buildings);
- Public hotspots (shopping malls, airports, train/subway stations, stadiums);
- Outdoor public areas sites (such as lamp posts).

With additional spectrum and sufficient density of small cells, it is possible to significantly increase the capacity of today’s networks.

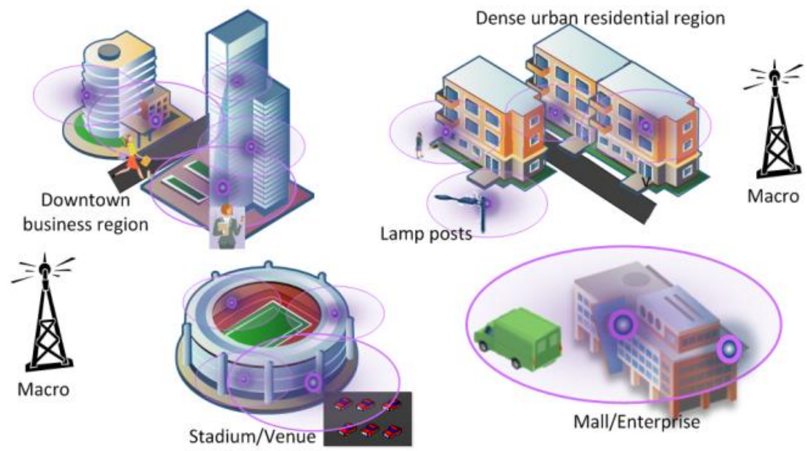

Figure 21. Future networks utilize dense open-access small cells for indoor and outdoor coverage.

4.3.1.1 DEDICATED CARRIER IN EACH LAYER

Small cells can be deployed in dedicated carrier while macro cells are operating in separate carriers. In this scenario, the interference between macro and small cells is usually not an issue. As a result, the small cell can cover a relatively large area without being affected by interference from macro signals. This configuration can support medium to high penetration levels of small cells, which has the potential to provide huge network capacity.

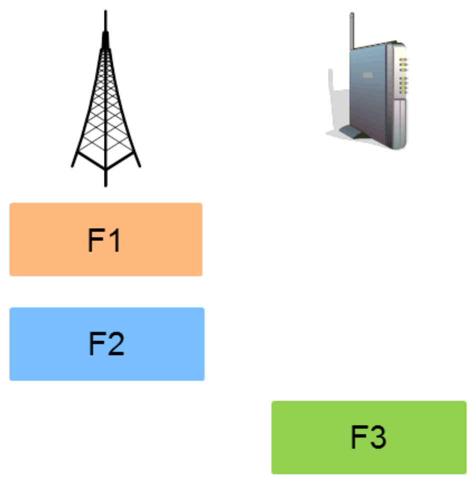

Figure 22. Dedicated carrier HetNets.

The mobility between macro and small cells are supported by inter-frequency operations. The idle mode UEs need to perform inter-frequency search and reselection while connected mode UEs will perform inter-frequency handovers to switch between macro and small cells. It is important to use optimized mobility management to avoid unnecessary handovers while maximizing traffic offload to small cells.

Dense deployment of small cells would create interference among small cells. Small cells would need to monitor neighboring cells and adapt to the changing environment. Transmission power and mobility parameters can be adjusted to maintain the proper cell boundary. Seamless mobility among small cells and frequent handover mitigation are critical for dense cell deployment. Load balancing and resource partitioning among different small cells is also crucial to improving the user experience.

4.3.1.2 SHARED CARRIER ACROSS LAYERS

Operators with limited spectrum may choose to deploy small cells in a shared carrier with macro cell. There is interference between macro and small cells which can be mitigated by the proper SON and advanced interference management techniques. Shared carrier configuration is often used with low penetration of small cells.

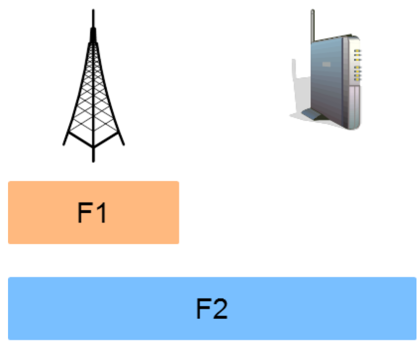

Figure 23. Shared carrier HetNets.

The small cell coverage will be determined by its own transmission power and macro signal level. It is important for small cells to take received macro signal strength into consideration when choosing their transmission power for the desired coverage. The mobility between macro and small cells are supported by intra-frequency operation. The proper configuration of a neighbor list and handover parameters are critical for robust mobility performance.

LTE-Advanced Further Enhanced Inter-Cell Interference Coordination (FeICIC) and advanced terminal receivers with Interference Cancellation (IC) techniques can be utilized by shared carrier HetNets to support small cell range expansion and resource partitioning between macro and small cells. Range expansion allows more UEs to benefit directly from low-powered small cells. Adaptive inter-cell interference coordination uses Almost-Blank Subframes (ABS) to provide smart resource allocation amongst interfering cells and improves inter-cell load balancing in HetNets.

4.3.2 CLOSED ACCESS (CSG) SCENARIOS

Since many small cells are owned by the end users or by a private enterprise, it is often desirable to allow only authorized subscribers to access their own small cells. Closed Subscribed Group (CSG) small cells are configured to limit access to authorized subscribers. CSG cells broadcast a CSG identity and a (TRUE) CSG indicator and perform CSG-based access control. However, harsh interference conditioned can result in CSG small cell deployment.

4.3.2.1 DEDICATED CARRIER IN EACH LAYER

CSG small cells can be deployed in dedicated carriers to avoid interference between macro and small cells. However, there can be strong interference between neighboring small cells that belong to different CSG groups. A barred UE may move into the coverage area of a CSG cell while being served by a neighboring CSG cell. The barred UE may suffer DL interference from the closer CSG cell which it is denied of access, and the barred UE transmission may also cause UL interference to the closer CSG cell. SON function can be helpful in this scenario to detect neighboring small cells and mitigate the interference.

Figure 24. Interference in the dedicated carrier CSG small cell scenario.

It is also important to provide mobility for UEs in idle and connected mode. UEs need to identify CSG of small cells on dedicated carrier and decide whether it is authorized to handover to the small cell. A cluster of CSG cells may be deployed to cover a large area or building. In this case, the proper configuration of the CSG cells and seamless mobility between CSG cells are important for good user experience.

4.3.2.2 SHARED CARRIER ACROSS LAYERS

If CSG small cells are deployed in the shared carrier with macro cells, interference between macro and small cells needs to be addressed properly. Due to the restricted nature of CSG cells, a UE close to a CSG cell may be denied service and forced to connect to a macro cell. The UE may see strong DL interference from CSG cell signal, while its transmission may cause significant noise rise at the CSG cell. In addition, CSG users close to macro site may cause unintended jamming effects on the uplink for the macro cells. SON features can help mitigate the interference in this scenario. CSG cells would also impose limitation on mobility optimization and load balancing between macro and small cells.

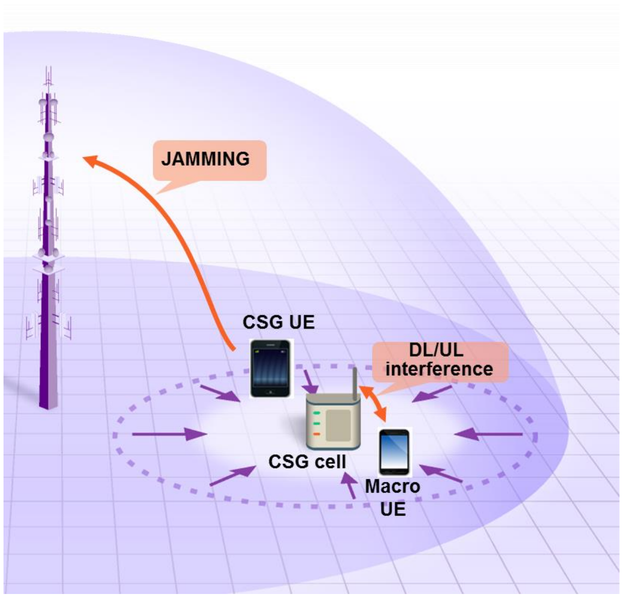

Figure 25. Interference in the shared carrier CSG small cell scenario.

5 SUMMARY AND CONCLUSIONS

This white paper is a continuation in part to the earlier 4G Americas white paper, *Self-Optimizing Networks: The Benefits of SON in LTE*, released in 2011 that addressed the SON features in Releases 8, 9 and 10. In this update, the enhancements of SON features in 3GPP Rel-11 and significant new ground in addressing the multi-vendor aspects of SON and its deployment challenges and opportunities are significantly covered. Market realities in HTN deployments make multi-vendor SON a strong requirement in many markets.

In addition, two SON *architectural patterns* that are expected in the vast majority of practical multi-vendor SON deployments are addressed in this report. The X2-based pattern, enables multi-vendor interaction by placing emphasis in 3GPP inter-NE RAN interfaces. As such, Interoperability Testing (IOT) of interfaces such as X2 has been deemed essential to the realization of this architecture. The Itf-N-based pattern enables multi-vendor SON by integrating and centralizing SON algorithms and services in the OSS and resolves several multi-vendor issues by a combination of 3GPP standardization and multilateral agreements between vendors on information model (schema) sharing and control. Practical hardware processing limitation issues related to the realization of X2 based architectures and Itf-N based architectures will further help decide a suitable choice of SON architecture for a given network. Possible deployment issues of multi-vendor SON were also addressed including the many permutations that have been identified in the OSG and CSG space to introduce further potential complexity in a multi-vendor self-organizing network.

Overall, there is no 'silver bullet', but rather, an optimal architecture that can simultaneously provide the best possible performance and simplicity. *It is expected that over the next few years, SON will possibly evolve towards hybridization to manage the tremendous complexity*. Some SON use cases deemed 'too complicated' will necessitate a supervisory entity at the OSS, which itself can be multi-vendor, while other SON use cases, fueled by the industry's IOT efforts, will be implemented without an OSS involvement. The SON space continues to be dynamic and deviations from such an architectural pattern may be influenced by dynamically changing market developments.

6 LIST OF ACRONYMS

ANR	Automatic Neighbor Relation
BSS	Business Support System
CCO	Coverage and Capacity Optimization
CM	Configuration Management
COC	Cell Outage Compensation
CQI	Channel Quality Indicator
CSG	Closed Subscriber Group
DAS	Distributed Antenna Systems
EMS	Element Management System
eNB	Enhanced Node Base station
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FM	Fault Management
GCI	Global Cell Identifier
GoS	Grade of Service
HO	Hand Over
HSPA	High Speed Packet Access
HTN	Heterogeneous Network
ICIC	Inter-Cell Interference Coordination
IRAT	Inter-Radio Access Technology
IRP	Integration Reference Point
KPI	Key Performance Indicator
LTE	Long Term Evolution
MDT	Minimization of Drive Test
MLB	Mobility Load Balancing
MME	Mobility Management Entity
MRO	Mobility Robustness Optimizations
NB	Node Base station
NGMN	Next Generation Mobile Networks
NM	Network Management
OAM	Operations Administration and Maintenance
OPEX	Operational Expenditure
OSS	Operations Support System
PCI	Physical Cell Identifier
PM	Performance Management
PRB	Physical Resource Blocks
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
RACH	Random Access Channel
RAN	Radio Access Network
RF	Radio Frequency
RLF	Radio Link Failure
RRC	Radio Resource Connection
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SDU	Service Data Unit

SINR	Signal to Interference and Noise Ratio
SON	Self-Organizing Networks
TAC	Tracking Area Code
TTT	Time To Trigger
UE	User Equipment

7 ACKNOWLEDGEMENTS

The mission of 4G Americas is to promote, facilitate and advocate for the deployment and adoption of the 3GPP family of technologies throughout the Americas. 4G Americas' Board of Governors members include Alcatel-Lucent, América Móvil, AT&T, BlackBerry, Cable & Wireless, Cisco, CommScope, Entel, Ericsson, Gemalto, HP, Mavenir, Nokia Solutions and Networks, Openwave Mobility, Powerwave, Qualcomm, Rogers, T-Mobile USA and Telefónica.

4G Americas would like to recognize joint project leadership and important contributions of Kamakshi Sridhar and Pantelis Monogioudis of Alcatel-Lucent, as well as representatives from the other member companies on 4G Americas' Board of Governors who participated in the development of this white paper.

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