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# Self-Optimizing Networks: The Benefits of *SON* in LTE

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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 permit 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.  SON improves network performance, but in no way replaces the wireless industry's important need for more spectrum to meeting the rising mobile data demands from subscribers.

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 has continued in Release 10 with additional enhancements in each of the above areas and new areas allowing for inter-radio access technology operation, enhanced inter-cell interference coordination, coverage and capacity optimization, energy efficiency and minimization of operational expenses through minimization of drive tests. This paper discusses the Release 8, Release 9 and Release 10 Self-Organizing Network (SON) techniques and explains how these capabilities will positively impact network operations in the evolved LTE network. Application of SON techniques by a 4G Americas member company operator in LTE networks and live results from the application of SON to HSPA+ networks are described, thus demonstrating the potential benefits of SON. Application of SON techniques to address deployment and operational challenges with Distributed Antenna Systems (DAS), and picos, femtos and relays are described to address the impact of SON on a variety of radio systems. This paper is an update of the paper published in 2009 on "Benefits of SON in LTE" [17] that addressed the rationale for SON and the description of SON features in 3GPP Releases 8 and 9.

## 1.2 TECHNOLOGY AND MARKET DRIVERS FOR SON

Reflecting upon recent wireless industry events, 4G Americas member companies observe several important trends that are driving additional network complexity and operations effort.

New and emerging classes of mobile devices (smartphones, PC data cards, USB modems, consumer devices with embedded wireless, machine-to-machine, etc.) are fostering explosive growth of wireless data usage by public and enterprise users. As a result, wireless service providers have to simultaneously support a growing number of higher-bandwidth data applications and services on their networks. The list of user applications and services is quite broad in scope, and includes Internet browsing, Web 2.0, audio, video, video on demand, gaming, location-based services, social networking, peer-to-peer, advertising, etc.

On the network side, wireless service provider networks are becoming more complex and heterogeneous. Projections point to rapidly growing numbers of femto and picocells (in order to drive greater coverage and/or offload capacity from macrocells), plus increasing prevalence of multi-technology networks (2G, 3G, 4G, plus WiFi). These trends pose potentially significant operational and network complexity regarding macro/femto and inter-technology handover, as well as management of macro/femto and macro/pico interference. Taken together, these trends place ever-increasing demands upon service providers' networks and their operational staff. Ensuring quality user experience requires more complex Quality of Service (QoS) and policy implementations while they simultaneously must increase network throughput in response to the rapid growth in wireless data.

Moreover, wireless data revenue measured on a per-megabit (Mb) basis is decreasing. Fortunately, spectral efficiency gains are provided by new wireless technologies, and do provide some measure of relief; however, the data throughput per user is growing (and revenue per Mb is dropping) so rapidly that spectral efficiency gains alone appear unable to keep up. Consequently, service providers – and infrastructure vendors – are increasing their focus on operational cost reductions. Reflecting upon these dramatic trends, it has become clear that traditional network management needs significant improvement for managing this growing data volume and network complexity in a cost-effective manner.

## 1.3 REASONS FOR AUTOMATION

At a high level, there are two underlying operational issues facing service providers. Some processes are repetitive, while others are too fast or difficult to be performed manually. The rationale for SON automation can be grouped into two broad categories:

1. Previously manual processes that are automated primarily to reduce the manual intervention in network operations in order to obtain operational and/or deployment savings. Automating repetitive processes clearly saves time and reduces effort. Auto-configuration and self-configuration fall into this category.

2. Processes that require automation because they are too fast, too granular (per-user, per-application, per-flow, as a function of time or loading), and/or too complex for manual intervention. Automatically collected measurements from multiple sources (e.g., from user devices, individual network elements, and on an end-to-end basis from advanced monitoring tools) will provide accurate real time and near real time data upon which these algorithms can operate thus providing performance, quality, and/or operational benefits.

Consequently, substantial opportunities exist for cross-layer, end-to-end, and per-user/per-application/ per-flow optimizations for extracting additional performance benefits and management flexibility. These categories need not be distinct, (e.g., a previously manual process that is growing too complex due to the above trends) may by necessity require automation in order to manage it.

Automation is not a new concept for wireless networks – clearly networks already critically depend on extensive use of automated processes. For instance, numerous examples abound just in the area of radio resource management (scheduling, power and/or rate control, etc.) that demonstrate that these automated features perform well. Thus, the appearance of SON algorithms represents a continuation of the natural evolution of wireless networks, where automated processes are simply extending their scope deeper into the network.

# 2 3GPP EVOLUTION AND SON

## 2.1 LTE SON HIGH-LEVEL SCOPE AND TIMELINE

Self-Organizing Networks capability is a key component of the LTE network. SON concepts have been included in the LTE (E-UTRAN) standards starting from the first release of the technology (3GPP Release 8), and expanding in scope with subsequent releases (3GPP Release 9 and 3GPP Release 10). Figure 1 provides the standardization timelines for the different 3GPP LTE releases, throughout which SON capabilities have been developed and enhanced.

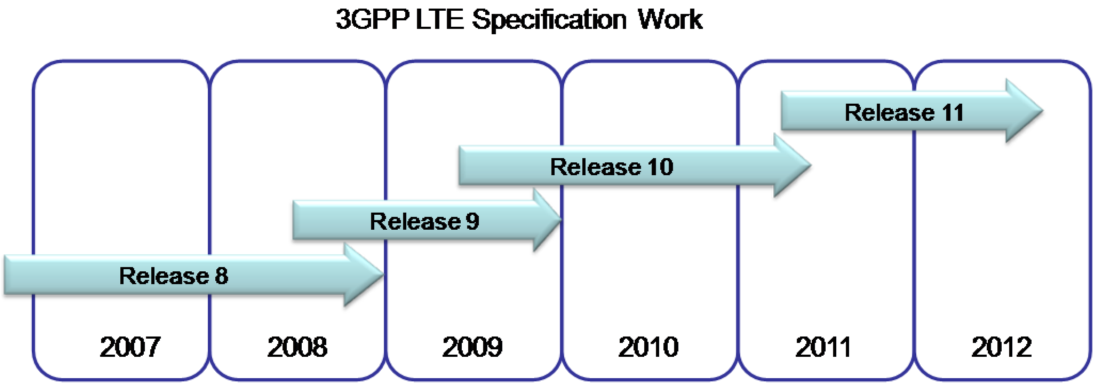


**Figure 1 - 3GPP LTE Specifications Timelines. Release 10 specifications were frozen in March 2011 and will be complete in Mid 2011.**

A key goal of 3GPP standardization has been the ability to support 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, reusing much functionality that existed prior to Release 8. 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, the focus of the Release 8 SON functionality was put on procedures associated with initial equipment installation and integration to support the commercial deployment of the first LTE networks, also known as “eNB self-configuration”. These procedures included:

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

Following this reasoning, the next release of SON (Release 9) provided SON functionality covering 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/Hand Over optimization
- RACH optimization
- Load Balancing optimization
- Inter-Cell Interference Coordination

The latest release of SON, being standardized in 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
- Enhanced Inter-Cell Interference Coordination
- Cell Outage Detection and Compensation
- Self-healing functions
- Minimization of Drive Testing
- Energy Savings

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 and beyond, to cover all key aspects related to network management, troubleshooting and optimization in multi-layer, multi-RAT heterogeneous networks.

## 2.2 SON DEVELOPMENT 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 whitepaper 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]. On the next page is a definition of the top 10 use cases indicated by NGMN, many of which have already been introduced in the 3GPP standards.

| | |
|---|---|
| **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** |

NGMN uses cases are defined at a higher level than 3GPP specifications, and are introduced way ahead of them, providing an initial guidance to the standards development and in some cases complementing existing standard functionality. A specific example is the interaction between home/macro BTS, for which NGMN has provided extensive recommendations to avoid excessive interference in the network (see section 3.8.6 for more details) and which in part has been standardized in 3GPP Release 10.

Another NGMN use case not yet developed by 3GPP is the optimization of QoS related parameters. QoS functionality is considered very important for wireless operators, especially with the deployment of very high-speed networks where data consumption is steadily increasing and will be approaching that of fixed broadband. Typically, the optimization of QoS related parameters governing the different network entities (scheduler, admission control, mobility, etc.) is very complex and requires expert resources. NGMN reckons that in the future, the networks should be able to adapt their quality automatically in response to external factors such as high load in specific areas, or based on special traffic patterns. At this point, the specific mechanisms to be used are not defined. However, NGMN has proposed a set of information elements that should be made available to be able to easily define such mechanisms. Below is a set of performance monitoring (PM) counters recommended for standardization:

- Number of successful sessions per QoS Class Identifier (QCI)
- Number of dropped sessions per QCI
- Cell specific customer satisfaction rate
- Min/Avg/Max throughput per QCI
- Min/Avg/Max round trip delay per QCI
- Packet loss per QCI

- Mean number of Radio Resource Control (RRC) connected users
- Mean number of RRC connected UEs with data to send per QCI
- Percentage of UEs per cell that is not achieving their required GBR and not achieving the required service data unit (SDU) error ratio per QCI
- Percentage of UEs for which transfer delay per IP packet was above a particular threshold
- Percentage of UEs for which average throughput measured at RLC layer for each non-real time (nRT) QCI was below a particular threshold
- Percentage of UEs per QCI for which the SDU error ratio is above a certain level
- Number of RRC connected UEs with measurement gaps configured.

In addition to the definition of use case functionality, the SON group in NGMN has been very active in defining Operations Support System (OSS) aspects of SON. These include support for more open OAM interfaces, and procedures to support the integration of non-3GPP elements such as operator databases and tools.

The objective of the OAM effort is to ensure a true multi-vendor ecosystem, where entities from different manufacturers could operate together in an automatic fashion.[16] For this purpose, a more open definition of the Northbound Interface (Itf-N) in 3GPP has been requested to reduce the integration efforts between the Network Management System (NMS) and the Element Management System (EMS), together with real-time reporting requirements to allow a third party vendor to take timely action in the network. In addition to generic requirements, the OPE recommendations define use-case specific OAM actions, as is the case of the Handover Optimization and Cell Outage Compensation. Other aspects covered by this project are the standardization of performance management information (counters and key performance indicators or KPIs) and their exchange formats.

The integration of OSS tools is also a very active area in NGMN. In every network deployment, there is a multitude of non-3GPP related elements that the operator needs to integrate with their existing network elements, such as RF planning databases, work flow databases and optimization tools (cell planning tools, third party SON tools, etc.). In order to integrate such entities, NGMN provides a set of generic guidelines including the following:

- Capability to run SON functionality in open (operator controlled) and closed (fully automatic) loop modes
- Deactivation of SON features in the Network Elements to pass control to the operator or external entities
- Support of centralized, distributed and hybrid architectures
- Real time synchronization with NMS
- Supply of relevant statistics and historical view to NMS
- Customization of SON policies.

In addition to generic guidelines, NGMN provides specific use-cases requirements for each of the use cases defined in 3GPP and NGMN. For example, in the case of the Automatic Neighbor Relation (ANR) usecase, NGMN requirements for full OSS integration are listed below:

- Support of CM Northbound Interface 3GPP BulkCM IRP (Bulk Configuration Management Integration Reference Point). ANR based changes in the eNB shall be "online" synchronized with EMS.
- Support of real time relationship configuration to ensure that HO is possible a few seconds after neighbor detection.
- OSS should be able to indicate which entity (such as the eNB or some other entity) takes control of the configuration for a given feature, say automatic neighbor relations (ANR).
- OSS should provide monitoring support of the main ANR steps: neighbor cell detection, X2 set-up, neighbor cell configuration adaptation and ANR optimization

## 2.3 SON ARCHITECTURE ALTERNATIVES

The specification covering the SON overview[15] identifies three different architectures for SON functionality: (a) Distributed, (b) Centralized and (c) Hybrid as shown in Figure 2.

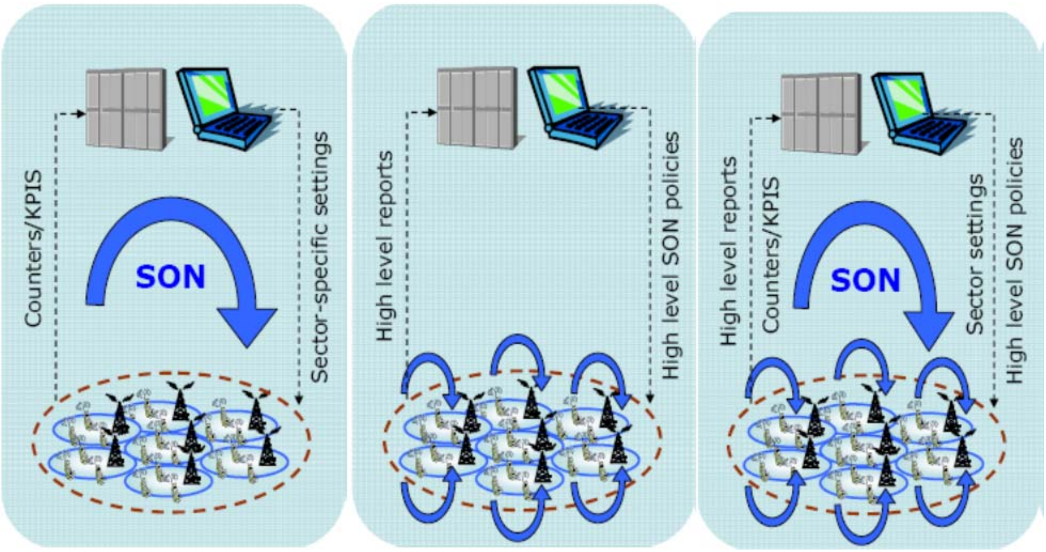


**Figure 2 – Different SON architecture approaches:**
**Centralized (left), Distributed (center) and Hybrid (right)**

In a centralized architecture, SON algorithms for one or more usecases reside on the Element Management System or a separate SON server that manages the eNBs. 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 usecase interactions between SON algorithms to be considered before modifying SON parameters. However, active updates to the usecase 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.

In practical deployments, these architecture alternatives are not mutually exclusive and could coexist for different purposes, as is realized in a hybrid SON approach. In a hybrid approach, part of a given SON optimization algorithm are 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.

# 3 KEY LTE RELEASE 8, RELEASE 9 AND RELEASE 10 FEATURES SON

## 3.1 BASE STATION SELF-CONFIGURATION

The deployment of a new network technology is a major investment for any service provider. In addition to the spectrum and equipment costs, the operator faces multiple challenges related to the network planning, commissioning and integration that often result in higher costs than the infrastructure equipment itself. Today, there are a number of computer-aid design tools that an operator uses to simplify these tasks, such as propagation tools, automatic cell planning (ACP) or automatic frequency planning (AFP) tools. However, much of the process related to network element integration and configuration is still performed manually. When a new base station (eNB) is installed, it requires that most aspects of its configuration are provided by the engineer(s) on site, including the setup of the transport links, adding the node to the corresponding concentration node (BTS or RNC), and establishing the connectivity with the core network. This is in addition to the configuration of all the radio-related parameters such as the cable and feeder loss adjustments, antenna type and orientation, transmit power, neighbor relations, etc. All these processes are cumbersome, time-consuming, error-prone, and, in general, will require the presence of more than one expert engineer, all the above resulting in an inefficient and costly process.

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. As will be seen in later sections, the scope of self-configuration functionality is expected to expand and evolve with upcoming versions of the LTE standard.

### 3.1.1 BENEFITS

Self-Configuration of eNBs will reduce the amount of manual processes involved in the planning, integration and configuration of new eNBs. This will result in a faster network deployment and reduced costs for the operator in addition to a more integral inventory management system that is less prone to human error.

### 3.1.2 DESCRIPTION

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.

The Self-Configuration algorithm should take care of all soft-configuration aspects of the eNB once it is commissioned and powered up for the first time. It should detect the transport link and establish a connection with the core network elements, download and upgrade the corresponding software version, setup the initial configuration parameters including neighbor relations, perform a self-test and finally set itself to operational mode.

In order to achieve these goals, the eNB should be able to communicate with several different entities, as depicted in the figure below.

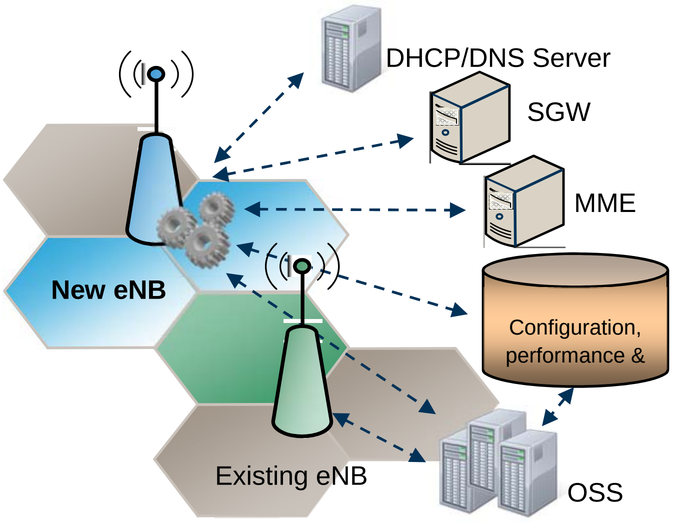


**Figure 3 - Self-Configuration of eNB in LTE**

To be able to successfully achieve all functions the following prerequisites should at least be met prior to the installation of the new node:

1. A network planning exercise for the cell should have been completed resulting in a set of RF parameters, including location, cell identities, antenna configuration (height, azimuth & type), transmit power, maximum configured capacity and initial neighbor configuration. This information should be made available in the configuration server.

2. The transport parameters for the eNB should be planned in advance, including bandwidth, VLAN partition, IP addresses, etc. The IP address range and Serving Gateway address corresponding to the node should be made available in the configuration server.

3. An updated software package download should be made available from the OSS.

The specific set of actions involved in the process will be covered in the next section.

### 3.1.3 SELF-CONFIGURATION ACTIONS

The Self-Configuration actions will take place after the eNB is physically installed, plugged to the power line and to the transport link. When it is powered on, the eNB will boot and perform a Self Test, followed by a set of self discovery functions, which include the detection of the transport type, Tower-Mounted Amplifier (TMA), antenna, antenna cable length and auto-adjustment of the receiver-path.

After the self-detection function, the eNB will configure the physical transport link autonomously and establish a connection with the DHCP/DNS servers, which will then provide the IP addresses for the new node and those of the relevant network nodes, including Serving Gateway, MME and configuration server. After this, the eNB will be able to establish secure tunnels for OAM, S1 and X2 links and will be ready to communicate with the configuration server in order to acquire new configuration parameters.

One of the OAM tunnels created will communicate the eNB with a dedicated management entity, which contains the software package that is required to be installed. The eNB will then download and install the corresponding version of the eNB software, together with the eNB configuration file. Such configuration file contains the pre-configured radio parameters that were previously planned.

Note that at the time of the installation most of the radio parameters will have the default vendor values. A finer parameter optimization will take place after the eNB is in operational state (self-optimization functions). The configuration of neighbor relations can optionally be performed through an automated SON functionality that is covered in a separate section of this paper, otherwise the initial setup will be done according to the output of the network planning exercise.

After the node is properly configured, it will perform a self-test that will include hardware and software functions, and will deliver a status report to the network management node. Also, the unit will be automatically updated in the inventory database that will incorporate the unique hardware identifier, as well as the current configuration and status of the node.

### 3.1.4 SELF-CONFIGURATION STATUS IN 3GPP

Current LTE standards incorporate functionality related to the self-configuration of eNB, including Automatic Software Management,[7] Self Test,[8] Automatic Neighbor Relation,[9] and Automatic Inventory Management.[10] It is expected that the first versions of the eNB self-configuration functionality in the eNB will have vendor-dependent aspects, as 3GPP has not fully specified a standardized self-configuration functionality. Examples of open areas in the standards include:

- A defined interface between operator planning tools, equipment inventory and network management entities
- Configuration of transport parameters
- Specific message formats for implementing the overall process

## 3.2 AUTOMATIC NEIGHBOR RELATION (ANR)

One of the more labor-intense 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; 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.[11]

### 3.2.1 BENEFITS

ANR will remove, or at least minimize, the manual handling of neighbor relations when establishing new eNBs and when optimizing neighbor lists. This will increase the number of successful handovers and lead to less dropped connections due to missing neighbor relations.

### 3.2.2 DESCRIPTION

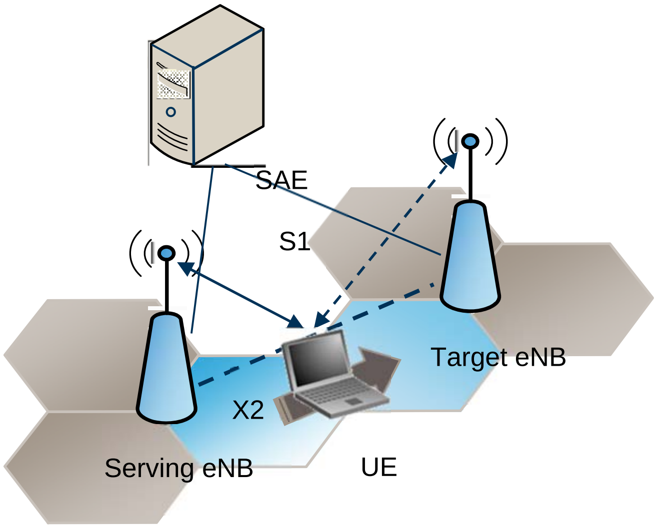


**Figure 4 - Automatic Neighbor Relation (ANR) in LTE**

The ANR in LTE allows automatic discovery and setup of neighbor relations when a user (UE) moves from a serving eNB to another (target) eNB. ANR also automatically sets up of the LTE unique X2 interface between eNBs, primarily used for handover.

There are two LTE distinctive functions that make ANR possible:

1. The UEs in LTE do not require a neighboring list and the reporting of unknown cells is fast enough to be used during handover preparation. It enables ANR to receive handover measurements on unknown cells that are not yet known by the serving eNB.
2. The possibility for the eNB to request the UE to make a full identification of a cell. It allows eNB to determine an unambiguous identity of a neighboring cell.

### 3.2.3 NEIGHBOR RELATION DISCOVERY

The UE is ordered to report measurements to the serving eNB directly after the RRC connection is set up (i.e. is attached to the cell) and continues to do so while staying in RRC connected mode. The UE reports all detected PCIs (Physical Cell Identities) – the short identity of the LTE cell – that fulfill the measurement criteria set by the eNB at RRC connection. The UE may also measure on legacy radio technologies if it supports multi-mode operation.

If there is an unknown cell included in the measurement report then ANR may begin actions to make the cell known and potentially enable handover to the cell.

### 3.2.4 ANR ACTIONS

If a PCI is reported by a UE that does not correspond to any of the serving eNBs' defined neighbor cells (i.e. it is not a neighbor cell), the ANR function in the serving eNB may request the UE to retrieve the Global Cell Identity (GCI) of the cell with the unknown PCI in order to identify the cell. This cell is from now called target cell (see figure 4 above). The UE reads the GCI, which is broadcast by the target cell and reports it to the serving eNB. When the serving eNB receives the GCI, it can – with help from MME, one part of SAE – retrieve the target eNB's IP address, which makes it possible for the serving eNB to contact the target eNB.

The serving and target eNBs are now in contact with each other and X2 can be setup. The serving eNB requests X2 setup to the target eNB and includes all necessary cell data to create a neighbor relation (i.e. PCI, GCI, TAC, PLMN-id and frequency) from the target cell to the serving cell. The target cell adds the serving cell to its neighbor list and the target eNB sends the corresponding data for the target cell (PCI, GCI, TAC, PLMN-id and frequency) to the serving cell which in turn adds the target cell to its neighbor list.

With the X2 interface in place, it is possible to use X2 for all future handovers between the cells. For handover from LTE to legacy systems (i.e. GSM and WCDMA), ANR works in the same way with the exception that it only needs to setup a neighbor relation to the target cell and not the X2 since the handover to non-LTE systems is always performed over SAE.

ANR can automatically remove unused neighbor relations based on the relation usage, handover performance or a combination thereof.

When adding and removing neighbors, ANR is under control of policies set by the operator. The black listing allows the operator to decide neighbor relations that ANR may never add as neighbors. The white listing allows the operator to decide permanent neighbor relations that ANR may never remove. These policies are controlled from an Element Management System (EMS) such as OSS.

### 3.2.5 INTER-RAT ANR

The inter-RAT ANR is applicable when different mobile network standards such as GSM, UMTS/HSPA, CDMA/EV-DO and LTE are deployed to cover the same geographical area.

In this section, the ANR Inter-RAT function is explained for the case when LTE is overlaid on one of the other networks, hereafter referred to as underlying networks. LTE is normally deployed on the same sites as the underlying network's radio base stations. It will therefore partially or fully cover the same area as the underlying network. Inter-RAT handover between LTE and an underlying network could be used for circuit switch (CS) fallback to the existing networks for voice calls and SMS, and load balancing of UEs when traffic on a network exceeds a threshold. This means that the UEs could handover between LTE and the underlying network even when the LTE cell coverage is good. Based on the above assumptions, the ANR function in LTE must be able to find the underlying network's cells with the same coverage as the LTE cells. To find these neighbors, an additional ANR method in LTE needs to be introduced whereby the UEs are ordered to report best serving cell periodically.

The ANR function in LTE orders the ANR capable multi-standard UEs, connected to LTE, to report best serving cell measurements from the underlying network periodically. There are different possible solutions for ordering the multi-standard UEs depending on which technology is used in the underlying network. The new SON unique report configuration, "*ReportStrongestCellsForSon*" could be used for UMTS/HSPA and CDMA/EV-DO. The existing "*ReportStrongestCells*" could be used for GSM. They are specified in 3GPP 36.331 (Release-8) and are used for specifying criteria for triggering of inter-RAT measurement reporting events B1 and B2. Event B1 refers to the event when inter-RAT neighbor has a higher value of RSRP/RSRQ than a threshold. Event B2 refers to the event when the serving cell has a lower of RSRP/RSRQ than a threshold, and inter RAT neighbor has a higher value than a threshold.

To minimize the load on the UEs, the ANR function in LTE should be able to adapt the number of UE measurements to the actual need. In the beginning, when many new cell relations are found, a more intense measurement activity is used. This enables a quick creation of necessary neighbor relations. After some time when less neighbor candidates are found, the ANR function should involve fewer UEs in the measurements. Even when new neighbors are not detected at all or very rarely, it is important that ANR maintains some minimal level of periodical measurements. This enables the ANR function to rapidly detect any network changes.

The LTE ANR procedure following the discovery of new neighbors is similar to the one for intra-LTE, described earlier. After the UE reports a strongest cell (identified with its PCI) that is not listed as a neighbor in the neighboring cell list, the ANR function on the eNB will add it to the neighboring cell list for the cell it was discovered in. Before doing so, the eNB needs to know the unique identity of the cell i.e. the Cell Global Identity, CGI. It can add the missing neighbor cell relation immediately if the cell CGI is already known by eNB. Otherwise the ANR function in the eNB first needs to identify the cell by finding out its CGI. In this case, ANR orders a CGI measurement from the UE, and once it is reported back, the new neighbor is added.

After the new IRAT neighbor is added to the eNB cell, it can be used for mobility handovers and for the other cases where neighbor cells are used. It should be noted that the neighboring cell relationship is only one way i.e. from the LTE cell to the cell in the underlying network. The underlying network's ANR function also needs to discover the LTE cell. A manual procedure could be used where the operator, when notified about the new neighboring cell relationship, adds the other direction manually or has a centralized solution that automates the procedure.

## 3.3 TRACKING AREA PLANNING

Wireless networks partition a typical market into non-overlapping Traffic Areas (TAs). Each TA is uniquely identified by the TA Identifier (TAI). Each and every User Equipment (UE) in the Power-ON state is mapped to one (or more) TAs. TAs were constructed to facilitate the Paging procedure. Note that whenever the switch (MME) receives a call for mobile M, it looks up the TA of mobile M – as TA(M)) – sends a page to all the eNBs in TA(M). Each eNB faithfully broadcasts the message on the Paging channel, which is received by UEs in Power-ON mode. When mobile M receives the page, it realizes that there is a terminating call (data transfer) for it, and it sends a paging response to its serving eNB – eNB(M). The eNB(M) responds with an affirmative to the switch, which goes on to direct the call towards eNB(M). Subsequently, call setup procedure is followed between mobile M, eNB(M), and MME/S-GW.

In order to ensure that the MME has the most recent information for each mobile in terms of its current TAI, all UEs are required to provide TAU as soon as they realize that their current serving eNB has a different TAI. Such an update is sent on the Random Access Channel (RACH). (Border eNB's are basically the eNBs which are on the border of a TA). Such a structure leads to a tradeoff between the RACH and paging channel. Observe that if each TA is kept small, then a moving mobile would cross through many TAs, and would need to make a random access attempt in one of the Border eNB of each TA. However, if the number of eNBs in a TA is large, then the RACH load on the Border eNBs would be less, but each terminating call/data transfer to a mobile M would lead to a broadcast of paging message from the MME to each eNB in that TA. This would certainly put additional pressure on the backhaul link. Additionally, on each of the eNBs, a page will also need to be sent using up the paging channel. Therefore, determining TA size and demographic is a tradeoff between the RACH load on the Border eNBs and the paging load on the backhaul and RF of the eNBs. Note that the RACH load affects only one cell, but the paging load translates into a broadcast message on all the eNBs belonging to that TA.

### 3.3.1 BENEFITS

Present day wireless operators have been forced to take an offline approach due to lack of any mechanism for effective and efficient adjustment of tracking areas. Due to the cumbersome nature of such a process, most carriers hardly change the tracking areas of their cells. In other words, TAIs for each cell are decided at the time of deployment based on rules-of-thumb, anticipated traffic patterns, etc., and are only altered in the event of extreme performance degradations. SON TA feature has the ability to change that, both at the time of deployment using Tracking Area Planning (TAP) and during the subsequent network optimization using Tracking Area Optimization (TAO).

At the time of deployment, TAP algorithm prepares the initial deployment plan for the cell sites of a market in an (semi) autonomous fashion. The output of the TAP drives the choice of tracking area that an eNB belongs to. The corresponding TAI is delivered to each eNB during the initialization phase. The inputs to such a deployment plan could be market geographical data, TAI range and values, eNB locations, market size, etc.

Once initial deployment is complete, the TAO algorithm actively monitors the Tracking Area Updates (TAU) and the load on the radio access channel (RACH) to continuously identify the eNBs that are most suited for a change in their TAI. The intention is to capture some of the mobility patterns for each eNB. For example, if a highway passes through a cluster of eNBs, it might make sense to ensure that tracking area boundary cleanly intersects with the highway, and avoids a UE in the car to ping-pong between multiple TAs. TAO algorithm has the ability to identify such eNBs and allocate them to appropriate TA.

## 3.4 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. These physical layer cell identities are grouped into 168 unique physical layer cell identity groups, where each group contains three unique identities. The overall signature PCI is constructed from primary and secondary synchronization IDs as follows:

$$PCI = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}$$

Where, $N_{\mathrm{ID}}^{(1)}$ is in the range of 0~167, representing the physical layer cell identity group, and $N_{\mathrm{ID}}^{(2)}$ is in the range of 0~2, representing the physical layer identity within the physical layer cell identity group. The hence constructed PCI is allocated to each eNB at the time of installation. Based on the allocated IDs, the eNB transmits the PCI on the downlink preamble. The UEs in its service area receive the preamble, and are able to identify the eNB, and the corresponding signal quality. It is possible, however, that a UE finds that there are two eNBs that have the same PCI. This is possible since the PCIs are reused by multiple eNBs. Note that there are only 504 PCIs, and a typical market might have 200 to 300 cell sites, assuming three eNBs per cell site leads to as many as a thousand eNBs in a market. Therefore, the service provider must carefully determine the PCI of each eNB to make sure that such conflicts do not happen, or are minimized.

Typical operators use an offline planning tool or depend on manual determination to develop a PCI deployment plan for a market. The plan uses basic information such as eNB location, potential neighbors, etc., to determine the PCI for each eNB. Such an allocation is carefully reviewed to ensure that the market does not have any PCI conflicts; hence the determined PCI values are communicated to each eNB during the installation using the configuration files or manually inputted by the staff. Needless to say, such a process does not lend itself to subsequent changes and is prone to human error.

### 3.4.1 BENEFITS

SON mechanisms enable the operator to automate this tedious process described above in section 3.4. In the SON framework, as soon as the eNB is powered up during the auto-configuration phase, it is allocated to a PCI (that is a primary and a secondary synchronization ID). Such a PCI is determined using a PCI Planning Tool (PPT) that not only uses the estimated coverage area information for each eNB, but also enforces significant margin and separation between two eNBs that are allocated to the same PCI. Additional considerations could also be included when determining such a plan. Nonetheless, SON ensures that each eNB has a PCI value at the time of installation without requiring explicit human intervention.

Subsequently, during the operational phase, each eNB collects the information pertaining to any PCI conflicts. Observe that PCI conflicts might happen due to errors during the initial PCI Planning phase, deployment of new eNBs, changes in the demographics of a market, power of eNBs, etc. Whenever an LTE UE receives power from two eNBs with the same PCI, it informs the serving eNB about the conflict. Such an alarm is relayed to the OSS/SON mechanism, which collects and logs the details of such conflicts. The operator can then decide on a suitable time interval for activating the PCI Optimization Tool (POT), (e.g., it might make sense to schedule such an activity during a lightly-loaded night-time period). The POT algorithm uses the collected logs, alarms and the updated coverage maps in order to identify the eNBs for which the PCI needs to be changed and the associated new PCI value. Furthermore, the SON algorithm ensures that the information is relayed to the correct eNBs. Upon reception, eNBs could wait for a hold period before they begin to deploy the newly allocated PCI values.

## 3.5 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 decision to re-balance a cell or move a particular user must take in to consideration the target for the user(s). It is not desirable to send a user to an alternate location (i.e. neighbor or co-located frequency) if that user will then have a reduced QoS or lower performance than remaining in the source, or if the resulting re-balance will result in reduced system capacity/utilization.

### 3.5.1 BENEFITS

The objective of Mobility Load Balancing is to intelligently spread user traffic across the system’s radio resources as necessary in order to provide quality end-user experience and performance, while simultaneously optimizing system capacity. Additionally, MLB may be desirable to shape the system load according to operator policy, or to “offload” users from one cell or carrier in order to achieve energy savings. The automating of this minimizes human intervention in the network management and optimization tasks.

### 3.5.2 DESCRIPTION

The term Mobility Load Balancing (MLB) is used in this section to refer specifically to the network cell (eNB) level only, not core entities such as the MME, gateways, etc. The goal of MLB is to spread user traffic across system radio resources in order to provide quality end-user experience and higher system capacity. This can be accomplished by one or a combination of algorithms that perform Idle or Active balancing of users. These SON algorithms for offloading traffic from one element to another can include intra-carrier, inter-carrier, or inter-technology resources, as long as there is software intelligence to ensure radio admission and continuity of service on the target element. The actual transfer of users is accomplished by modification of handover threshold parameters. This can require coordination with competing SON algorithms and standardized messaging with multi-vendor equipment to ensure robustness and stability.

LTE is better suited to a distributed algorithm utilizing the X2 interface, while technologies with a BSC/RAN architecture and/or macro-diversity may favor a more centralized approach. The text in this section is suited to single-link technologies such as LTE.

- **Distributed LB:** Algorithms run locally in the base stations. Load information is exchanged between base stations so that Idle/Active HO (handover) parameters may be adjusted and/or adjustments to RRM functionality can be made.

- **Centralized LB:** Algorithms run in a core network element. Base stations report load information to a central entity which then responds with appropriate modifications to idle/active HO parameters.

In either case (distributed or centralized), it is assumed there will be centralized Operations, Administration and Management (OA&M) control for an operator to enable/disable and configure relevant algorithm settings.

### 3.5.3 DETERMINING A LOAD IMBALANCE CONDITION

Load balancing mechanisms must work together with the scheduler and admission control. For non-Guaranteed Bit Rate (GBR) users, there is no constraint on the minimum performance those users receive except within the scope of the maximum number of users per cell (admission control) and perhaps a vendor-imposed minimum throughput (scheduler). For GBR users, the scheduler must ensure that all radio bearers are granted resources in a manner that satisfies their specific service. Therefore, a system may be considered “in balance” as long as there are no users being denied resources and all active services are being supported within the scope of their QoS needs.

Simple thresholds can be implemented where low, medium and high load conditions equate to a given number of active users in the cell for the non-GBR case. These can serve as triggers to modify idle mode parameters and/or to handover active users to neighbors (i.e. cell-edge intra-carrier, collocated inter-carrier or collocated inter-technology handover). However, more intelligent metering is needed for GBR users since it is possible for a small number of such users to “load” a cell depending upon their requirements.

### 3.5.4 IDLE MODE LOAD BALANCING

The LTE system does not have a real-time, per-cell view of idle mode users. The only time the system becomes aware of the exact cell a user is in, while in idle mode, is when the Tracking Area of the user changes and a TAU message is sent by the UE. Therefore, while parameters that control how and when a UE performs cell reselection (idle handover) are modifiable, there is no direct measurement mechanism for the system to determine when there are "too many" idle users. Note that this "too-many idle user condition" has no direct bearing on either system capacity or user experience besides increased signaling on core network nodes.

The way around this immeasurable condition is for the system to adjust cell reselection parameters for the idle users based on the current active user condition. As real-time traffic and/or QoS demands increase in a cell, it would be possible for the cell to adjust the cell reselection parameters in order to force users nearest the cell edge to select their strongest neighbor to camp on, or to force a handover to a co-located carrier that has more resources available.

Care must be taken to coordinate such parameter adjustments between cells (i.e. utilizing the X2 interface) in order to prevent service-outage holes, as well as to adjust active mode parameters to avoid immediate handover upon an idle to active transition.

In LTE, idle mode inter-frequency load balancing is controlled by the cell reselection procedure. System parameters that control cell reselection and the operator's channel frequency preferences are transmitted to UEs in the System Information Blocks (SIBs).

### 3.5.5 ACTIVE MODE LOAD BALANCING

Active load balancing allows active mode UEs to be load balanced across cells to lower the overall congestion across cells. The advantage of active load balancing is that the system has a direct measurement mechanism and knowledge of each user's traffic requirements and radio conditions before deciding to load balance. Therefore, in conjunction with the scheduler and interfaces to other base stations (X2 interface for intra-LTE and/or S1 interface for inter-RAT), it is possible to make accurate decisions for load-based HO. A "load-based HO" reason code is included during handover (HO) messaging to allow the target cell knowledge for admission control.

#### 3.5.5.1 INTRA-LTE MOBILITY LOAD BALANCING

Intra-LTE mobility load balancing refers to a load balanced handover within the current LTE network, typically utilizing the X2 interface to exchange load reporting information, to geographically neighboring cells or co-located cells on a different carrier frequency.

The load information consists of:

- Radio Resource Usage
    - Uplink/Downlink Guaranteed Bit Rate (GBR) Physical Resource Block (PRB) usage
    - Uplink/Downlink non-GBR PRB usage
    - Uplink/Downlink total PRB usage
- Hardware (HW) load indicator

  - Uplink/Downlink HW load: Low, Mid, High, Overload
- Transport Network Load (TNL) indicator
  - Uplink/Downlink TNL load: Low, Mid, High, Overload
- Cell Capacity Class value (Optional)
  - Uplink/Downlink relative capacity indicator
- Capacity value
  - Uplink/Downlink available capacity for load balancing as percentage of total cell capacity

#### 3.5.5.1 INTER-RAT MOBILITY LOAD BALANCING

Inter-RAT MLB refers to a load balanced handover between LTE and another network, utilizing the S1 interface to exchange load reporting information. In the event the handover is to non-3GPP technology, then load reporting on the relevant interfaces still need to be standardized.

A dedicated procedure for inter-RAT cell load request / reporting is provided with minimal impact using a generic SON container extension of the RAN Information Management (RIM) mechanism.

Load information is provided in a procedure separated from existing active mode mobility procedures, which is used infrequently and with lower priority with respect to the UE dedicated signaling.

The load information consists of:

- Cell Capacity Class value
  - Uplink/Downlink relative capacity indicator
- Capacity value
  - Uplink/Downlink available capacity for load balancing as percentage of total cell capacity

NOTE 1: Capacity value is expressed in available E-UTRAN resources.

NOTE 2: A cell is expected to accept traffic corresponding to the indicated available capacity.

### 3.5.6 ADAPTING HANDOVER CONFIGURATION

The adaptation of handover configuration function enables requesting of a change of handover and/or reselection parameters at target cell, as a part of the load balance procedure. The source cell that initialized the load balancing estimates if the mobility configuration in the source and/or target cell needs to be changed. If the amendment is needed, the source cell initializes mobility negotiation procedure toward the target cell. This is applicable for both idle and active mobility cases.

The source cell informs the target cell about the new mobility settings and provides cause for the change such as, load balancing related request. The proposed change is expressed by as the difference (delta) between the current and the new values of the handover trigger. The handover trigger is the cell specific offset that corresponds to the threshold at which a cell initializes the handover preparation procedure. Cell reselection configuration may be amended to reflect changes in the handover setting. The target cell responds to the information from the source cell. The allowed delta range for handover trigger parameter may be carried in the failure response message. The source cell should consider the responses before executing the planned change of its mobility setting. All automatic changes on the HO and/or reselection parameters must be within the range allowed by OAM.

## 3.6 MOBILITY ROBUSTNESS / HANDOVER OPTIMIZATION

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.

There is also some potential for interaction with Cell Outage Compensation and Energy Savings as these could also potentially adjust the handover boundaries in a way that conflicts with MRO.

While the goal of MRO is the same regardless of radio technology namely, the optimization of end-user performance and system capacity, the specific algorithms and parameters vary with technology. The description below is for LTE releases 8, 9 and 10, with its single-link (no macro diversity) approach and X2 interface between eNBs.

Whether a distributed or centralized MRO function is implemented (distributed is more applicable in the description text), it is assumed there will be centralized OAM control for an operator to enable/disable and configure relevant algorithm settings.

### 3.6.1 BENEFITS

The objective of MRO is to dynamically improve the network performance of HO in order to provide improved end-user experience as well as increased network capacity. This is done by automatically adapting cell parameters to adjust handover boundaries based on feedback of performance indicators. Typically, the objective is to eliminate Radio Link Failures and reduce unnecessary handovers. Automation of MRO minimizes human intervention in the network management and optimization tasks.

### 3.6.2 DESCRIPTION

The scope of mobility robustness optimization as described here assumes a well-designed network with overlapping RF coverage of neighboring sites. The optimization of handover parameters by system operators typically involves either focused drive-testing, detailed system log collection and post-processing, or a combination of these manual and intensive tasks. Incorrect HO parameter settings can negatively affect user experience and waste network resources by causing HO ping-pongs, HO failures and Radio Link Failures (RLF). While HO failures that do not lead to RLFs are often recoverable and invisible to the user, RLFs caused by incorrect HO parameter settings have a combined impact on user experience and network resources. Therefore, the main objective of mobility robustness optimization should be the reduction of the number of HO-related radio link failures. Additionally, sub-optimal configuration of HO parameters may lead to degradation of service performance, even if it does not result in RLFs. One example is the incorrect setting of HO hysteresis, which may results in ping-pongs or excessively delayed handovers to a target cell. Therefore, the secondary objective of MRO is the reduction of the inefficient use of network resources due to unnecessary or missed handovers.

Most problems associated with HO failures or sub-optimal system performance can ultimately be categorized, as either too-early or too-late triggering of the handover, provided that the required fundamental network RF coverage exists. Thus, poor HO-related performance can generally be categorized by the following events:

- Intra-RAT late HO triggering
- Intra-RAT early HO triggering
- Intra-RAT HO to an incorrect cell
- Inter-RAT too late HO
- Inter RAT unnecessary HO

Up to Release 9, a UE is required to send RLF report only in case of successful RRC re-establishment after a connection failure. Release 10 allows support for RLF reports to be sent even when the RRC re-establishment does not succeed. The UE is required to report additional information to assist the eNB in determining if the problem is coverage related (no strong neighbors) or handover problems (too early, too late or wrong cell). Furthermore, Release 10 allows for precise detection of too early / wrong cell HO.

### 3.6.3 INTRA-RAT LATE HO TRIGGERING

If the UE mobility is faster than the HO parameter settings allow for, handover can be triggered when the signal strength of the source cell is too low, leading to a RLF. The signature of too-late HOs may be summarized by:

- RLF in the source cell before the HO was initiated or during HO procedure
- Terminal re-establishes in a different cell than the source

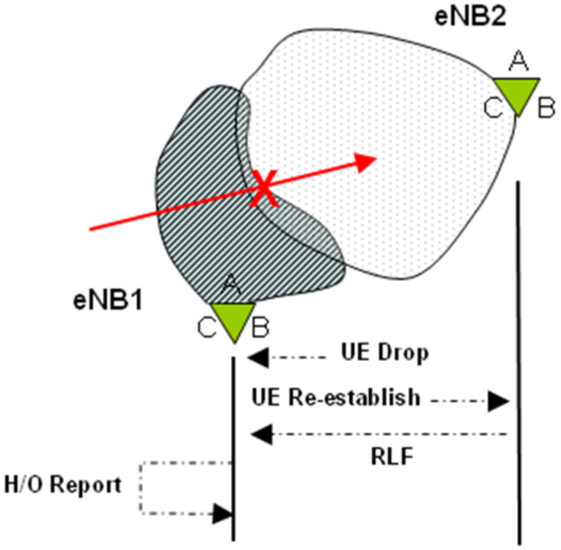


**Figure 5 - Too-Late Handover**

The general principles of MRO are based on the RLF and Handover Report messages over the X2 link. After a Radio Link Failure (RLF), the UE provides the RLF information to the cell to which it reconnects after the failure. That cell always forwards the RLF message over the X2 to the cell that actually dropped the UE. The information is analyzed by the cell that receives the RLF, and if required, the results of the analysis are forwarded in a Handover Report over the X2 to the cell that needs to take corrective action. In the too-late case above, a failure occurs in the handover from eNB1(A) to eNB2(C). The UE reconnects to eNB2(C) and the RLF message is forwarded to eNB1. eNB1 analyses the data and, in this case, determines that the problem is resolved by adjusting thresholds at eNB1(A), specifically relating to its neighbor relationship with eNB2(C). There is no need to send a handover report to any other cell. RLF indication and Handover Report are X2 messages and as such are only relevant in the inter-eNB case. For cells on the same site, similar message structures can be used internally without the need for X2 interfaces.

### 3.6.4 INTRA-RAT EARLY HO TRIGGERING

Too-early HO can be triggered when the terminal enters an island of coverage of another cell contained inside the coverage area of the serving cell. This is a typical scenario for areas where fragmented cell coverage is inherent to the radio propagation environment, such as dense urban areas. The signature of too-early HO may be summarized by:

- RLF occurs a short time after the HO trigger to the target cell. The HO may or may not be completely successful, depending on the over-the-air-messaging in the target cell.
- Terminal re-acquires the system in the source cell

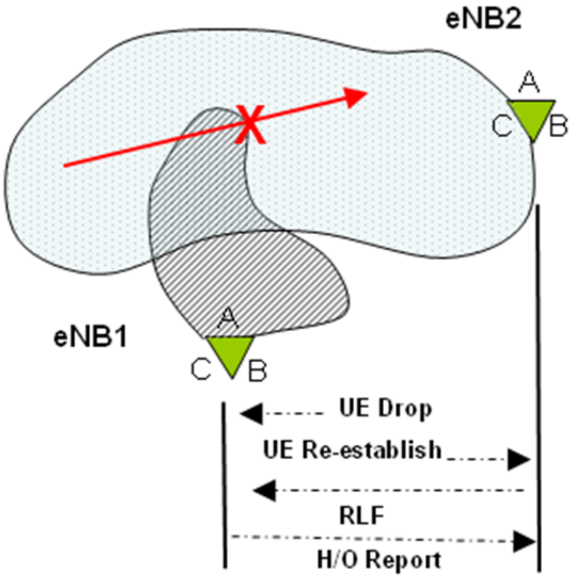


**Figure 6 - Too-Early Handover**

In the too-early case above, the UE has contiguous coverage from eNB2(C), but due to a region of strong coverage from eNB1(A), a handover takes place to eNB1(A). As the UE exits this region of coverage, an RLF occurs and the UE reconnects to eNB2(C). eNB2 sends the RLF to eNB1 as eNB1(A) actually dropped the UE. eNB1(A) analyses the RLF and checks the length of time it carried the call. If eNB1(A) carried the call for less than *Tstore_UE_cntxt* seconds, it then concludes that the UE should not have handed to eNB1(A) in the first place. eNB1 sends a Handover Report to eNB2 and the neighbor relationship from eNB2(C) to eNB1(A) is adjusted such that the UE does not handover to eNB1 in the first place.

### 3.6.5 INTRA-RAT HO TO AN INCORRECT CELL

It is possible if the cell-neighbor-pair parameters are set incorrectly that the handover may be directed towards a wrong cell. The signature of HO to a wrong cell is summarized by:

- RLF occurs a short time after the HO trigger to the target cell. The HO may or may not be completely successful, depending on the over-the-air-messaging in the target cell.
- Terminal re-establishes in a different cell than the source or target

It is important to note that the messaging sequence is different depending on whether the original handover is successful. The reconnect cell will always send the RLF message to the cell that dropped the UE. If the handover succeeds, the RLF is sent to the original target cell. If the handover fails, the RLF is sent to the source cell. In either case, the original source cell eventually receives either the RLF or Handover Report messages, and takes the necessary corrective action.

Note this event could also be a case of rapid HO – where the terminal quickly and successfully performs handovers from cell A to B to C. This could be argued as either a too-early case for A-B or simply too-late for A-C.

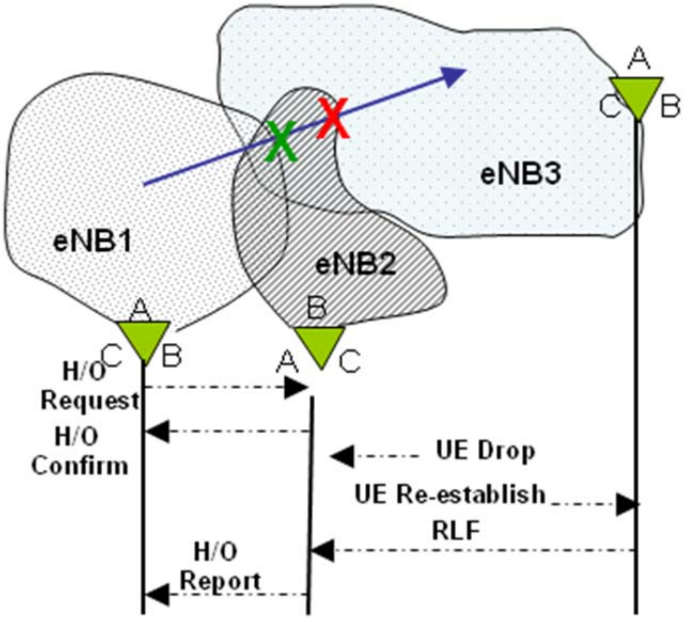


**Figure 7 - Wrong Cell Handover (RLF after handover)**

In Figure 7, the handover to eNB2(B) succeeded, but failure immediately after that indicates that eNB2(B) was not a good candidate. On reconnect to eNB3(C), the RLF gets forwarded to eNB2(B). eNB2 analyses the RLF and determines that since it carried the call for less than *Tstore_UE_cntxt* seconds, it was therefore never a good candidate. It then sends a Handover Report to eNB1. eNB1(A) needs to correct its relationships such that eNB2(B) becomes less attractive and eNB3(C) becomes more attractive.

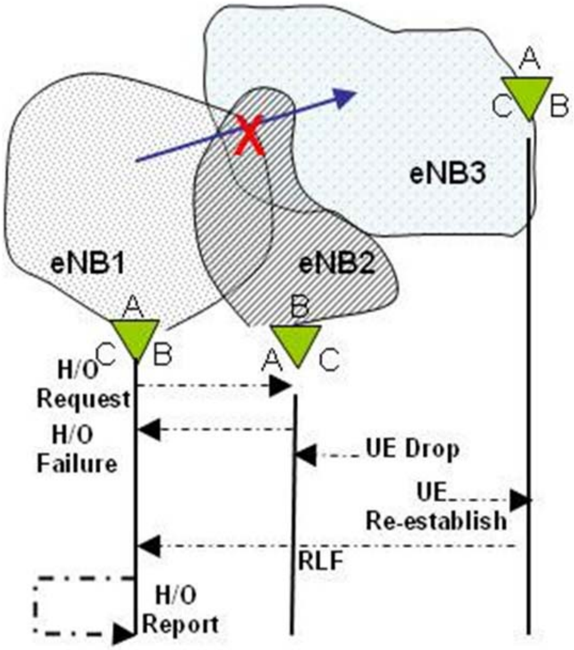


Figure 8 - Wrong Cell Handover (RLF before Handover)

Figure 8 shows the case where a RLF occurs before handover. In this case, the initial handover attempt to eNB2(B) had not been completed when the RLF occurred.  After reconnect to eNB3(C), the RLF is sent directly to eNB1(A) since this is the cell that dropped the call.  In this case, as  eNB1(A) is both the cell that did the RLF analysis and also the cell that needs to make the correction, it is not necessary to send a handover report to another cell.

Most vendors are likely to adjust the Cell Individual Offset (CIO) in order to correct the MRO problems described here.  The CIO is a per neighbor offset applied to measurement reporting configuration such that it changes the point at which a measurement report qualifies to get sent to the eNB.

The measurement gets sent to the eNB only after the criteria remains valid for a period of Time-To-trigger (TTT). Because of this relationship, TTT is also sometimes used as one of the MRO adjustment parameters.

### 3.6.6 INTER RAT TOO LATE HO

Delayed inter-RAT handovers when a UE moves from one RAT to another could result in RLF’s and possibly dropped calls. Inter RAT too late handovers may be detected and reported in two ways.

The first option is that the UE reports the RLF to the cell where it connects immediately after the RLF. In this case, the reporting is performed in a different RAT than the cell the UE was connected to before RLF. This requires a new message across RATs in order to transfer the information to the cell where the UE was connected to before HO, since this is where the mobility parameters shall be adjusted.

Another option would be to let the UE send the RLF report when it returns to the RAT where it experienced the RLF, but not necessarily to the same cell. In this case, there is no need to send messages across the two different RATs.

### 3.6.7 INTER RAT UNNECESSARY (TOO EARLY) HO

The HO target cell (UTRAN or GERAN) is configured with minimum radio quality (of E-UTRAN) thresholds during handover preparation phase. The target cell will instruct the incoming UE to continue to measure the source cell (E-UTRAN) after successful IRAT handover.  Based on such threshold, the target cell can detect whether or not the handover has been performed too early and report it back to source cell (E-UTRAN).

### 3.6.8 ALGORITHM FOR SON HANDOVER PARAMETER OPTIMIZATION

The SON HO optimization function is an algorithm or set of algorithms designed to improve performance of HOs from one cell to another. Performance data collected from each cell is analyzed in order to correlate HO failures that may be due to improperly configured or unoptimized parameters. Adjustments can then be made to the configuration in an attempt to improve the overall HO performance of the network.

Care must be taken to provide a methodical adjustment to network parameters.  Assuming certain cell-pair neighbors exhibit poor performance exceeding an operator-defined threshold, such as target KPIs not being met, the expected flow of operation comprises the following steps:

1. Monitor the network for a sufficient period of time in order to accurately baseline the performance of all cells with respect to traffic loading, traffic type, time-of-day, etc. This may take days or weeks depending on the amount of user traffic in the cells.

2. Output from HO algorithms suggests changes to the network parameters that should provide overall increase in successful HO's across the network. These changes or subset of changes are then applied to the network.

3. The network is monitored for a sufficient period of time in order to accurately compare the performance of the network with respect to the baseline in step 1.

4. Keep track of attempted changes and repeat this iterative process as necessary until the target KPI thresholds are met.

5. Update centralized data base with "final" outputs.

Possible cell or cell-neighbor-pair parameter modifications (in Step 2) include:

- Trigger Thresholds
- Time-to-Trigger
- Hysteresis values for ping-pong control
- Neighbor List Relation
- Speed-dependent parameters

- Antenna Remote Electrical Tilt
- Idle mode parameters to avoid immediate HO trigger when transitioning from idle to active states

Note that certain technologies may allow faster performance monitoring and a distributed approach to the MRO algorithm. For example, the non-BSC based E-UTRAN of LTE and X2 interface messaging could allow a de-centralized MRO algorithm that operates on much faster time scales than the above text for the algorithm flow implies.

### 3.6.9 EXAMPLES OF SON ALGORITHM INTERACTIONS

Each self-organization use case modifies a set of configuration parameters in the corresponding network elements to achieve the intended self-configuration, self-optimization or self-healing goals. A key issue that naturally arises in such a use case centric approach is that the various use cases are optimized on an individual basis, without taking into account potential effects on other use cases. The presented use cases are not independent of each other and the modification of a parameter beneficial for one use case may have a negative impact on another use case. Overall system performance may depend on conflicting parameter adjustments. Therefore, the interaction of self-organization functionalities needs to be analyzed in order to identify functionalities (usecases) that need to be coordinated. Interaction problems can be classified into two classes, namely parameter value conflicts and metric value conflicts.

- Parameter value conflicts occur if any two use cases have access to the same control parameter.

- Metric value conflicts occur if any two use cases influence a common metric that is used as feedback information to influence either use case.

Consider the interaction between RACH optimization and Mobility Robustness Optimization (MRO). Assume that at a given time the RACH is at its capacity limit and unable to accommodate any new terminals and assume that the RACH optimization process does not react to this situation because it is difficult to allocate further resources. The MRO use case will detect a higher handover failure rate and potentially decrease the time-to-trigger value. This in turn would have the effect of resulting in even more handovers, and there could be even more access attempts on the RACH – an instability with a self-reinforcing feedback loop.

SON usecase interactions are also noted when Load Balancing and/or Neighbor List optimization algorithms are triggered at the same time as Cell Outage Compensation. Interactions could also occur between interference mitigation, load balancing and optimization of capacity and coverage because these goals could be achieved through modifying common parameters such as radio bearer transmit power, radio bearer assignment and antenna parameters.

To mitigate the unwanted effects of interactions, algorithms for these usecases must consider the impact of one parameter change on the performance of the other algorithms using the same parameter. One approach to avoid interaction conflicts is by a scheme where use cases trigger each other in a consecutive order [9]. In situations where this is not feasible, multiple use cases cooperate/co-act in a use case bundle which is recommended to be treated as one optimization problem. Approaches for addressing SON usecase interactions are areas for further study.

## 3.7 RACH (RANDOM ACCESS CHANNEL) OPTIMIZATION

The configuration of the random access procedure has a critical impact on end-user experience and overall network performance. A poorly configured Random Access CHannel (RACH) may increase access setup time and accesses failures, impacting both call setup and handover performance. 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 creating 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 basic concept is well suited for eNB function localization where the eNB optimizes the random access channels in its cells based on UE feedback and knowledge of its neighboring eNB’s RACH configuration.

### 3.7.1 BENEFITS

An optimized RACH configuration enables end-user benefits and network performance gains through:

- Reduced connection time
- Higher throughput
- Better cell coverage.

By automating the optimization of RACH, maximum performance is achieved with no operator intervention or effort. The network will dynamically adapt to network changes and end-user behavior to always deliver best possible performance and resource utilization.

### 3.7.2 DESCRIPTION

A User Equipment (UE) in idle state is unknown to an LTE network. In order to start establishing a relation to the LTE network, the UE searches for the most suitable cell and reads its broadcast system information. The broadcast system information (SIB2) from the cell provides the UE with cell-specific random access format and procedure details. These details determine essential parameters, such as preamble format and initial power setting. The UE randomly selects one of the preambles in an attempt to establish a relation to the cell. As long as no other UE is using the selected preamble at the same time instant, the access attempt can succeed. The success also relies on that the preamble can be heard and identified by the eNB. If there is no response or rejection from the eNB, the UE needs to retry until it succeed. The impact on user experience during the random access procedure is mainly delayed access and interrupted transmission during a handover. The automatic RACH optimization function will balance between optimal access performance and least resource utilization needed to meet set quality target such as, an acceptable level of access success rate. By selecting the most suitable preamble format, based on say traffic type, and dynamically adjusting the broadcast power control parameter ($P_0$), the access success rate can be optimized while still maintaining a low interference level. This results in best user experience with fast access and best possible throughput.

The automatic RACH optimization function can be executed continuously resulting in RACH related parameters being modified automatically. The changes could be based on inputs from both the connected UEs and each cell's neighboring cells. By collecting the recently introduced RACH report from the UE, the actual access delay can be determined. The RACH report is included in the message *UEInformationResponse* (3GPP Rel-9 spec TS 36.331). It contains two new parameters: *numberOfPreamblesSent* and *contentionDetected.* Based on this new information, the automatic RACH optimization function can adjust the power control parameter ($P_0$) or change the preamble format to reach the set target access delay. By optimizing $P_{0,}$ the probability for an eNB to read the preamble increases. However, as a result, the interference on neighboring cells may also increase. The second option adjusts the preamble format to use, under the premise that a correct preamble format assures successful preamble detection for the traffic type in a cell.

The automatic RACH optimization function automates the required continuous adaptation of the RACH. The automatic RACH optimization function can automatically react when receiving notification over X2 of a RACH parameter change in a neighboring cell. The information is transmitted via the eNB configuration update X2 message. For instance, allocation of same root sequence index in neighboring cells should be avoided to reduce interference. Automatic RACH optimization, based on the optimization on real traffic data and neighbor cell information, makes it well suitable for eNB function localization. The automatic RACH optimization function can execute autonomously with no operator intervention or effort. The operator controls the function with a few policies that set the outer limits for the function. These limits assure that the function will not move to an extreme setting when finding the best tradeoff between access delay and resource utilization.

## 3.8 INTER CELL INTERFERENCE COORDINATION

Reuse one cellular networks are 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 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. ICIC is accomplished as follows:

- Users can be scheduled in units of a physical resource block (PRB) which is 180 KHz.
- Neighbouring cells can coordinate which portions of the bandwidth are used in each cell and the transmission powers across various frequency resource blocks.
- Inter-cell interference can be reduced or avoided in uplink and downlink by a coordinated usage of the available resources (PRBs) in the related cells which leads to improved SIR and corresponding throughput. This coordination is realized by restriction and preference for the resource usage in the different cells. This can be achieved by means of ICIC related RRM mechanisms employing signalling of the following standards-defined metrics:
    1. High Interference Indicator

2. Overload Indicator
3. Relative Narrowband Transmit Power (RNTP)

Exchanging the above information would allow an advantageous RRM resource usage by means of preferences with respect to the e.g. available time/frequency resources, neighbourhood relations of the cells and QoS requirements targeted by the operator.

Expected results of automated ICIC parameter settings include the automatic configuration or adaptation, with respect to cell topology, of:

1. ICIC reporting thresholds/periods
2. Resource preferences in eNBs
3. RSRP threshold for ICIC

ICIC RRM might be configured by ICIC related configuration parameters like reporting thresholds/periods and preferred/prioritized resources. Then these have to be set by the operator for each cell. Setting and updating these parameters automatically is the task of a SON mechanism. The objective of SON is the self-configuration and self-optimization of control parameters of RRM ICIC schemes for uplink (UL) and downlink (DL) ICIC. SON based ICIC requires the exchange of messages between the eNBs of various cells, via X2 interface, for interference coordination. By means of ICIC related Performance Measurements (PM) analysis, the SON function may properly tune ICIC configuration parameters like reporting thresholds/periods and resource preference configuration settings in order to make the ICIC schemes effective with respect to Operator's requirements.

### 3.8.1 BENEFITS

Shaping the inter-cell interference allows an improved SINR to be realized in certain portions of the spectrum. This can be exploited by the scheduler to provide an improved trade-off between sector throughput and cell-edge bit rate. The result is improved SINR for cell edge UEs to achieve better edge rates and cell throughputs, improved hand-off performance for cell edge UEs (Lower handoff delays and lower handover failure rate) etc. The goal of SON based ICIC is to have minimized human intervention in network management and optimization tasks.

### 3.8.2 DESCRIPTION OF ICIC OPERATION

Inter-cell interference coordination relies on intelligent resource allocation to eliminate interference. SON aims to configure and optimize the network automatically, so that the need for manual intervention is reduced and the capacity of the network can be increased by having it adapt to operating conditions automatically as required for optimum performance. The capabilities provided by a SON fit very nicely with the operational requirements for ICIC. ICIC requires that neighboring cells exchange information about which portion of the total bandwidth they are using. SON provides the ability for self-configuration and self-optimization of which portion of the total bandwidth a particular cell will use. There are 3 basic components to a SON ICIC implementation:

1. Core ICIC algorithm
2. Frequency planning

3. Inter-eNB communications

The core ICIC algorithms are those that determine how the resources (time, frequency and power) available are managed to realize interference coordination between the cells. Various ICIC techniques have been developed with varying degrees of performance and complexity.

In the downlink, the common theme of ICIC is to apply certain restrictions to the downlink resource management in a coordinated way between cells. The restrictions are distributed usually using the X2 connections to different cells during cell setup or when cells are de-activated and are generally constant on a time scale corresponding to days. These restrictions determine the time/frequency resources currently available to the Radio Resource Manager (RRM), as well as restrictions to the transmit power that can be applied to certain time/frequency resources. These restrictions shape the interference power spectrum of a given cell on the DL. The power constraints on the transmitted PRBs in one cell lead to improved SINR and cell edge data rates/coverage for the corresponding time/frequency resources in a neighbor cell.

Figure 9 shows the operation of one DL ICIC scheme known as the Inverted Reuse scheme. Three cells are shown with each cell transmitting at a certain nominal power across the entire bandwidth except for a restricted portion of the bandwidth. In the restricted PRBs, transmissions are either at a lower power, resulting in a soft partial frequency reuse scheme or there may not be any transmissions at all, resulting in a hard partial frequency reuse scheme. Neighboring cells have restrictions in different portions of the total bandwidth. A neighboring cell can schedule its cell edge users in the restricted PRBs of its neighbors and realize an improved SINR since the neighboring cells are either transmitting with a lower power or not transmitting at all on those PRBs. Users are classified into generally two groups: cell inner and cell edge groups with the classification being made based upon a number or combinations of such metrics such as a user's serving cell path loss and differential path loss between that user's serving and neighboring cells.

The performance of ICIC depends upon a number of factors such as cell size, cell load, propagation channel, user mobility, traffic model, traffic type, etc.

In the uplink, it is the UEs near the cell border which cause most of the interference to adjacent cells. The basic concept in the UL is to concentrate the bulk of the inter-cell interference in a small portion of the total bandwidth, thereby preventing any impact to the majority of users since the interference is now localized to certain sub-carriers and the sub-carriers are orthogonal to each other.

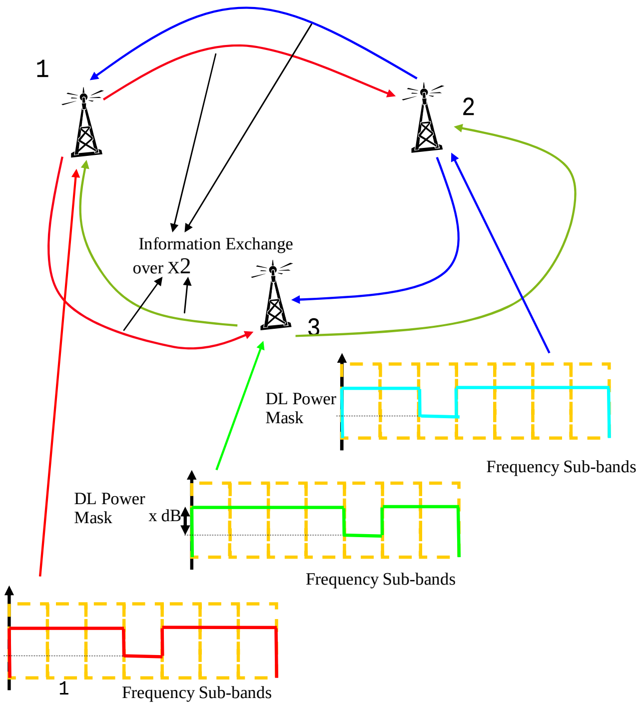


**Figure 9 - Inverted 1/7 Soft Re-use ICIC DL Scheme**

### 3.8.3 FREQUENCY PLANNING

Static ICIC techniques require that every cell designates a certain portion of the bandwidth to be in some kind of restriction. These restrictions correspond to the PRBs for the Interference Bearing Zone for the UL and in the DL to those PRBs that are transmitted at a lower power. In addition, these restricted PRBs on both the UL and DL should not overlap across neighboring cells. This is classic frequency planning. It is desirable that this frequency planning be completely automated for LTE as operators do not want to deal with the logistical complexity of manual frequency planning and deployment. Once a particular colour has been assigned to a cell, each eNB informs its neighbours of its transmit PSD mask through RNTP reporting over the X2 interface.

Some of the constraints of the frequency planning are:

1. Two neighbouring cells must have different colours.
2. As far as possible, a cell should not have two neighbours with the same colour.
3. Assign colours to cells such that same coloured cells are as far apart as possible.

### 3.8.4 SELF-TUNING X2 INDEPENDENT ALGORITHMS

Self-tuning techniques, in the form of channel aware or interference aware packet schedulers, which treat the problem of interference looking at the information available in the victim cell (i.e. CQI sub-band reports, channel state information (CSI), or other eNB measurements), can achieve similar performance without the need to implement X2 communication.

These techniques may create reuse patterns within the cell or allocate additional resources to improve the performance of cell edge users, but the settings are adjusted automatically based on the measurements within the cell, without need for external communication or control from centralized entity.

Autonomous and self-adjusting frequency re-use mechanisms may provide even greater benefits for uncoordinated LTE deployments such as addition of femto and pico cells[14].

### 3.8.5 PERFORMANCE OF ICIC TECHNIQUES RELATIVE TO SELF-TUNING X2 INDEPENDENT ALGORITHMS

ICIC techniques typically improve cell edge user performance and provide significant gains on top of basic packet scheduler. The gains from ICIC vary depending on the architecture, specific ICIC algorithm and the scenario.

The performance of ICIC is dependent upon the ICIC algorithm used, and several other parameters such as the propagation channel, user mobility, scheduling algorithms, cell size, cell load, traffic type, whether the ICIC technique is static or dynamic in operation, metric types used to classify cell center versus cell edge users, user distribution inside cell, etc. 3GPP does not specify the type of ICIC technique to be used, allowing different vendors the freedom to implement different techniques. What is standardized however are a set of metrics that can be exchanged used in the implementation of the ICIC technique.

Reuse 1 techniques, such as Frequency Selective or Channel Aware Scheduling, can also provide performance similar to ICIC techniques in certain scenarios, such as for users at low user mobility and when scheduling can be done every sub-frame.  The availability of sub-band SINR information through the use of narrow band channel quality indicators (NB-CQIs) on the downlink helps the Channel Aware scheduler to mitigate interference quite well. Additionally, when working at fractional loads, reuse 1 schemes may allocate additional bandwidth to users at cell border to compensate for lower average SINR. In this scenario, ICIC provides little to no gain over a channel aware scheduler. Furthermore, there may be ICIC implementations where X2 communication delays reduce potential gains under realistic scenarios since the feedback may not follow up with fast changing conditions of the interference and fast fading. In addition, requirements for X2 communication may cause problem in areas belonging to different MME, and inter-vendor borders.

On the other hand, there are scenarios where ICIC may provide gains over a reuse 1 channel aware scheduler, such as in uplink direction, for high user mobility and when Semi-Persistent Scheduling is used. Dynamic ICIC schemes have been shown to provide even better performance compared to their static counterparts. Finally, it has been shown that ICIC techniques provide good performance in Heterogeneous Network scenarios where they are used to manage the interference from the macros into the small cells.

To conclude, it is important to note that the performance of ICIC algorithm is closely tied to the specific implementation. Latencies due to X2 signaling depend on the deployment architectures as well as the ICIC algorithms themselves. In certain architectures, there may be no extra latency or complex signaling required as information from multiple cells is readily available in a centralized processing site, without the need for X2. Finally, there are ICIC algorithms that require less signaling support compared to others.

### 3.8.6 OPTIMIZATION OF COVERAGE/INTERERENCE WITH H-ENB

Release 8 and Release 9 standards for Home eNBs did not provide any control mechanisms between the HNB and the macro base stations. As result, there could be situations where potential DL/UL interference is created between these two cells, or weak in-home coverage. **Error! Reference source not found.**10 illustrates the potential interference scenarios between a Home eNB and a macro cell.

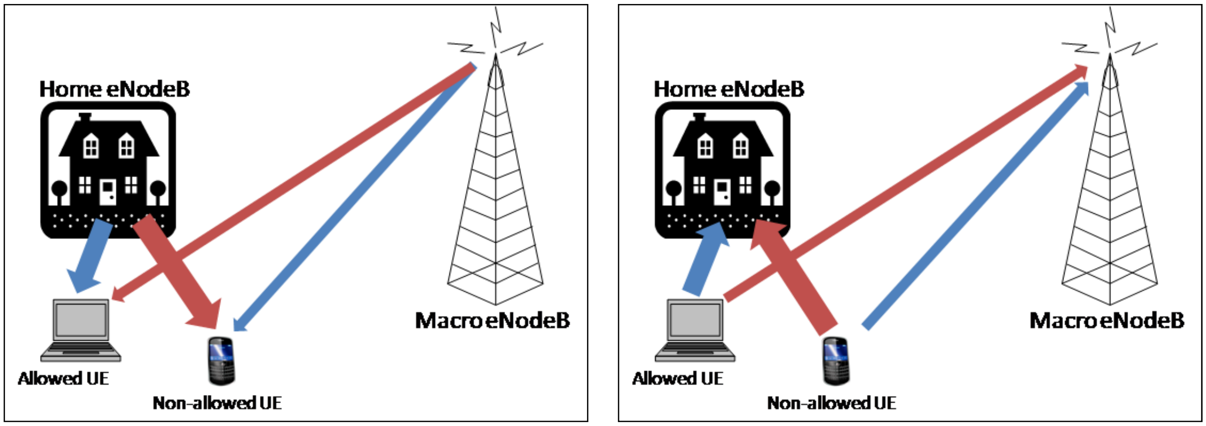


**Figure 10 - Potential Interference situations in a Macro-Home eNB interaction**

With Release 8 and Release 9 mechanisms, in cases where the DL signal from the macro cell is low, the HNB will typically adjust its power to prevent interference to other UEs in the network, resulting in a weaker coverage for the home user; alternatively it can keep the transmit power up, which will result in high interference to the macro BTS users at the cell edge that cannot camp on the HNB. Another problem is the UL interference generated to the HNB from UEs that are connected to macro base stations, and are not allowed to camp on the HNB (Right picture in Figure 10)). This in turn, can make the UEs that are camping on the HNB to increase their UL power thus affecting the UL performance of the macro base station.

NGMN has suggested a series of mitigation techniques for these problems that would require the interaction between Home eNB's and macro base stations.

UE Assisted DL Control

There are two different techniques proposed to improve the current power control mechanism in case of HNB-macro BTS interaction. In the first approach namely, signaling of power down indication, the macro BTS instructs the HNB to adjust its DL power after it receives multiple reports from different UE's indicating high interference from that HNB. The HNB will power up steadily after a certain time assuming the interference situation has disappeared.

In the second approach, the macro BTS would forward the measurement report to the HNB in the case of detected interference, thus providing the HNB with more detailed information from the interference situation that would allow the HNB to balance the power considering the interfered UEs and its own served users.

Fractional Frequency reuse

In case of high interference, the HNB and macro BTS can coordinate their schedulers to assign different time/resource blocks for transmission to avoid co-channel interference, or to reduce the power in certain blocks. To do this, the macro BTS would indicate to the HNB a set of resources that it would like to use for the interfered UE, and the HNB would adjust their transmission patterns accordingly.

Partial co-channel deployment

While Fractional Frequency Reuse is effective in reducing interference to the data channels, by either reducing power or totally eliminating transmission, it would not eliminate the interference on control channels. With a partial co-channel deployment, the HNB can be allocated a small subset of the available bandwidth for macro base stations to avoid high interference in the control channels. Such bandwidth would be indicated by the macro base station to the HNB in case of interference situations.

Noise padding

The uplink interference from macro UEs, especially those at cell edge, can create serious problems to the HNB. If the source of the interference is bursty, the rate prediction and error correction mechanisms in the HNB will not work well. With this technique, the HNB will identify such interference situations and temporarily increase the noise figure to compensate for this. In order to avoid UL power racing between the macro and HNB UEs, the macro BTS would signal to the HNB a maximum noise figure, maximum transmit power or overload indicator.

### 3.8.7 RELEASE-10 ICIC ENHANCEMENTS

Dominant interference condition has been shown when Non-CSG/CSG users are in close proximity of femto. In this case, Rel8/9 ICIC techniques are not fully effective in mitigating control channel interference, and therefore enhanced interference management is needed.

Release 10 has introduced enhanced ICIC mechanisms. 3GPP has proposed candidate solutions for Interference coordination for non-CA based heterogeneous networks focusing on macro-femto deployment scenario and macro-pico scenario. Three different candidate solutions for eICIC are:

- Time-domain solution – Subframe utilization (Almost Blank Subframes (ABS)) across nodes are coordinated through backhaul signalling.
- Power control solution – HeNB adjusts its transmit output power to avoid interference to other nodes.
- Frequency-domain solution – Orthogonal bandwidth for control signaling and common information are configured across nodes.

## 3.9 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.

Currently network elements can only be put in stand-by mode using modems managed by separate tools. For an integrated energy saving functionality, network elements should provide a stand-by mode with minimum power consumption and a possibility to switch on and off this stand-by mode remotely via the element management system without affecting the customer experience such as dropped calls.

Mechanisms to realize energy savings are being investigated in 3GPP.

### 3.9.1 BENEFITS

Sustainable development is a key criterion for telecom operators, to address the problems of resource shortage and environmental deterioration due to greenhouse emissions. Energy saving mechanisms allow operators to reduce OPEX and provide the quality of experience to end users with minimal impact on the environment. The possibility to temporarily switch-off some parts of radio access network nodes, such as a given Radio Access Technology (GSM, UMTS), will reduce the operational costs related to power consumption.

### 3.9.2 DESCRIPTION

Energy savings by switching off/on cells can be initiated in several different ways as follows:

- By the operator, from the OAM manager;
- Setting policies and conditions that result in autonomous switching off/on cells when the conditions are met;
- Completely autonomous by the eNB with information exchanged on the X2, S1 interfaces.

When a cell is switched off, there may be a need for the neighboring cells to pick up the load. However switching off a cell should not cause coverage holes or create undue load on the surrounding cells. A switched off cell is not considered a cell outage or a fault condition. All traffic on that cell is expected to be moved to the underlying umbrella cells before any switch off occurs.

When a NE is "switched off" for energy savings purposes, no alarms should be raised to the OAM manager for a condition that is a consequence of a "switched off" NE. The operator should have the capability to prevent the network from automatically compensating based on the cell that is in energy savings mode in order to prevent unnecessary disruption in the network.

3GPP is examining solutions for energy saving in E-UTRAN, so that a subset of them can be used as the basis for further investigation and standardization. The following use cases are considered:

- Inter-RAT energy savings
- Intra-eNB energy savings
- Inter-eNB energy savings

In defining the various energy saving solutions, valid scenarios based on cell/network load situation, impacts on legacy and new terminals when introducing an energy saving solution are considered. The objective of the technical work in 3GPP energy saving management is to identify automated energy savings management features. 3GPP addresses the following.

- Select existing measurements which can be used for assessing the impact and effect of energy saving actions corresponding to above energy saving use cases.
- Define new measurements which are required for assessing the impact and effect of energy saving actions, including measurements of the energy consumption corresponding to above energy saving use cases.

3GPP has scoped that the following criteria should be met:

- User accessibility should be guaranteed when a cell transfers to energy saving mode.
- Backward compatibility and the ability to provide energy savings for Rel-10 network deployment that serves a number of legacy UEs should be met.
- The solutions should not impact the physical layer.
- The solutions should not impact negatively the UE power consumption

Energy savings should not lead to service degradation or inefficiencies in the network since the activation status of radio stations (on/off) introduces a new scale of dynamicity for the UE and network. The increase in signaling potentially endangers the network stability and needs to be handled properly.

### 3.9.3 DEPLOYMENT SCENARIOS WITH LTE IN CLUSTERS, OVERLAYING AN UNDERLYING 2G/3G NETWORK

Initially, LTE will be deployed in clusters as an overlay for capacity enhancement at hot spots with an underlying 2G/3G network.

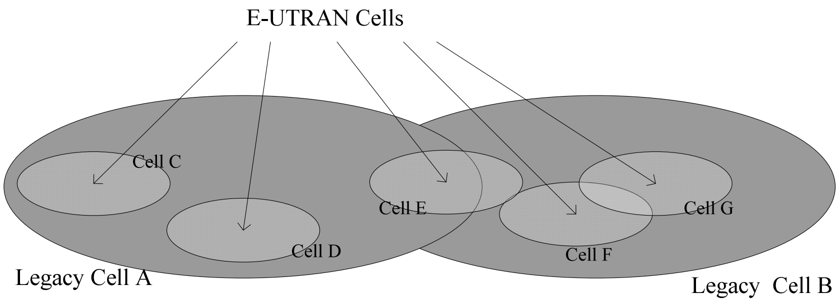


**Figure 11 - Inter-RAT energy saving scenario**

In Figure 11, E-UTRAN Cells C through G are totally covered by the same legacy RAT Cell A and B (e.g. UMTS or GSM). Cells A and B have been deployed to provide basic coverage of the services in the area, while other E-UTRAN cells boost the capacity.

In such networks, the legacy network provides the basic coverage for those UEs with multi-mode capability and the E-UTRAN only UEs are not served when they are out of the coverage of E-UTRAN. The energy savings procedure can be enabled based on the interaction of E-UTRAN and UTRAN system.

#### 3.9.3.1 SOLUTIONS FOR CELL SWITCH ON/OFF IN INTER-RAT SCENARIO

Solution 1: Cell switch on/off via OAM commands: With this solution, an E-UTRAN cell can be switched off/on by the centralized OAM system based on some RAN information, e.g. load information. The Intra-RAT and Inter-RAT neighbor nodes should be informed either by the OAM or through signaling.

Solution 2: Cell switch on/off autonomously at the RAN node via local policies downloaded by OAM: With this solution, the E-UTRAN node can switch the cell on/off according to a certain policy configured by OAM, and its Intra-RAT and Inter-RAT neighbor nodes should be informed, either by the OAM or by the signaling. An example policy would be, switching on the cell 3 hours after switching it off, or switching off the cell at 1:00 am and switching on it again at 7:00 am. As a part of energy saving operation, the E-UTRAN node may first handover the capable UEs to the UTRAN/GERAN.

Solution 3: Cell switch on/off based on signaling across RATs: With this solution, the capacity boosting E-UTRAN cell may be switched off autonomously based on information available in the cell. Switch-on may be performed upon request by one or more neighbor inter-RAT nodes. Intra-RAT and Inter-RAT neighbor nodes should be informed after on/off decision is made.

#### 3.9.3.2 FURTHER ENHANCEMENTS FOR INTER-RAT SCENARIO

**Issue:**

Further enhancements need to be addressed for Inter-RAT scenarios. The reason is that when the E-UTRAN cells are not active and the load increases, the legacy cells for coverage will not know which cell should be woken up, especially when the increased load is in one or few hotspots.

Enhancements based on solution 3 to select the appropriate cells to activate include the following.

Solution 4: In this enhancement, when the load is heavy and some E-UTRAN cells need to be switched on, those legacy cells for coverage will activate its dormant neighbors. After that, if some E-UTRAN cells find that it could return to sleep mode, they can switch themselves off again.

Solution 5: In this enhancement, the listening capability of the E-UTRAN cells may be enabled independently from other functions of the cell. In that case, the sleeping cells may monitor, when requested, interference over thermal (IoT) ratio, which is obtained based on received interference power and thermal noise power. When the legacy cells providing coverage detect high load, they may request the E-UTRAN cells within their coverage to provide IoT measurements. The legacy cells could then compare measurements reported from all the hotspots, including stored RSRP measurements from served users. In most cases, the legacy cells will be able to find which E-UTRAN cells are the most appropriate to serve the higher load. Accordingly, those legacy cells could activate the appropriate cells in E-UTRAN while keeping other hotspot cells in sleep mode.

### 3.9.4 SCENARIOS FOR FURTHER STUDY

In later phases of LTE deployment, when operators deploy the LTE network without any 2G/3G overlay, the application scenario for energy savings is as follows.

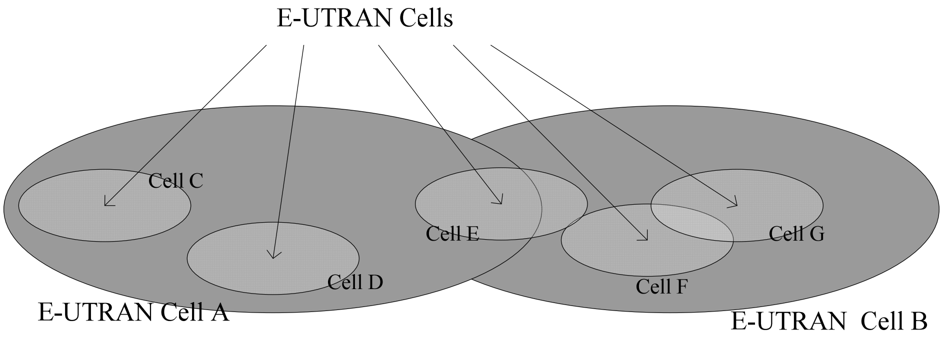


**Figure 12 - Inter-eNB scenario 1 for energy saving**

In Figure 12, E-UTRAN Cells C through G are totally covered by the E-UTRAN Cell A and B. Here, Cells A and B has been deployed to provide basic coverage, while other E-UTRAN cells boost the capacity. When some cells providing additional capacity are no longer needed, they could be switched off for energy optimization. In this scenario, both the continuity of LTE coverage and service QoS could be guaranteed.

## 3.10 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.

### 3.10.1 BENEFITS

Detection and Compensation provide distinct benefits to the Operator. Previous generations of cellular infrastructure have experienced failures of which Operators had no knowledge until such time as receiving notification from customer support of problems in the field. Cell Outage Detection ensures that the operator knows about the fault before the end user does.

Cell Outage Compensation provides temporary alleviation of the problem caused by the loss of a Cell from service. Compensation mode alleviates the outage, but the level of service provided to users in the affected area is likely to be restricted by local topology, distance from neighboring serving cells and available capacity.

### 3.10.2 CELL OUTAGE DETECTION

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.

In the case of complete eNB failure, OAM will be unable to communicate with the eNB to determine whether its cell is in service.  Lack of communication could be a symptom of failure on the OAM Backhaul rather than an indication that the site is down.  In this case, the Network Manager needs to have other evidence to determine the nature of the problem.  If the cell is still in service, it will continue to interact with the core network, so the Network Manager should be able to determine from core network metrics whether there is ongoing interaction with a specific eNB or cell.

Latent fault determination is the term used when the fault detection is based on evidence, such as anomaly statistics, rather than an alarm or state change. This is the most challenging of the Cell Outage Detection scenarios since OAM indications will suggest that it continues to operate normally.  This type of detection may be achieved with a combination of statistics and activity watchdog timers.  The operator will typically have a set of generic policies defined where each policy describes the combination of stats or events that are deemed to indicate a Cell Outage.  This may be enhanced using a set of “Cell Type” specific rules where all cells of a specific type use a separate or additional policy.  Perhaps the most valuable of the evidence based detection mechanisms, is the use of time / day profiling on a per cell basis.  This is achieved by collecting stats over a period of time and gradually building a statistical picture of expected performance for a given time of day, weekday, or weekend.  When stats collected for a cell deviate significantly from values normally seen for that cell, then there is a likelihood of a latent fault.

### 3.10.3 CELL OUTAGE COMPENSATION

Before considering the many complex reconfigurations available to ensure that neighboring cells provide service in the area affected by cell outage, it is important to understand that in most urban cases, the majority of external users are likely to have at least a minimum level of service from those neighboring cells even without any reconfiguration.

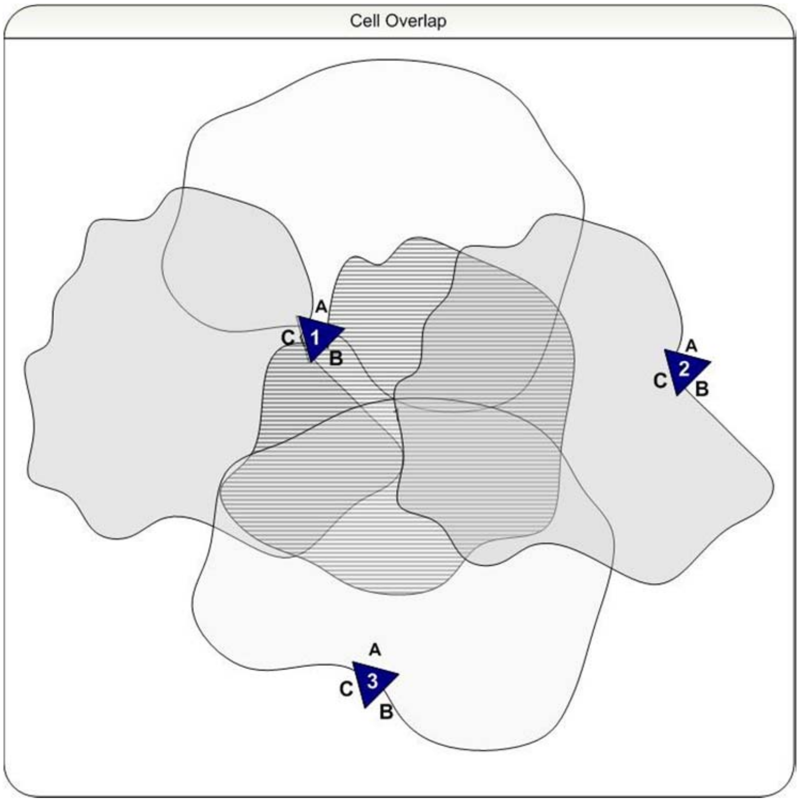


**Figure 13 - Outage compensation scenario**

In the example of Figure 13, eNB 1(sector B) is experiencing an outage. Note that there is significant overlap both from eNB 1(sectors A and C), and also from eNB 3(sector A) and eNB 2(sector C). These cells will experience slightly improved performance at their cell edges due to the removal of interference from eNB 1(sector B).

Typically, tilt based compensation would be limited to facing sectors, i.e. eNB 2(sector C) and eNB 3 (sector A) since tilt generally has the greatest coverage impact at boresight and the least impact on the borders with co-sited neighbors. Therefore, tilting eNB 1(sectors A and C), is likely to do more harm than good.

There are three main areas that need to be addressed in trying to improve on the existing default Cell overlap.

1. Neighbors
   With a given cell out of service, it is essential that neighboring cells on opposite sides of the outage are configured as neighbors. In most cases, this relationship is likely to exist by default, since most neighbor planning, both manual and automatic, tends to include a second ring of neighboring cells and not just those on the immediate border. It may also be advantageous to enable the Automatic Neighbor Relationships use case (ANR) on cells surrounding the outage to ensure that no essential relationships are missed. In most cases, neighbors that are added to enable support of a neighboring cell outage will not subsequently need to be deleted after normal service has been restored.

2. Physical Layer Cell Identities (PCIs)
   The implicit change in neighbor relationships in the case of an outage, also requires a recheck of the rules relating to PCIs.

   - A cell and its neighbor must not have the same PCI.

   - Neighbors of a given cell must not share the same PCI.

   By revalidating the PCIs in the same way that the operator used to recheck the neighbors, one can ensure that neither of these rules is broken. As in the case for new neighbors, it is generally advantageous to plan PCI allocation for worst case as represented by a cell providing coverage for a neighbor's outage.

3. Coverage Footprint
   There are three methods for adjusting a cell's coverage footprint:

   a. Handover Parameter offsets
      It is possible within limits to adjust a cell's handover boundary with an immediate neighbor through change of cell individual offsets (CIO) or similar parameters, however this has no relevance in the case of adjusting coverage in the direction of a Cell Outage.

   b. Transmit Power
      Transmit power has an immediate impact on the cell boundary, however, most cell planning makes maximum use of available power, leaving very little positive headroom to enable a cell to increase its coverage in the direction of a neighboring outage.

   c. Antenna adjustment
      Most discussions on cell outage coverage adjustment focus on change of antenna pattern to achieve the additional coverage for the neighbor. In most cases, changes are achieved with antenna tilt, i.e. alteration of the vertical pattern. However, newer antenna technology enables many complex adjustments of the coverage pattern on demand.

      There are industry collaborations between Radio Planning Tool vendors and Antenna manufacturers in which Beam-Shaping adjustment is guided by data from the Radio Planning Tool. The Antenna Interface Standards Group (AISG) has defined Standards for tilt and Azimuth steering. These are consistent with the 3GPP standards for Remote Electrical Tilt (RET) antennas: (TS 25.460 - TS 25.463). AISG has already been deployed in some 2G and 3G networks, but is expected to be more widely deployed for LTE.

      The real challenge with use of antenna pattern adjustment in support of any SON features, is ensuring there is a control loop to guarantee that antenna adjustment to improve coverage in one area, doesn't either worsen coverage or create too much interference in another area. SON needs to collect sufficient measurements to profile the impact of antenna pattern adjustment. The goal for SON is to converge to a point where a cell outage results in each of the surrounding cells adjusting their patterns by an amount that is preconfigured for that specific neighbor relationship to shrink the coverage hole that was created.

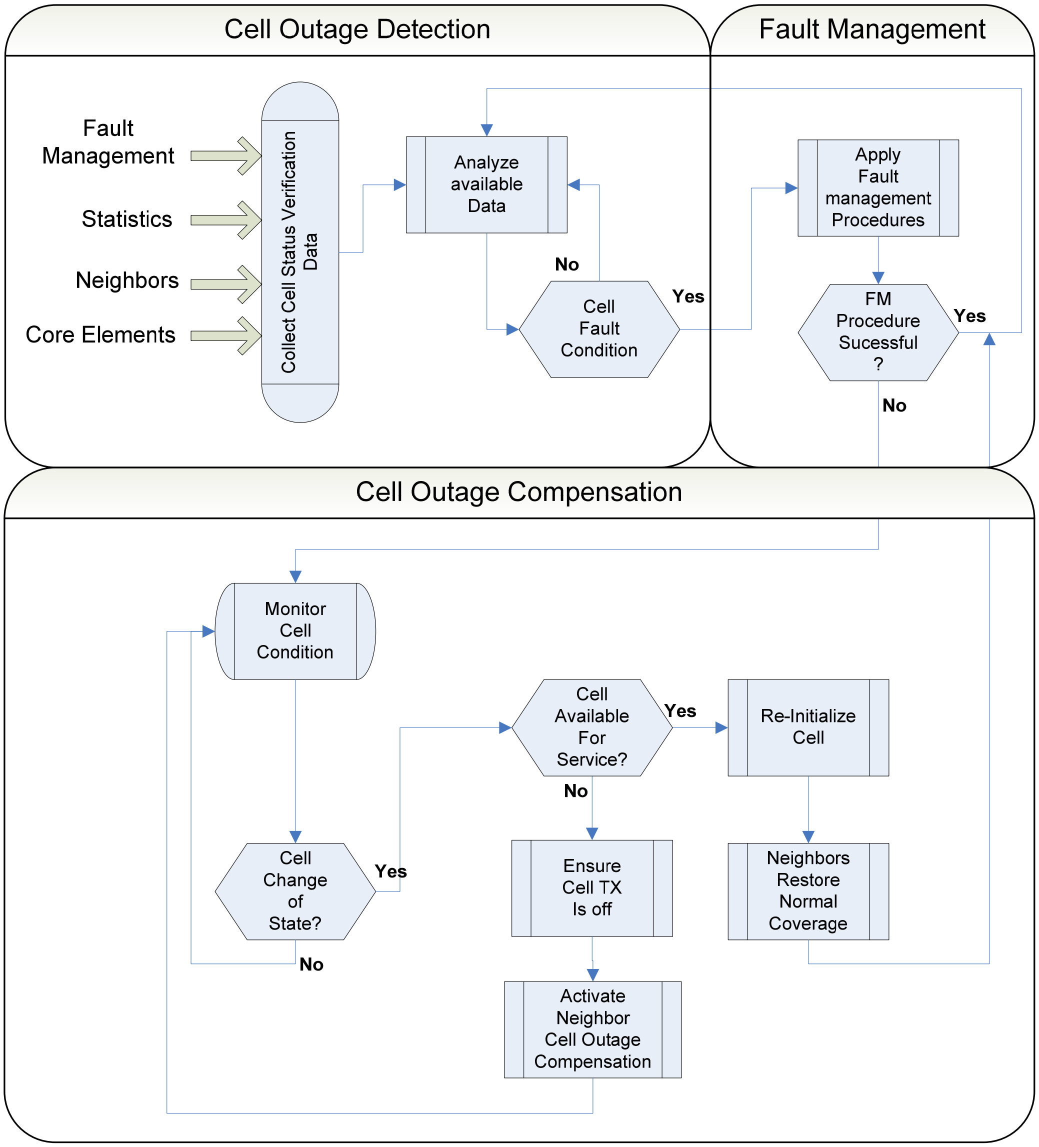


**Figure 14 - Roles of Cell Outage Detection, Fault Management and Cell Outage Compensation**

Figure 14 represents the generalized case of Cell Outage Detection and Compensation. It separates the roles of Cell Outage Detection, Fault Management (FM) and Cell Outage Compensation. The specific details will vary significantly between implementations. However, it is expected that detection would be based on the following generic data to address those cases where the RAN OAM path is down but the Network Elements are functional:

- FM information for conventional alarmed failures;
- Statistics for detection of latent fault conditions;
- Neighbor reports to help detect latent failures, and
- Core statistics to catch those cases where the RAN OAM path is down but the Network Elements remain functional.

Cell Fault conditions are passed to normal FM procedures. Some vendors or operators may choose to do this manually. Cell Outage Compensation technique is utilized when a fault cannot be resolved remotely in a few minutes. During Cell Outage Compensation, SON will continue to monitor the impacted cell and once advised that it is ready for service, it will re-initialize the cell and back out the compensation.

## 3.11 COVERAGE AND CAPACITY OPTIMIZATION

### 3.11.1 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.

#### 3.11.1.1 BENEFITS

Self-optimization of coverage and capacity reduces manual operational tasks, resulting in OPEX reduction and user QoE improvement. The feature will provide optimal coverage where LTE system is offered. Thereby, users can establish and maintain connections with acceptable service quality, according to operator’s requirements. This feature will provide optimal capacity where LTE system is offered according to operator’s policy setting. Since coverage and capacity are linked, a trade-off between the two of them would be dependent on optimization criteria.

### 3.11.1.2 DESCRIPTION

The term Coverage and Capacity Optimization (CCO) is very generic and covers a broad range of use cases. In reality, many of the SON use cases defined in 3GPP are somehow related to a coverage/capacity optimization effort such as, Cell Outage Compensation, Mobility Load Balancing and the Interaction between Home and Macro eNB. As defined by 3GPP, the CCO use case is understood as automatic cell planning, in which the SON algorithm has to find the optimum antenna and RF parameters for the sectors that serve a certain area for a particular traffic situation. The optimum result should maximize network throughput/capacity while complying with a certain service confidence level, as specified by the operator.

The objective of the CCO use case as defined in RAN *(*3GPP TR 36.902) is to provide optimal coverage and optimal capacity. The 3GPP TR 36.902 defines coverage and capacity as follows:

“In the area, where LTE system is offered, users can establish and maintain connections with acceptable or default service quality, according to operator’s requirements. It implies that the coverage is continuous and users are unaware of cell borders. The coverage must be provided in both, idle and active mode for both, UL and DL. While coverage optimization has higher priority than capacity optimization in Rel-9, the coverage optimization algorithms must take the impact on capacity into account. Since coverage and capacity are linked, a trade-off between the two of them may also be a subject of optimization.”

The term “coverage” could mean coverage of basic service or coverage of user services. Basic service includes reception of DL control channels and setting up a signaling radio bearer. User services refer to services such as speech, video telephony, etc.

The term “capacity” could have various interpretations. There are several options for capacity, e.g., cell throughput, median user throughput, xth-percentile cell edge throughput, and number of served users (with a specific service or bit rate requirement).

There is a tradeoff between coverage and capacity. Typically, increasing the coverage results in less spectral efficiency due to deteriorating signal power, resulting in less capacity. One cannot optimize both coverage and capacity at the same time, and therefore there is a need to balance and manage the tradeoff between the two.

The self-optimizing CCO function is a continuously running process which continuously gathers measurements and takes actions, if needed. The operator can specify the desired performance optimization target and the balance between different targets to achieve tradeoffs. Measurements and reports from the network are used by CCO to estimate entities related to coverage and capacity according to the target given by the operator. Minimization of Drive Test reports may be used to monitor and detect coverage problems in the network.

CCO corrective actions comprise changes in radio parameters such as, antenna tilt and UL power control parameters. Deployment of pico cells or coverage/capacity enhancing features are also corrective actions that may be proposed by CCO to reach desired target. The CCO should not react to performance of individual users, but rather compute appropriate CCO actions based on long-term statistics.

As with other aspects of SON development, it is expected that coverage and capacity optimization techniques will change over time, adapting to the maturity level of the networks. In the initial stages of commercial LTE network operation, traffic load will not be a major concern, and it is expected that there will be coverage challenges due to lack of sufficient cell density or configuration errors. Therefore, CCO techniques will primarily be focused around providing service coverage with a certain minimum quality.

The coverage area and capacity of a network, or some cells in the network, may vary due to addition of base stations, malfunctioning base stations, or change in user distribution. Suboptimal coverage area and capacity leads to inefficient use of network resources and lower quality. Furthermore, adapting to network changes manually is very expensive and time consuming. Thus, the CCO function operates continuously to gather measurements and takes actions if needed. CCO should be a slow activity where statistics and measurements are used as basis for decision.

3GPP TS 32.521 specifies the following requirements on CCO:

- Coverage and capacity optimization shall be performed with minimal human intervention.
- Operator shall be able to configure the objectives and targets for the coverage and capacity optimization function.
- Operator shall be able to configure the objectives and targets for the coverage and capacity optimization functions differently for different areas of the network.
- The collection of data used as input into the coverage and capacity optimization function shall be automated to the maximum extent possible and shall require minimum possible amount of dedicated resources.

The 3GPP specifications provide a set of use cases that the CCO function should cover. These use cases are defined in a very generic manner, and simply indicate that the system should have functionality that addresses these particular issues, without providing further guidelines. The following sections describe the specified scenarios.

#### 3.11.1.3 USE CASE1: E-UTRAN COVERAGE HOLES WITH 2G/3G COVERAGE

Consider the scenario in Figure 15 (left), in which an LTE network has been deployed on top of a legacy 2G or 3G network with a suboptimal RF and radio resource parameter configuration. Even if the LTE coverage area is not contiguous, continuity of calls will be maintained due to inter radio access technology handovers that allows the various RF carriers to be treated as a pooled resource. This situation may not always be desirable in order to avoid unnecessary handovers that may lead to dropped calls. Therefore, one objective of the CCO algorithm could be to try and minimize the coverage holes by expanding the LTE footprint as illustrated in Figure 15 (right).

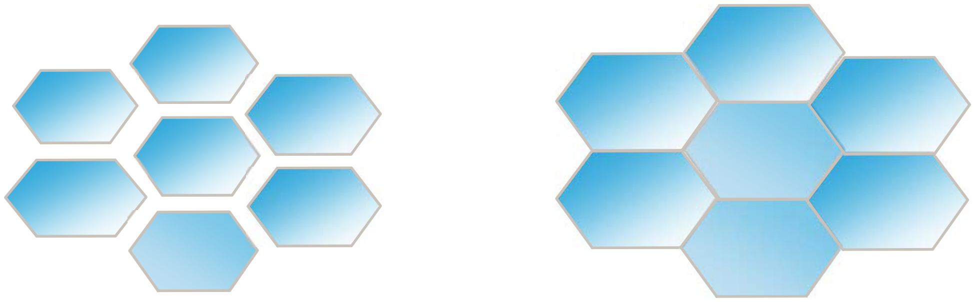


**Figure 15 - Optimization of IRAT coverage holes: before (left) and after (right)**

While this use case focused on IRAT optimization to minimize coverage holes, the SON system could also be used to optimize the IRAT parameters in a totally different way. For example, one objective of the Capacity and Coverage Optimization might be to offload voice traffic from LTE towards the underlying network and data traffic to LTE by making use of Load Balancing SON algorithms. The operator should have the control to govern the different policies of the SON system and adjust them to their specific needs.

#### 3.11.1.4 USE CASE2: E-UTRAN COVERAGE HOLES WITHOUT ANY OTHER COVERAGE

The second use case is one in which, due to cell planning mistakes or operator restrictions on cell site locations, one particular area of the network does not have sufficient coverage neither with LTE nor with any other legacy networks, thus leading to increased dropped calls in the area. The system should detect such situation and, if possible, adjust the configuration of the neighboring sectors to cover the gap. Figure 16 illustrates this scenario.

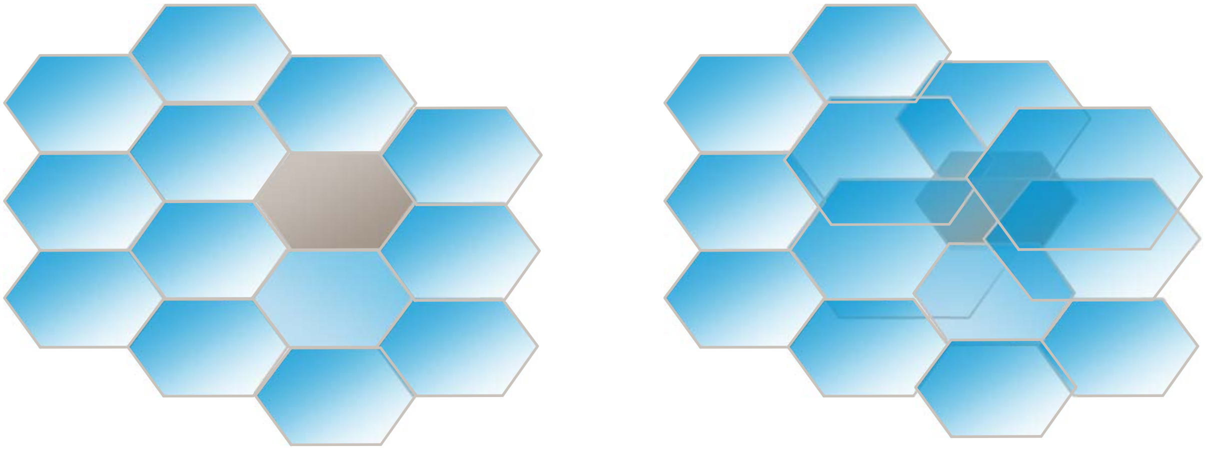


**Figure 16 - Illustration of coverage gap optimization: before (left) and after (right)**

#### 3.11.1.5 USE CASE3: E-UTRAN COVERAGE HOLES WITH ISOLATED ISLAND COVERAGE

This scenario covers the case in which operators are deploying LTE systems with islands of coverage as opposed to contiguous coverage in one region. However, due to poor RF planning, the deployed network may fall short of the designed footprint. In this case, the LTE network coverage should increase only in those areas where there is a mismatch with the original plan, as shown in Figure 17.

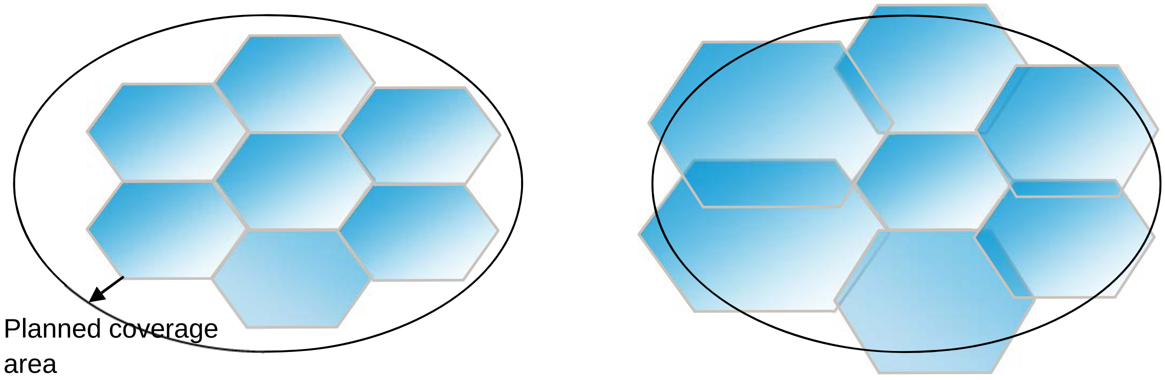


**Figure 17 - Isolated island coverage optimization**

### 3.11.1.6 USE CASE4: E-UTRAN COVERAGE HOLES WITH OVERLAPPING SECTORS

This scenario covers the case in which an operator adds new sectors, for capacity reasons, to an area with existing coverage. In order to optimize the capacity of the cluster, the existing sectors need to readjust their footprint to avoid excessive interference into the target area.

The figure below illustrates this scenario, in which a new site (shown in red on the left side of Figure 18) is introduced in an area with existing LTE coverage. In this case, the new site and the surrounding eNB need to automatically adjust their antennas and power to minimize interference in the area, while maintaining the service coverage (Figure 18: right).

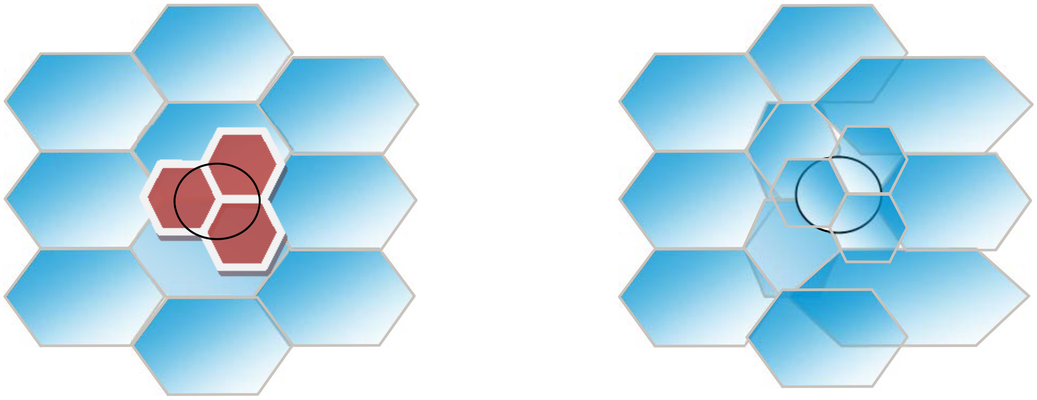


**Figure 18 - Optimization of coverage with newly added capacity sites**

There are currently a very limited number of specific CCO scenarios mandated by 3GPP. However, given the amount of available information available to the SON system both from the UEs and the eNBs, and increased flexibility of the network with the development of active antennas, CCO techniques will continue to evolve to establish finer tradeoffs between coverage and capacity in more mature networks.

As an example, Figure 19 illustrates one potential usecase in which the different sectors adjust their antenna orientation and transmit power to optimally capture UE traffic at different locations (shown in red) while minimizing the interference to other cells. Such method will be invaluable to network operators, since the location of the sectors is often constrained, and complicated network designs are required to serve the existing traffic optimally.

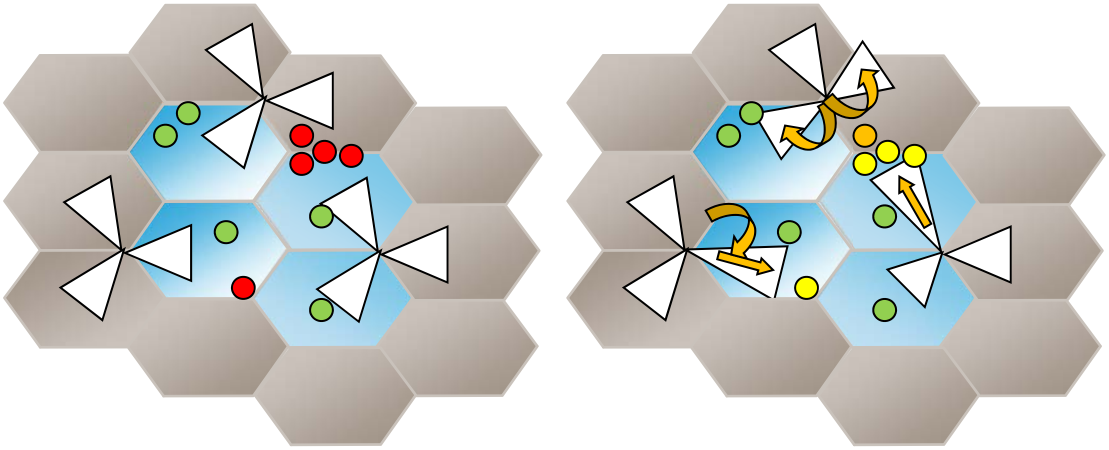


Figure 19 - Example of CCO based on traffic location

### 3.11.2 MINIMIZATION OF DRIVE TESTS

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 in 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 of using drive tests for network optimization purposes is expensive, 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 vs. position, etc. 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.

#### 3.11.2.1 BENEFITS

The MDT data reported from UEs may be used to monitor and detect coverage problems in the network. Some examples of use cases of coverage problem monitoring and detection include the following.

- **Coverage hole:** A coverage hole is an area where the signal level SNR (or SINR) of both serving and allowed neighbor cells is below the level needed to maintain basic service (signaling radio bearer (SRB) & DL common channels). Coverage holes are usually caused by physical obstructions such as new buildings, hills, or by unsuitable antenna parameters, or just inadequate RF planning. An UE in a coverage hole will suffer from call drop and radio link failure. Multi-band and/or Multi-RAT UEs may go to another network layer instead.

- **Weak coverage:** Weak coverage occurs when the signal level SNR (or SINR) of serving cell is below the level needed to maintain a planned performance requirement (e.g. cell edge bit-rate).

- **Pilot Pollution:** In areas where coverage of different cells overlap a lot, interference levels are high, power levels are high, energy consumption is high and as a result, cell performance may be low. This phenomenon is called “pilot pollution”, and the problem can be addressed by reducing coverage of cells. Typically in this situation, UEs may experience high SNR to more than one cell and high interference levels.

- **Coverage mapping:** There should be knowledge about the signal levels in the cell areas in order to get a complete view for the coverage and be able to assess the signal levels that can be provided in the network. This means that there should be measurements collected in all parts of the network, and not just in the areas where there are potential coverage issues.

- **UL coverage:** Poor UL coverage might impact user experience in terms of call setup failure / call drop / poor UL voice quality. Therefore, coverage should be balanced between uplink and downlink connections. Possible UL coverage optimization comprises adapting the cellular coverage by changing the site configuration (antennas).

#### 3.11.2.2 DESCRIPTION OF MDT REPORTING MODES

The general principles and requirements guiding the definition of functions for Minimization of Drive Tests are described in this section. There are two modes of reporting for the MDT measurements: non-real-time or immediate reporting.

**Immediate MDT** refers to MDT functionality involving measurement performance by UE in connected/active state and reporting of the measurements to eNB/RNC available at the time of reporting condition.

**Logged MDT** refers to MDT functionality involving measurement performance by UE in idle state at points in time when configured conditions are satisfied. This measurement log is reported to the eNB at a later point in time when the UE goes into connected mode.

A UE in connected mode is configured with Immediate MDT that implies immediate reporting. A UE in idle mode of operation is configured with Logged MDT. After having initiated Logged MDT, the UE will not immediately report the data to the eNB. Key requirements for MDT include the following.

1. **UE measurement configuration**
   The operator should be able to configure MDT measurements for the UE logging purpose independently from the network configurations for normal RRM purposes.

2. **UE measurement collection and reporting**
   It should be possible for measurement logs to consist of multiple events and measurements taken over time. The time interval for measurement collection and reporting shall be separately configurable in order to limit the impact on the UE battery consumption and network signalling load. It shall be possible to collect measurements logs preceding a particular event (e.g. radio link failure).

3. **Geographical scope of measurement logging**
   It should be possible for the operator to configure the geographical area where the defined set of

measurements shall be collected. Some measurements might run independent of any geographically defined area.

4. **Location information**
   The measurements should be linked to available location information and/or other information or measurements that can be used to derive location information.

5. **Time information**
   The measurements in measurement logs should be linked to a time stamp.

6. **Device type information**
   The terminal used for MDT should indicate a set of terminal capabilities which allows the network to carefully select the right terminals for specific MDT measurements.

The solutions for MDT 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 as much as possible rely 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.

Measurements supported for Immediate MDT performance include:

- RSRP and RSRQ measurement by UE with periodic, event A2, or Radio Link Failure as reporting triggers.

- Power Headroom (PH) measurement by UE

- Uplink signal strength/SINR measurement by eNB

The measurement quantity for Logged MDT consists of both RSRP and RSRQ for E-UTRAN.

MDT measurement collection task may be initiated in two distinct ways.

Management based MDT task is sent from the OAM towards a PLMN or a limited region within a PLMN (limited by a cell list, a TA list, a LA list or a RA list) without targeting a specific UE.

Signaling based MDT task is sent from the OAM and initiated towards a specific UE and a PLMN or a limited region within a PLMN (limited by cell list, a TA list, a LA list or a RA list) by the signaling trace activation messages from core network nodes.

Management based MDT and Signaling based MDT capabilities are specified in 3GPP TS 32.421, TS 32.422 and TS 32.423.

## 3.12 APPLICATIONS OF SON TO ADDRESS DEPLOYMENT AND OPERATION OF DAS AND SMALL CELLS

### 3.12.1 SON INTERACTIONS WITH DISTRIBUTED ANTENNA SYSTEMS

LTE macro base stations can provide high data rates when higher modulation schemes are used in conjunction with high signal to noise ratios. Macro eNBs can provide high signal to noise ratios but only with high power levels on the downlink and addition of tower mounted amplifier on the uplink. Even then extreme care must be taken to make sure the extra power does not pose interference to other sites. Another approach to solving this issue would be to install a Distributed Antenna System (DAS) whereby the signal source is brought to within a few hundred feet of the users while the interference remains unchanged. Hence, signal to noise ratio improves substantially allowing for higher data rates without a significant increase in power levels.

SON functionality is typically geared towards managing base stations (macro, pico or femto) in cellular networks. Distributed Antenna System (DAS) coverage solution networks are often provided by vendors besides the vendors providing the RAN. These coverage solution networks are often managed by an EMS separate from that managing the RAN. Consequently, the performance input from RAN is not readily available to the coverage solution networks. Therefore, the full extent of the SON benefits is not afforded to coverage solution networks. Further, each host eNB may host multiple DAS nodes but is unaware of the hosting relationship. SON functionality relating to optimization relies on Key Performance Indicators (KPIs) to tune the network for optimal coverage, capacity or performance. However, it is difficult to associate performance statistics to a specific DAS node coverage area.

To overcome these issues, the following options should be explored:

- Develop a coordination mechanism between coverage solution network EMS and RAN EMS.
- Develop a mechanism that provides a host eNB visibility into whether it is deployed as a DAS network host.
- Develop a mechanism to facilitate communication between the host eNB and the DAS node(s).

Such mechanisms could allow the operators to provide solutions such as:

- Adjust coverage under overload conditions to drive hand-off of traffic to unloaded DAS sectors especially in stadiums and convention centers.
- Offload traffic from cellular network to WiFi network under overload conditions.

### 3.12.2 SON WITH PICOS/FEMTOS/RELAYS

With the data explosion observed in the last years, and the forecasted continuous growth in data traffic even LTE networks will suffer capacity constraints as the radio link spectral efficiency approaches its theoretical maximum Shannon limits. One way to increase spectral efficiency is to provide methods to serve the traffic closer to where it is originated, making sure that the available SINRs is always high and the system can operate using the best possible modulation and channel protection scheme, operating at a lower transmit power level. Such a paradigm will result in heterogeneous networks where a variety of base station transmitters will be used to flexibly accommodate the high traffic demand in different environments: home/office, dense hotspots, isolated high-demand areas, etc.

There are a variety of base stations available today for LTE and other technologies as follows.

- Micro or pico cells are designed to serve hotspots within a macro cell without causing additional interference. Their typical cell radius is one order of magnitude less than the macro cell by a factor of 10. These units operate at a lower power than regular eNBs but would have similar functionality and would require installation by the operator.
- Home eNode-B (HeNBs) or femto cells are designed to cover few customers, typically in a home or small office environment, using a transport method provided by the customer such as cable, ADSL, etc.
- Relays or repeaters provide a flexible method to cover weak coverage areas and increase capacity with minimum installation costs, since they use the wireless network spectrum for backhaul transmission.

Strictly speaking, these units are not new to the industry and have been in use with previous network technologies. However LTE has taken special note of them during the specification phase to be able provide a fully functional heterogeneous network. NGMN and 3GPP have recognized that heterogeneous networks can result in a significant operational complexity increase for carriers and is actively working in specifying methods to provide a smooth integration of the different units into the macro network and simplify their operation.

Examples of specific SON considerations for heterogeneous networks can be found in the Automatic Neighbor relation requirements indicated by NGMN, in which ANR mechanisms must be made aware of the type of base station during the procedure. This allows the system to make the appropriate handover between macro and micro cells based on UE speed and cell capacity.

One important focus area of SON is the support of HeNBs, for which multiple requirements have been identified to improve the integration and interference management with the macro cell. Rel-10 3GPP specifications provide standardized interfaces and OAM for the HNB to ensure a successful HNB self-configuration installation in a multi-vendor environment. The specifications also provide a reference management architecture with standardized information elements to facilitate the remote control of the units by the operators. In addition, NGMN is actively working on proposals to improve the integration of the units in the network causing minimal impact to the surrounding base stations, by providing methods to automatically control the level of interference generated by non-coordinated HNB deployments. These methods have led to standardization in 3GPP Rel-10, as described in Section 3.8.7, and will be continued in Release 11.

### 3.12.3 USING SON TO FACILITATE THE DEPLOYMENT OF REPEATERS/RELAYS

Repeaters and Relays are nodes that retransmit the data transmitted by a macro cell: repeaters receive a signal and amplify it, including the wanted signal and the interference, while relays are more sophisticated and are able to receive the wanted data and retransmit it.

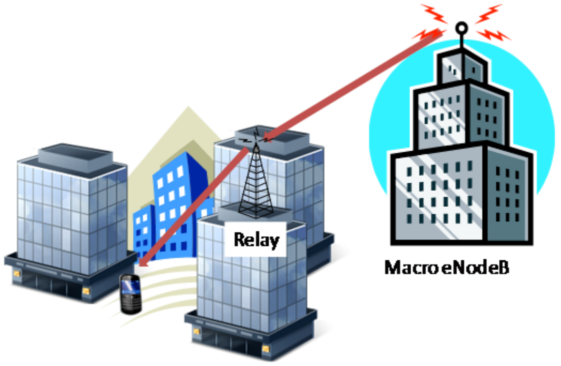


**Figure 20 - Role of relays in providing additional coverage or capacity**

Both repeaters and relays can be very useful for operators that need to bring additional coverage or capacity to specific areas with a smaller investment since there is no separate backhaul required to provide service. On the other hand, the deployment of these units in some situations may create more problems than actually improving the coverage or capacity of the network. The use of Self-Organizing Networks can help mitigate these problems with automated solutions in the following areas:

- Automatic site selection
- Automatic parameter configuration
- Interference coordination
- Self-healing (cell outage detection and compensation)
- Resource sharing
- Load balancing
- Handover optimization

These items are candidate features to be addressed in subsequent releases of 3GPP. As LTE networks mature and relays become more relevant, SON techniques will likely be developed to facilitate their deployment.

# 4 4G AMERICAS OPERATOR USE CASES

The following are LTE SON use cases from a 4G Americas operator. This operator is investigating a hybrid architecture deploying ANR, PCI, Cell Outage and Energy Savings SON features. Dynamic updates will be reflected into the operations architecture and synched with applicable planning systems. Deployment timelines will impact implementation decisions such as whether they fully implement a given capability within each phase, or whether they go more quickly towards an ultimate goal.

## 4.1 4G OPERATOR USE CASE: ANR/PCI

### 4.1.1 ANR/PCI PHASE 1

In the first phase, both ANR and PCI functions will be supported in network management (NM) layer radio frequency (RF) planning tool, and downloads will be made to the EMS layer to provision the eNBs and neighboring 3G and 2G cells. This phase encompasses the following aspects.

- NM layer RF planning tool initial plan takes into account the complete neighbor list, and PCI plan, as well as criteria on distance, min RSRP or -120 dBm and margin of overlap, hence minimizing chance of possibility of PCI conflict or confusion.
- Periodic, post consistency check, updates will be made to the same EMS: specifically from the NM layer RF planning tool to EMS to a given eNB say eNB1.
- Periodic, post consistency check, updates will be made to a different (e.g., bordering) EMS: specifically from the network management (NM) layer RF planning tool to a different EMS, say EMS2, to eNB2.
- Periodic updates of the RF planning tool will be made with any ANR or manual PCI changes: specifically from the EMS1 to NM layer RF planning tool.
- NM layer RF planning tool also incorporates PCI algorithm.

### 4.1.2 ANR/PCI PHASE 2

In the second phase, when vendor ANR and PCI features are delivered, additional ANR and PCI capability will be supported within the network and EMS layers.

Neighbor relation deletions, additions or modifications can be executed within the Network and EMS layer replacing the NM Layer as the database of record for SON-related CM changes and augmenting the RF planning tool as source for PCI's. Configuration changes can be sent Northbound to NM Layer for non-real time analysis and the revised propagation environment can be used in the new PCI plan. This phase is characterized by the following aspects.

- More dynamic uploads, consistency checks and downloads will be performed between the EMS systems and NM Layer RF planning tool.
- Standard 3GPP configuration management integration and applicable network resource models will be realized.

### 4.1.3 ANR/PCI PHASE 3

In the third phase, introduction of a solution with real time or near real time analysis is currently being investigated. A closed loop architectural option is being investigated which supports granular data analysis, dynamic data updates and user friendly visualization of those changes. This data will also need to be reflected into operational and planning systems to support root cause analysis, and possibly diagnostics / ticketing functions. The benefits of a closed loop architectural solution are less error through manual process elimination (i.e. increased accuracy) and reduced operating expense. The dynamic aspect of a closed loop architectural solution provides even further benefits such as:

- Precision – performance feedback allows for dynamic compensation and correction.
- Performance – improved system level performance.

The small cells layer is tied into the same EMS as the macro layer. The small cells layer will use an independent PCI list separated from the macro PCI range initially. Currently, a range of PCIs have been set aside to accommodate the small cells layer. The small cells have network scanning functionality that is used to detect neighbors. The initial neighbor list for LTE small cells can be sent to the ACS (Auto Configuration Server) via TR-196 data model (Broadband Forum – TR-069 Architecture) as the baseline neighbor list. The neighbor data for the small cell will be stored in the EMS and possibly sent northbound to NM Layer RF planning tool. Enhancements to neighbor lists will be based on uplink measurements from the UEs served on the small cell as described in the ANR SON feature.

## 4.2 4G OPERATOR USECASE: CELL OUTAGE

### 4.2.1 CELL OUTAGE DETECTION

In the first phase, when vendor features are delivered, capability is supported within the Network and EMS layers. At this point, these changes must be passed from the EMS systems through applicable fault management (FM), performance management (PM), configuration management (CM) network management (NM) layer systems.

### 4.2.2 CELL OUTAGE COMPENSATION THROUGH ANTENNA TILT MODIFICATION – PHASE 1

In the initial phase of cell outage compensation, the NM layer will provide the configuration file for the eNB antenna tilt modifications. The configuration file will be sent through to the EMS layer to provision / adjust antennas on the eNBs and neighboring 3G and 2G cells. The goal is to adjust surrounding neighbor cell parameters by a small preconfigured amount based on cell outage/compensation. Standard 3GPP SON self-configuration management integrations will be used. The dynamic and complex antenna adjustment (through AISG standards: http://aisg.torni.fi/) is agreed to be the most viable approach for cell outage compensation. Such adjustment requires analysis of measurements over time to determine the impact of antenna changes.

### 4.2.3 CELL OUTAGE COMPENSATION THROUGH ANTENNA TILT MODIFICATION – PHASE 2

The second phase of cell outage compensation will shift to the EMS/eNB layers. The shift will enable more real time dynamic changes to compensate for cell outages. Changes can include, and are not limited to, cell mobility parameter offsets, transmit power increases and antenna tilt modifications. The introduction of a third party or eNB vendor supported cell outage compensation (i.e. antenna tilt modification) is present in this stage. Triggering of the cell outage compensation will be based on PM/CM and FM triggers. Probe based solutions are being considered to improve the timeliness of the cell outage compensation solution.

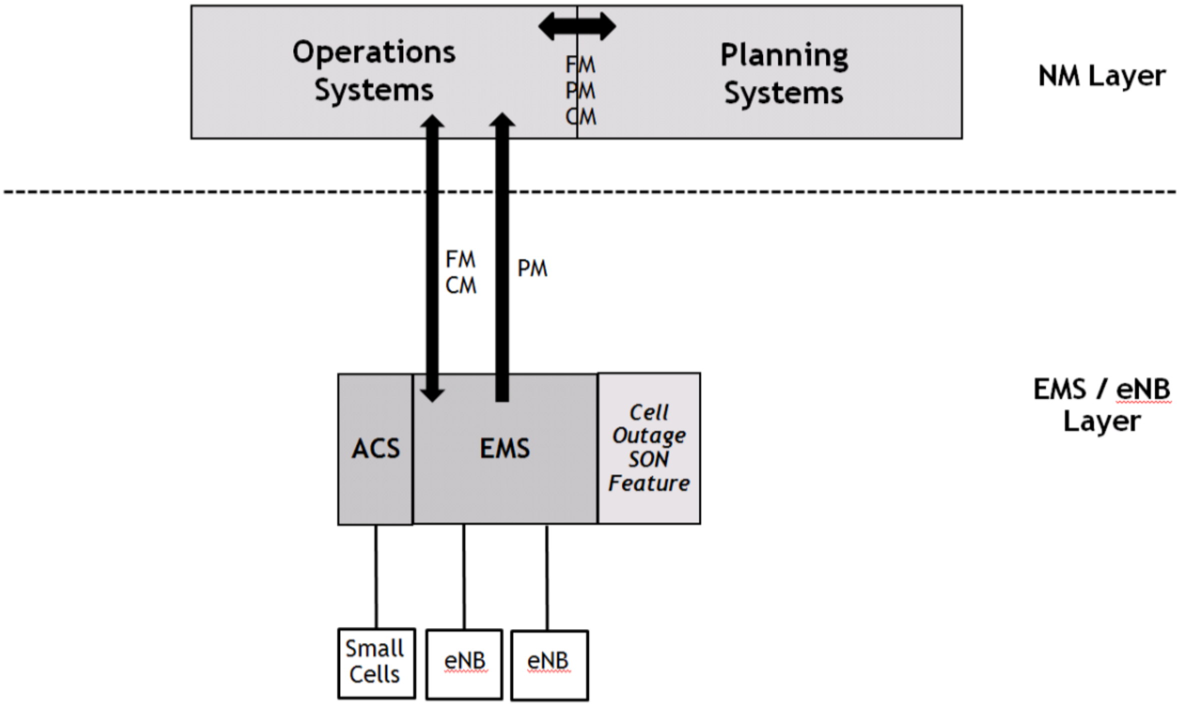


Figure 21 - 4G Operator implementation of SON usecase Cell Outage Compensation

# 5 RESULTS FROM LIVE OR TRIAL NETWORKS

This section discusses the result of a SON trial in a live HSPA network consisting of over 250 sectors in a mixed urban/suburban environment. The trial area, shown in Figure 22, illustrates the layout of the base stations.

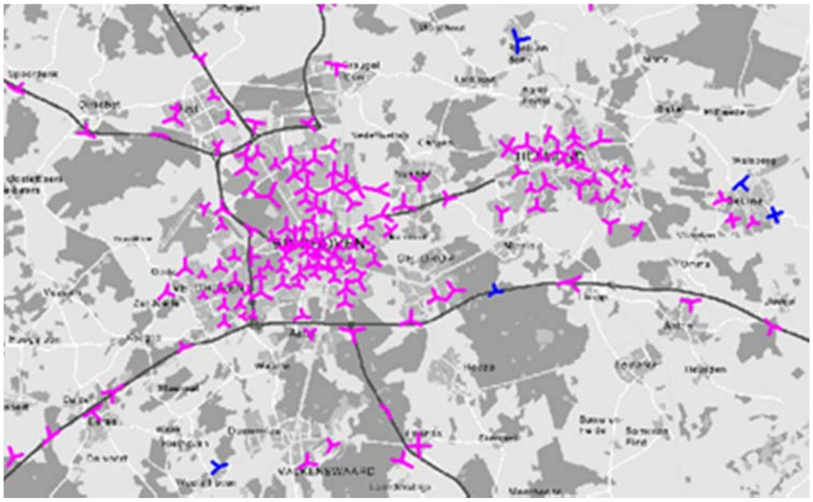
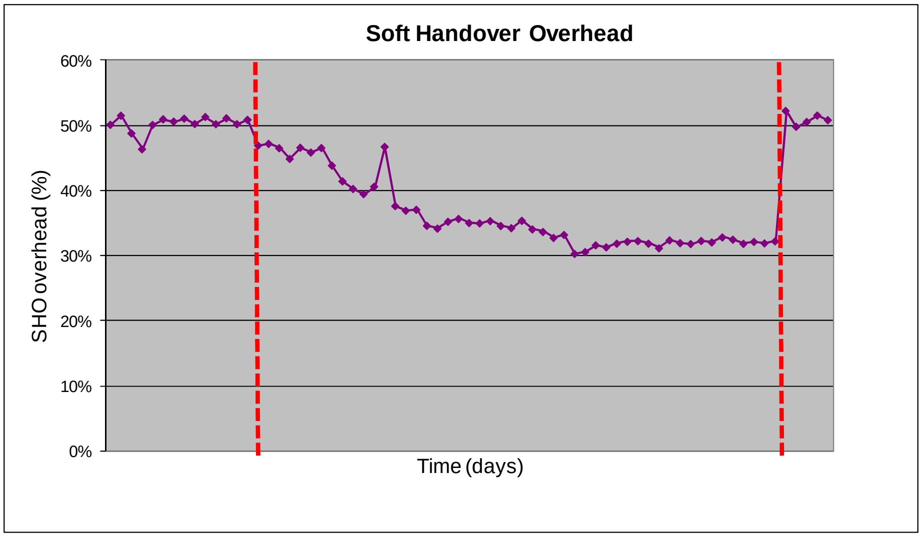


**Figure 22 - Trial area network with 3G base stations**

A third party tool was used that was connected to the network OSS, and such tool would collect the network KPIs on a daily basis and provide recommendations on the configuration parameters on a cell basis, every day for the duration of the trial. The objective of the optimization was to improve the performance of the HSDPA service in the area, which was achieved by improving the sector dominance (through power and soft handover optimization). The charts in Figure 23 illustrate the changes in the soft handover overhead and the CQI distribution in the area for the duration of the trial, which are two key metrics correlated to the quality of the HSDPA service. The red lines indicate the beginning of the trial and the end, where the parameters were reverted to the original values (pre-optimization).



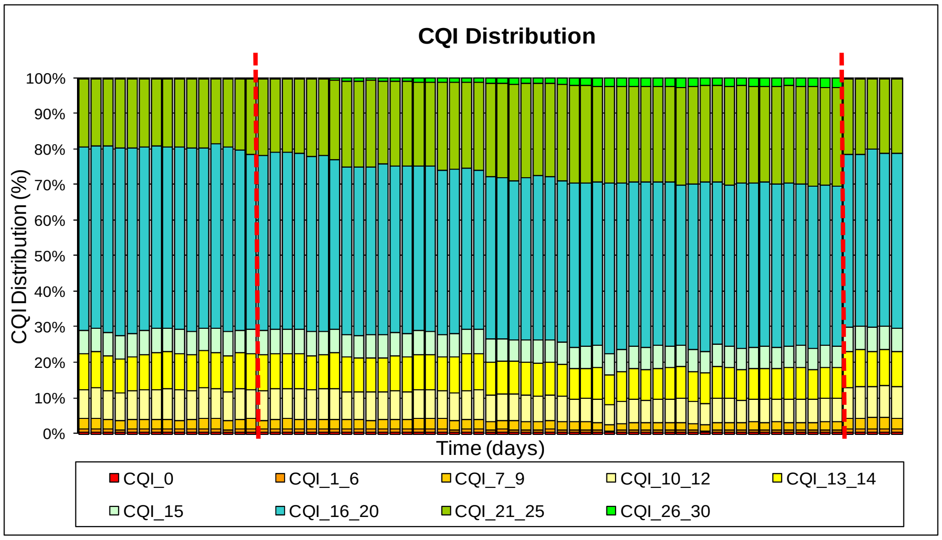


**Figure 23 - Trial results from live SON trial in HSPA+ network: Soft Handover Overhead (up) and CQI (bottom)**

The SON tool was used in the trial area for multiple consecutive days operating in an autonomous manner, gathering KPIs from the network and providing new parameter configuration per each cell on a daily basis.

In HSDPA systems, where the traffic channel cannot be in Soft Handover, having too much cell overlap will result in high channel interference and an ultimate degradation of the service. The objective of this optimization exercise was therefore to improve the quality by reducing the cell overlap. As can be observed in the top chart on Figure 23, during the optimization period the soft handover overhead in the area was steadily reduced from 50% to close to 30%. When the trial was finalized the parameter changes were reverted and the soft handover overhead (SHO) jumped again to the original 50% value. The chart on the bottom of Figure 23, illustrates the Channel Quality Indicator (CQI) values reported by the mobiles in the trial area. Each of the different colors indicates a certain CQI range: 26-30, 21-25, etc. The bigger the CQI value, the better the quality and the higher the HSDPA throughput. As can be observed, the number of high CQI values reported by the mobiles increased steadily when the SON solution was used, returning to the original values when the parameter changes were reverted. The rest of the KPIs did not change significantly, with the exception of data traffic, which increased steadily following the regular growth pattern in the area. This simple exercise demonstrates that it is possible to optimize current 3G networks making use of SON-like techniques.

# 6 SON CAPABILITIES IN HSPA+ TECHNOLOGY

While Self-Organizing Network management techniques are typically associated with the LTE technology, this concept is not new to the industry and it can be applied to any network technology. In fact, early SON techniques had been discussed, and even tried in 2G systems in the early 2000's.

Wireless networks have been steadily increasing their level of automation, starting with early Automatic Frequency Planning tools, which are today a "must have" tool for any GSM network, and more recently continuing with the use of Automatic Cell Planning tools for the deployment and optimization of HSPA networks. Furthermore, today many HSPA infrastructure vendors offer a set of automatic optimization algorithms that are embedded in their OSS, which provide simplified network management such as neighbor list optimization, planning of scrambling codes, optimization of power parameters, etc. Additionally, there is a growing number of third-party companies that offer automatic optimization tools that can connect to the operator's OSS to extract the relevant performance management information and provide an optimized set of parameters for the network.

The existing SON algorithms in HSPA+ are based on a centralized architecture and are therefore somehow limited as compared to what LTE can provide. Furthermore, SON has not been standardized in HSPA+ and all available techniques are fully vendor dependent. On the other hand, much of the performance management architecture is standardized in 3GPP, and some infrastructure vendors are working towards embedding certain SON functionality in their NodeB, which will likely provide improved performance and greater flexibility in the future.

The following are example SON functionalities available for HSPA+ networks today:

- Antenna optimization (through Remote Electrical Tilts)
- Sector Transmit power optimization (pilot and common control channels)
- Neighbor list optimization
- Soft Handover parameters optimization
- HSPA Optimization
- Energy savings
- IRAT optimization

# 7 SUMMARY AND CONCLUSION

New and emerging classes of mobile devices are driving significant growth of wireless data usage. Consequently, wireless service providers must now support a growing number of higher-bandwidth data applications and services on their networks, while simultaneously driving down the delivery cost per bit. This growth in wireless data demand is so rapid that it is also expected to increase Radio Access Network complexity through addition of femtocells, picocells, as well as WiFi access points in order to drive increases in coverage and capacity. These and other trends portend ever-increasing demands upon service providers in the areas of network performance and operations. It has become increasingly clear that traditional network management is inadequate for managing the growing data volume and network complexity in an efficient manner. Whereas SON is an important tool for operators to improve network management and efficiency, it does not replace the tremendous need for more spectrum for the wireless industry to meet the growing mobile broadband data demands of customers.

Previous 4G Americas white papers and technical studies have shown that LTE – with its wideband, highly spectrally efficient, low-latency and cost-effective technology – is ideally suited to serving these new applications.[12] A key component of the LTE advantage is SON, which is being standardized by 3GPP in Release 8, Release 9, Release 10 and beyond.[13] LTE SON leverages network intelligence, automation and network management features in order to automate the configuration and optimization of wireless networks, thereby lowering costs and improving network performance and flexibility.

This white paper has described the motivation for SON, and provided a description of the key SON features contained in LTE Releases 8, 9 and 10. It builds on the descriptions of the SON features described in the 3G Americas SON paper[17], by describing the newer LTE SON features in 3GPP Release 10 that further enhance the benefits of reduced OPEX and improved performance in operator networks. These features address the self-optimization and self-healing capabilities of SON that will allow the networks to operate at the lowest cost per bit while providing overall improved user performance. A key goal of LTE SON standardization is the support for multi-vendor network environments, which has resulted in the definition of standard messaging formats to convey information between entities that can be used to implement a given SON algorithm. Examples of interactions between the various SON use cases are described to illustrate the need for careful design of various algorithms and the setting appropriate thresholds to ensure stable and robust operation. Each of the LTE Release 8, Release 9 and Release 10 SON features clearly provide different and significant operator benefits in terms of performance gains as well as operational benefits. Strong operator interest in LTE SON is evident from the significant SON contributions coming from organizations such as the Next Generation Mobile Networks (NGMN), and examples of the deployment of various SON use cases by 4G operators in their respective networks. Results from SON trials in a live HSPA network demonstrate the benefits for operators and provide further validation of the potential benefits of SON in LTE networks. Finally, the scope of LTE SON functionality will clearly continue to expand and evolve with upcoming releases of the LTE standard, thereby ensuring LTE's continued success in tomorrow's wireless marketplace.

# LIST OF ACRONYMS

| | |
|---|---|
| ANR | Automatic Neighbor Relation |
| 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 |
| HO | Hand Over |
| HSPA | High Speed Packet Access |
| 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 |
| MRO | Mobility Robustness Optimizations |
| NB | Node Base station |
| NGMN | Next Generation Mobile Networks |
| NM | Network Management |
| OAM | Operations Administration and Maintenance |
| OPEX | Operational Expenditure |
| 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 |
| 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 |

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